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Snoqualmie River Low Flow Water Quality Assessment

July-September 1989

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Snoqualmie River Low Flow Water Quality Assessment

July - September 1989

by
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ABSTRACT

A low flow water quality study was conducted on 44.5 miles of the Snoqualmie River from July through September, 1989. The primary purposes were to: describe baseline water quality, evaluate the relative impacts of current point and nonpoint discharges of conventional contaminants, develop a computer model to assess the future impacts from point sources, and recommend a protection plan. Based on the physical, chemical, and biological water quality data collected, portions of the river did not meet Class A water quality standards for fecal coliform and temperature. Point and nonpoint sources contributed to the current major and minor water quality impacts during the low flow period. Simulations performed using QUAL2E and QUAL2E-UNCAS demonstrated some potential impact of future point sources on Snoqualmie River water quality. Major recommendations included: actively manage nonpoint sources on the mainstem, set a total phosphorus management guideline of 50μg/L in the lower river during low-flow periods, and monitor ammonia and dissolved oxygen concentrations as river facilities are expanded.

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EXECUTIVE SUMMARY

Purpose of the Study

The Washington State Department of Ecology (Ecology) is aware that Snoqualmie River Basin communities are undergoing increasing growth. These communities will require expanded or new sewage treatment facilities if current growth rates persist. To properly evaluate sewage facility plans for these communities, the current water quality of the Snoqualmie River and its tributaries must be known. Also, the most prudent approach for maintaining Class A and Class AA water quality in the basin would be for comprehensive facilities planning, i.e., planning for the impact of all discharges in the basin on the water resource.

In response to these concerns, the Northwest Regional Office (NWRO) of Ecology requested the Environmental Investigations & Laboratory Services Program (EILS) of Ecology to conduct a water quality survey of 45 miles of the Snoqualmie River. Project goals were to provide NWRO staff with basic information on water quality to evaluate sewage plans and permits, and to provide a tool to project water quality impacts from various growth scenarios. Four objectives were identified to obtain these goals:

1. Evaluate the relative impact of major tributaries, point and nonpoint source discharges on current bacterial, nutrient, and dissolved oxygen (D.O.) conditions in the mainstem Snoqualmie River from the mouth to North Bend (45 river miles) during summer low flow.

2. Involve local agencies and groups in appropriate portions of the project, and coordinate and share data.

3. Develop a computer model that would allow the NWRO to generally predict the impact of new or expanded point source discharges on instream D.O. and trophic status during low flow conditions.

4. Make recommendations for protecting river water quality and beneficial uses from point source impacts.

The study was also a step toward establishing total maximum daily loads (TMDLs) in the basin, with subsequent waste load allocations (WLAs) for point sources, and load allocations (LAs) for nonpoint sources. The study would help direct more specific work on these issues in the future.

Study Activities

A water quality monitoring network of 18 mainstem stations, and 16 tributary and point source stations was established after evaluating land use, hydrological, and historical data. Samples were collected from these stations on four occasions at three-week intervals between July 24th and September 5th, 1989.

Special surveys were also conducted to address specific concerns or provide data for modeling. These surveys included:

- Measurement of channel cross-sections and velocity profiles at 22 sites within the study area for use in the dye studies and modeling work.
- Dye studies to observe time of travel through various reaches of the study area.
- Periphyton and macroinvertebrate sampling to establish baseline information and evaluate any apparent spatial and temporal differences.
- Outfall dilution and dispersion surveys to evaluate mixing zone compliance.
- Intensive water quality sampling in the vicinity of the Snoqualmie wastewater treatment plant (WWTP) to determine its effect on specific historical water quality problems in the reach.
- Diurnal D.O. monitoring to evaluate primary production in select reaches of the river.
- Diurnal temperature monitoring for general water quality evaluation.
- Fish tissue collection at one site for baseline analysis of metals, pesticides, and other organic contaminants.
- Class II Inspections of the three existing WWTPs to determine National Pollutant Discharge Elimination System (NPDES) permit compliance and current operating conditions.
- Sample splits with Tulalip Tribes staff as a mutual quality assurance check.

The combination of routine and intensive monitoring strategies provided an excellent database from which to achieve the objectives of the study.

Current Water Quality

Two Ecology ambient monitoring stations located at Carnation at river mile (RM) 23.0, and at Snoqualmie at RM 42.3, have been sampled since 1970. Ecology has historically relied on this data for water quality characterization of the entire river. Analysis of monthly data from these two stations indicated the Snoqualmie River meets all Class A criteria and beneficial uses.

In contrast, analysis of 1989 low flow study data showed that several portions of the Snoqualmie River, South Fork Snoqualmie, and several tributaries did not meet some Class A criteria, or were experiencing impairment of beneficial uses. River water quality was being adversely affected by some point source discharges, tributaries, and mainstem nonpoint discharges. Some physical characteristics of the river also contributed to some of the observed water quality problems.

Flood control measures taken over the years in the way of channelization, revetment, and diking have resulted in reduced riparian shading. These channel alterations, the dam at Snoqualmie Falls, and the natural debris dam from the Tolt River slow water movement in the river. Together these factors allowed direct solar heating of the river, with instream temperature increases to 20°C or more during July and August. These temperatures exceeded the 18°C Class A criterion.

Fecal coliform Class A criteria violations were most prevalent in five tributaries and at four mainstem river stations, although other stations showed violations as well. Also, the Duvall WWTP did not meet its NPDES permit fecal coliform limits during any of the four surveys. Mainstem nonpoint sources, tributary, and point source loads contributed to the general fecal coliform problem in the river.

Mainstem and tributary D.O. concentrations met Class A standards during the four routine monitoring events. Middle Fork and North Fork Snoqualmie samples met Class AA D.O. standards. Loading of oxygen demanding materials from tributaries and point sources appeared to be generally low in comparison to the D.O. reserves in the river. Primary production at four sites in the river was greatest in the reach upstream of Fall City. D.O. losses through the Snoqualmie Falls pool were not as severe as they had been during a consultant's survey performed in 1987.

Nutrient concentrations showed a general increase moving downstream. However, the Tolt River appeared to temporarily dilute mainstem concentrations of several nutrients. Ammonia concentrations along the entire river were low enough that un-ionized ammonia toxicity was not a threat to aquatic life under observed temperature and pH conditions. Total phosphorus (TP) and nitrogen (TN) concentrations in most mainstem reaches were usually at or below a eutrophication scale "problem threshold" level, and never reached a "problem likely" level. TN:TP ratios suggested the Snoqualmie River was phosphorus-limited in most reaches. The WWTPs were the most significant sources of phosphorus. Tributaries and mainstem nonpoint sources contributed the most significant nitrogen loads.

Water column chlorophyll *a* samples revealed no detectable amount of free-floating phytoplankton in the study area. Primary production results were also generally low compared to data from other river systems. Chlorophyll *a* biomass of periphyton communities in the South Fork Snoqualmie River was much greater than that of mainstem communities. South Fork periphyton standing crop, as measured by chlorophyll biomass, exceeded a "nuisance level" of 100 mg/m^2 in three of four samples collected.

Several other biometric results were evaluated. Benthic macroinvertebrate diversity and abundance at five sites in the study area did not show significant trends. Fish tissue analyses revealed low metals and pesticide concentrations. A low to moderate lifetime carcinogenic health risk was estimated for consumption of aldrin contained in the whitefish sample. A review of fish habitat data indicated mainstem salmonid spawning areas were scarce and needed protection.

Point Source Compliance and Impacts

All three municipal WWTPs (North Bend, Snoqualmie, and Duvall) were approaching their design flow capacities, which probably contributed to poor effluent quality sometimes observed during the study. The Weyerhaeuser log mill pond had minimal discharge during the study. Since its primary purpose is stormwater detention, evaluation of its compliance to permit limits would be best performed in winter or spring. Tokul Creek hatchery discharge and Carnation Research Farms land application operations were not investigated, but should be in future water quality surveys.

Effluent from the three municipal WWTPs did not always meet BOD or TSS limits in their NPDES permits. Fecal coliform limits were exceeded at North Bend and Duvall on one or more occasions. Residual chlorine, several metals and sometimes ammonia concentrations exceeded chronic and acute aquatic toxicity criteria. Alpha-chlordane detected in undiluted North Bend effluent, and total phthlate esters in undiluted Duvall effluent exceeded chronic toxicity criteria. Only the Duvall WWTP effluent exhibited toxicity to bioassay organisms. Outfalls did not conform with current mixing zone guidelines because of their bank-side locations.

QUAL2E Model Simulation Results

The QUAL2E model was used to simulate water quality conditions under two possible future point source expansion scenarios. The model was calibrated to study field data first. Four mainstem nonpoint sources were generated to better simulate chloride, ammonia, total phosphorus, and fecal coliform field results. Reasonably good calibration of model D.O., chloride, phosphorus, ammonia, and fecal coliform profiles to field results were obtained.

Two future scenarios under 7-day, 10-year low flow (7Q10) conditions were modeled. Scenario 1 assumed the three existing WWTPs were at design capacity and meeting NPDES permit conditions. Scenario 2 assumed the addition of secondary treatment facilities at Fall City and Carnation. Both future scenarios assumed no improvements in nonpoint source management had been made.

- According to the model simulations, average D.O. concentrations would not be expected to violate the Class A standard, 8 mg/L, under either scenario. However, diurnal field data and uncertainty analyses performed on D.O. model variables suggested excursions below the Class A standard could occur. The pool above Snoqualmie Falls and the mouth of the river would be especially sensitive in both scenarios.

- Total phosphorus concentrations in the South Fork Snoqualmie River under the Scenario 1 simulation could exacerbate "nuisance" periphyton conditions. Mainstem TP concentrations would rise over current levels, but would generally stay below the 50 μg/L guideline recommended to avoid eutrophication conditions. Scenario 2 conditions would result in TP concentrations exceeding the guideline in most of the mainstem below Snoqualmie Falls.

- Ammonia would not pose a toxicity threat to aquatic life according to Scenario 1 simulation results. Mainstem nonpoint source contributions of ammonia would still be more significant than expanded point source contributions (assuming normal secondary treatment is achieved). Under Scenario 2 conditions, point and mainstem nonpoint source contributions would be similar. Average ammonia concentrations would not likely be a problem. Uncertainty analyses of ammonia model variables indicated the upper range of ammonia concentrations in the lower river could create toxic conditions when temperatures exceed 20°C, and pH exceeds 7.8.

- Fecal coliform simulation results under both scenarios remained similar to current conditions. Mainstem nonpoint sources and tributary inputs dominated the profiles as long as standard permitted point source effluent limits were being met.

A mixing zone modeling exercise was also performed for all point source outfalls. Model results indicated ammonia toxicity would probably not occur within proposed mixing zone dimensions if mid-stream diffusers were installed, and effluent ammonia concentrations were less than 4 mg/L. Other effluent constituents (e.g. metals and pesticides) with more stringent criteria might not meet water quality criteria within the mixing zones because of elevated background concentrations, and relatively low 7Q10 dilution ratios.

Conclusions and Recommendations

The study was successful in establishing baseline information for the Snoqualmie River under summer, low flow conditions. Water quality in many portions of the river met Class A state and federal standards. Class A fecal coliform and temperature standards were exceeded in other portions and in some tributaries. Nutrient concentrations were relatively low in the mainstem Snoqualmie River, but may be of concern in the South Fork and some tributaries. Some historical D.O. problems did not manifest during the survey. The benefical uses of the river appeared to be threatened, but not seriously impaired in 1989.

Evaluation of point, tributary, and nonpoint sources using field data and the QUAL2E model provided insight. Briefly:

- Although all three WWTPs were experiencing operational problems, their relatively small size limited their impact. They currently provide a large share of the TP in the system. They are also responsible for local aquatic toxicity problems from chlorine residual, ammonia, and probably metals. If the three facilities expand and two more are added to the Snoqualmie, their cumulative impact will probably require discharge limits on phosphorus and ammonia. North Bend WWTP will experience difficulty in meeting dilution ratio criteria in the South Fork, and Snoqualmie WWTP will have difficulty with mixing zone dispersion and dilution.

- Many tributaries were not meeting Class A fecal coliform and temperature criteria. Except for the net positive impact of the Tolt River, the impacts of the tributaries on mainstem water quality were minor despite their impaired water quality. Ames-Sikes Creek, Cherry Creek, Griffin Creek, Patterson Creek, and Kimball Creek exhibited fecal coliform problems. Ames-Sikes Creek, Tokul Creek, Patterson Creek and the Tolt River were nutrient loading sources. The fish hatchery may be an important source of nutrients to Tokul Creek .

- Mainstem nonpoint sources (NPS) were suspected as major causes of fecal coliform loading which resulted in water quality criteria violations in the mainstem. They also contributed to measurable mainstem nutrient loads. Mainstem NPS inputs were most evident in selected reaches between Fall City and the mouth of the river. Livestock access and manure handling practices were the primary suspected sources, but septic tank effluents, golf course, and crop field run-off probably contributed as well.

Based on our study results, the Snoqualmie River basin requires both immediate and long-term actions from Ecology and others. With active managment, the river has potential to meet all Class A standards except temperature, and during low flow periods, it appears the river could support most Class A beneficial uses.

The nonpoint source problems and WWTP permit compliance issues are of most immediate concern. Ecology and conservation district staff need to establish nonpoint management plans to identify and control NPS impacts on the mainstem, and in Patterson, Ames-Sikes, Griffin and Cherry creeks. Ecology NWRO staff need to ensure permit compliance at the WWTPs and carefully review facilities plans. Ecology also needs to provide technical assistance through the roving operator program to WWTP operators.

For future management of the Snoqualmie River, information in several areas is needed, and data collection efforts should be continued. The current Ecology monitoring station at Carnation (RM 23.0), which is highly influenced by the Tolt River, should be moved downstream to the High Road bridge (RM 2.7) to better reflect the water quality of the river. The efficacy of the recommended 50 μg/L phosphorus guideline should be evaluated, and if acceptable, a long-term phosphorus, ammonia, and D.O. monitoring plan should be initiated. The QUAL2E model should be verified during a summer low flow event to test its accuracy as a planning tool. Metals and organic compounds in the water column and sediments still need to be evaluated to properly address point source permit limits. An intensive study of point and nonpoint source impacts during wet weather, moderate flow events should be performed.

If growth should continue at a rapid rate in the Snoqualmie River valley, Ecology will need to work quickly and progressively to ensure Class A and AA standards will be maintained. Facilities design, effluent limits, and outfall locations will need to be intensively reviewed to protect current recreational uses and aquatic life. Protection of Snohomish River (downstream) water quality will need to be considered. More information will be necessary before TMDLs can be reasonably established, and the WLA/LA process undertaken. Information in this study will be helpful in these activities, but will not provide all of the answers.

INTRODUCTION

The Snoqualmie River Valley is located within 15 miles of the Seattle-Bellevue metropolitan area. An era of rapid growth is expected for the valley as the metropolitan area expands (King County Planning, 1988). There are five communities in the basin, each with 500 to 2000 residents: North Bend, Snoqualmie, Fall City, Carnation, and Duvall. These communities have historically relied on agricultural and logging based economies. Sewage services provided by these communities were limited. However, now they are becoming the focal points for residential, commercial, and industrial project proposals. In many cases, these communities will be expected to provide wastewater treatment services for these new projects. Snoqualmie and Duvall are currently in the process of planning wastewater treatment plant upgrades to handle increased loads. North Bend is expected to soon start this process as well. Carnation and Fall City are in the wastewater facilities planning process (evaluating their current reliance on individual on-site systems).

To properly evaluate the impact from expanded or new wastewater facilities, the current water quality conditions of the receiving water must be known. Unfortunately, water quality in the Snoqualmie River and tributaries has not been comprehensively monitored and evaluated. Local nonpoint source problems have been suspected from dairying, logging, on-site septic systems, and agricultural activities in the basin. Point source related problems have recently occurred as some wastewater treatment plants (WWTPs) have become overloaded. Few of these water quality problems have been documented in the basin, especially under low-flow critical conditions.

Some water quality and water resource data have been collected from parts of the Snoqualmie River system (USGS, 1985; URS, 1977; Tulalip Tribes, 1988; Beak Consultants, 1987; Ecology, 1990a). The Washington Department of Ecology (Ecology) has maintained two ambient monitoring stations on the river for several years. Samples have been collected monthly at each station and analyzed for a wide range of parameters. These data have generally indicated good water quality at the two sites (Ecology, 1990a).

In contrast, data obtained by others suggest water quality problems occur in some reaches of the river and in some tributaries. They have reported fecal coliform criteria violations in the lower river (URS, 1977; Tulalip Tribes, 1988), high fecal coliform and nitrate loads in some tributaries (Tulalip Tribes, 1988), and low instream dissolved oxygen (D.O.) concentrations above the current Snoqualmie wastewater treatment plant outfall (Beak Consultants, 1987). Complaints investigated by the Ecology Northwest Regional Office (NWRO) and Soil Conservation Service (SCS) verify there are bacterial, nutrient, and solids problems in areas of the watershed. Other portions of the river or watershed lack water quality data, precluding a comprehensive water quality assessment at this time.

The NWRO requested a low flow survey to assess the current water quality conditions of the lower 45 miles (72.4 kilometers) of the Snoqualmie River. Staff from Ecology's Environmental

Investigations and Laboratory Services Program (EILS), designed and conducted the survey in July through September, 1989.

Purpose and Scope

EILS project goal was to provide Ecology NWRO and Water Quality Program (WQP) staff with the basic data they needed to start making appropriate and informed water quality management decisions in the lower Snoqualmie River Basin. To meet this goal, project objectives were to:

1. Evaluate the relative impact of major tributaries, point discharges, and nonpoint discharges on current bacterial, nutrient, and D.O. conditions in the mainstem Snoqualmie River from the mouth to North Bend (45 river miles) during summer low flow.

2. Involve local agencies and groups in appropriate portions of the project, and coordinate and share data.

3. Develop a computer model that would allow the NWRO to generally predict the impact of new or modified point source discharges on instream D.O. and trophic status.

4. Make recommendations for protecting river water quality and beneficial uses from point source impacts.

High fecal coliform bacteria counts, low dissolved oxygen, and nutrient enrichment have been the historical water quality problems of this rural watershed. We focused on these problems because they would likely be present or aggravated as new discharges are established and land development proceeds. Our primary focus was also on point source discharges during low flow when dilution of wastewater is most critical. We knew nonpoint sources would probably not be as evident during low flow, but we thought some evidence of their impacts might appear.

The water quality of the Snoqualmie River and its tributaries may require additional protection through establishment of total maximum daily loads (TMDL) for one or more water quality parameters if population in the area rapidly increases. The TMDLs put a regulatory "lid" on the allowable pollutant loads discharged to an effected waterbody. The TMDLs are apportioned between point and nonpoint sources as wasteload (WLA) and load (LA) allocations, respectively (Kendra, 1990). Additional allocations may be set aside for safety or future growth in a basin. Ecology is presently working to establish reasonable safety and growth allocation guidelines. The TMDL, WLA, and LA process has several steps and will not be resolved by this single study and modeling effort. However, the low flow study will be useful for directing the focus of the TMDL process, and directing general water quality management decisions.

EILS staff also realized one season of survey data would not be adequate for showing statistically significant changes in water quality due to the addition of a new WWTP discharge, or implementation of a best management practice (BMP) program. More years of data would be necessary to accomplish that goal. However, we intended that the data from this single season project would provide information on basic elements controlling D.O. and nutrients in the Snoqualmie River, and help focus planning of future intensive surveys.

Study Area

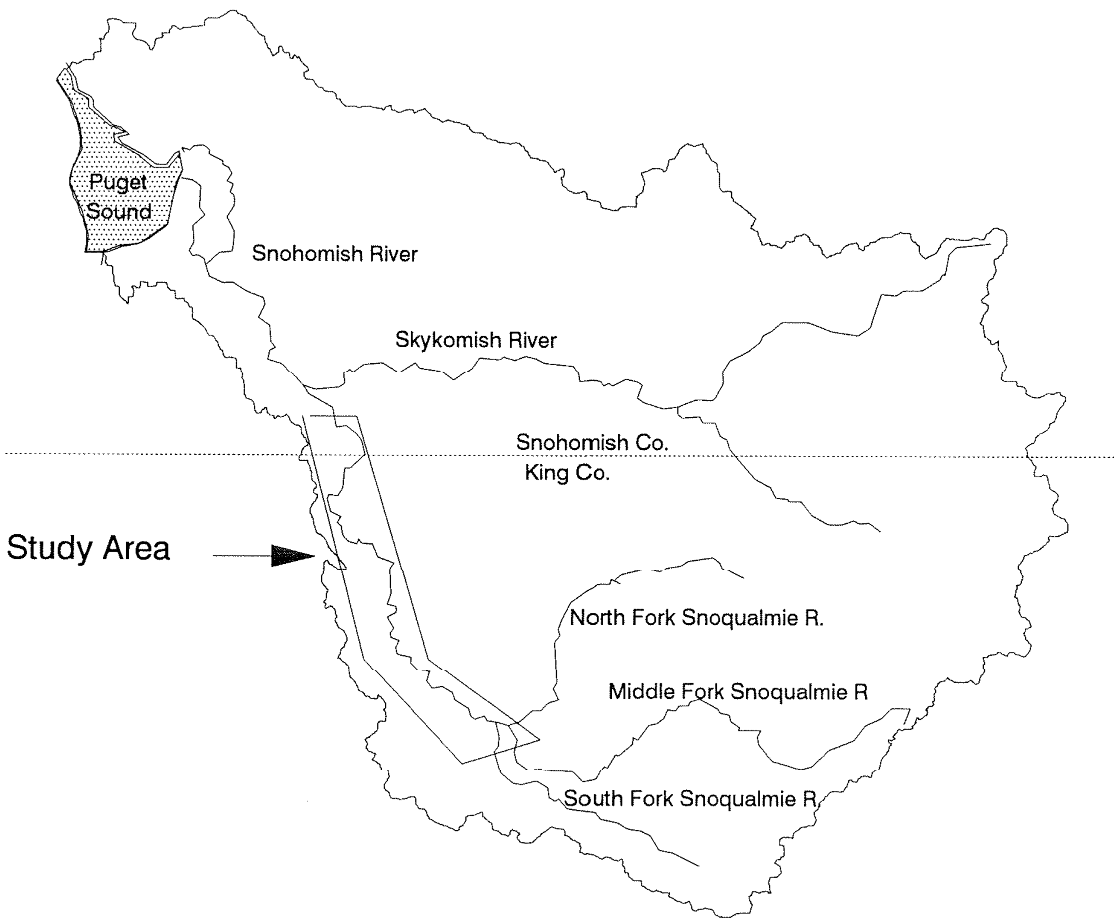
The Snoqualmie River system drains 700 square miles (mi.^{2}) in King and Snohomish counties (Figure 1) before meeting the Skykomish River to create the Snohomish River. The three main forks of the river originate in the Cascade range at elevations of 5800 to 7400 ft. (1770 to 2255 meters). They flow west and meet near North Bend (elevation 400 ft.). The mainstem then flows north to the confluence of Skykomish River at Monroe (elevation 15 ft.). There are no permanent glaciers, so snowpack and rain at the higher elevations determine discharge volumes. Most portions of the river system are unregulated; winter and spring flooding in the Snoqualmie Valley is common. Approximately 90% of the basin land is forested, and about 5% is used for agricultural purposes. Community development is concentrated in the lower valley.

The study area encompassed the lower portion of the Snoqualmie River from river mile (RM) 2.7 to the Three Forks area at RM 44.4, and on up the South Fork to RM 2.8 - approximately 44.5 mi. (71.6 km) in all, with a drainage area of 340 square miles (880.6 km^2) (Figure 2). The Middle and North Forks were included only as "tributaries" within the study area. The river is primarily one of low gradient with a meandering channel across the valley floor, much of which has been diked and revetted. A major physical feature of the river in the study area is Snoqualmie Falls at RM 40.3. The natural drop of the falls is 268 feet. Puget Power and Light Company (PP&LC) regulates flow over the falls by way of a 17 foot high dam, and partial or total diversion through generator penstocks. Another major feature is the Tolt River which drains a 101 square mile (261.6 km^2) basin, and is the largest tributary in the lower basin (Figure 2).

In 1986, more than 23,000 people resided in this lower basin area (King County Planning, 1988). The area is predominantly rural. Agricultural land lies in the river's flood plain, primarily between the mouth and RM 36. Dairy farms, berry fields, and row crops predominate. The valley slopes and eastern sub-basins support forests and related activities. For example, approximately 20 square miles (51.8 km^2) of the Tolt River basin is used as municipal watershed. Several recreational facilities are located in the study area: three golf courses, Snoqualmie Falls viewpoint, several parks, and five boat launches.

There are eight NPDES permitted wastewater discharges in the study area. A description of the facilities and their permits are presented in Table 1. Three are municipal wastewater treatment plant discharges, one is a log pond storm water discharge, two cover a single fish hatchery, and two allow manure application to spray fields from a large research farm. The three municipals and the log pond discharge directly to the Snoqualmie River, the hatchery and rearing pond discharge to Tokul Creek, and the spray fields do not allow direct discharge to surface water.

Figure 1. Location of the 1989 Snoqualmie River low flow study area within the Snohomish River basin.



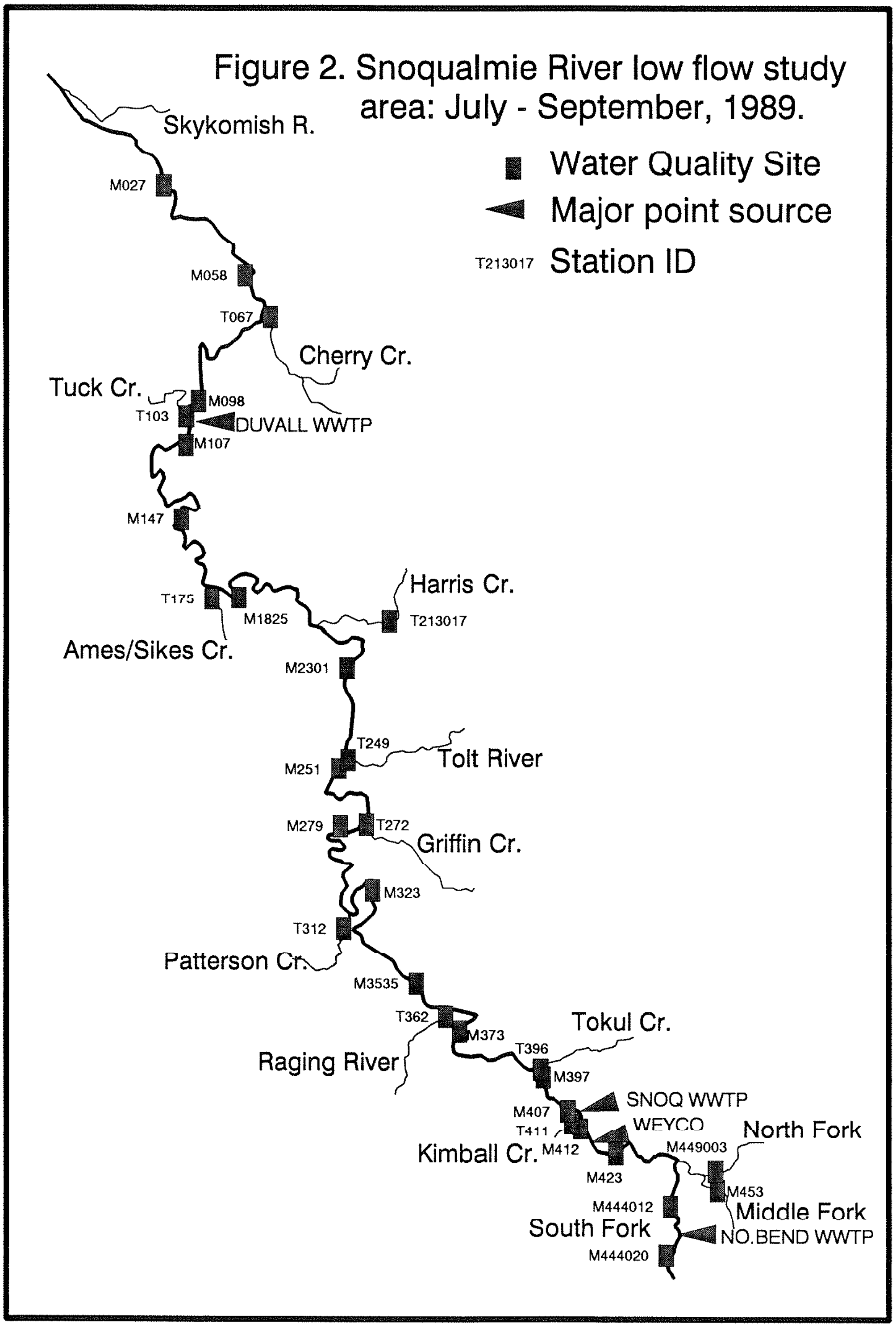


Figure 2. Snoqualmie River low flow study area: July - September, 1989.

Table 1. NPDES Wastewater Permit Dischargers in the Snoqualmie River drainage.

Name/ Permit Number	Issue	Expire	Flow* (MGD)	BOD Monthly	BOD Weekly	TSS Monthly	TSS Weekly	Fecal Coliform** Monthly	Fecal Coliform** Weekly	pH Range
City of Duvall WA-002951-3	1985	1990	0.2	30 mg/L 50 lbs/day 85% removal	45 mg/L 75 lbs/day	30 mg/L 50 lbs/day 85% removal	45 mg/L 75 lbs/day	200	100	6-9
Carnation Farms ST5139			--							
Tokul Creek Rearing Pond WA-003023-6	1986	1991	5.0	--	--	< 3.3 mL/L settleable solids at any time	--	--		
Tokul Creek Hatchery WA-003022-8	1986	1991	1.25	--		TSS: Settleable: Suspended:	15 mg/L daily max. 0.1 mL/L daily ave. 0.2 mL/L daily max. 141 lbs/day average 186 lbs/day maximum	--	--	
City of Snoqualmie WA-002240-3	1977	1982	0.26	30 mg/L 51 lbs/day	45 mg/L 76 lbs/day	75 mg/L 163 lbs/day	110 mg/L 239 lbs/day	200	400	6-9
Weyerhaeuser Mill/ Log Storage WA-000173-2I	1986	1991	1.73	20 mg/L	228 lbs/day	110 mg/L	1585 lbs/day	--	--	6-9
City of North Bend WA-002935-1	1982	1987	0.4	30 mg/L 100 lbs/day 85% removal	45 mg/L 150 lbs/day	30 mg/L 100 lbs/day 85% removal	45 mg/L 150 lbs/day	200	400	6-9

* Average Design Flow, million gallons per day (MGD).
** As colonies/100 mL.

The Snoqualmie River and all tributaries are Class A waters from the mouth to the west border (RM 9.1) of Twin Falls State Park on the South Fork. The Middle and North Fork, and South Fork above RM 9.1 are Class AA waters - WAC 173-201-080 (100-103). The South Fork of the Tolt River system is also Class AA, with a special condition on the upper watershed (a Seattle water supply) above RM 6.9 prohibiting any waste discharge - WAC 173-201-080 (119, 120). The criteria and beneficial uses for these water body classifications are summarized in Table 2.

Acknowledgments

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DATA COLLECTION METHODS

Measurement of Discharge and Channel Characteristics

Cross-sectional and velocity measurements were recorded at 22 sites on the river from RM 2.7 to RM 42.3 (Figure 3). USGS methods were followed using a metered, fixed cable and a boat-mounted "A-reel" and propeller velocity meter (Buchanan and Somers, 1969). The sites selected were characteristic of riffle, pool and glide areas of a particular river reach. General benthic substrate, riparian characteristics, and channel width information were recorded. D.O., pH and temperature profiles were performed at most sites at two or three points along each cross-section using a multi-probe field unit.

Staff of the Tacoma USGS Water Resources office mounted staff gages, measured discharge and developed rating curves at four tributary sites: Patterson, Griffin, Harris, and Cherry creeks. USGS data from continuously recording gaging stations at seven other sites were also used (Figure 3, Table 3). USGS provisional discharge data for the mainstem and gaged tributaries were retrieved from the ADAPS system for the days of the surveys.

Table 2. Class AA (extraordinary) and A (excellent) freshwater quality standards and characteristic uses (WAC 173-201-045)

	CLASS AA	CLASS A
General Characteristic:	Shall markedly and uniformly exceed the requirements for all, or substantially all uses.	Shall meet or exceed the requirements for all or substantially all uses.
Characteristic uses:	Shall include, but not be limited to, the following: domestic, industrial, and agricultural water supply; stock watering; salmonid and other fish migration, rearing, spawning, and harvesting; wildlife habitat; primary contact recreation, sport fishing, boating, and aesthetic enjoyment; and commerce and navigation.	Same as AA
Water Quality Criteria		
Fecal Coliform:	Shall not exceed a geometric mean value of 50 organisms/100 mL, with not more than 10% of samples exceeding 100 organisms/100 mL.	Shall not exceed a geometric mean value of 100 organisms/100 mL, with not more than 10% of samples exceeding 200 organisms/100 mL.
Dissolved Oxygen:	Shall exceed 9.5 mg/L.	Shall exceed 8.0 mg/L.
Total Dissolved Gas:	Shall not exceed 110% saturation.	Same as AA.
Temperature:	Shall not exceed 16.0°C due to human activities. When natural conditions exceed 16°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C. Increases from non-point sources shall not exceed 2.8°C with a maximum of 16.3°C.	Shall not exceed 18.0°C due to human activities. When natural conditions exceed 18°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C. Increases from non-point sources shall not exceed 2.8°C with a maximum of 18.3°C.
pH:	Shall be within the range of 6.5 to 8.5 with a man-caused variation within a range of less than 0.2 units.	Shall be within the range of 6.5 to 8.5 with a man-caused variation within a range of less than 0.5 units.
Turbidity:	Shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10% increase in turbidity when the background turbidity is more than 50 NTU.	Same as AA.
Toxic, Radiodactive, or Deleterious material:	Shall be below concentrations which may adversely affect characteristic water uses, cause acute or chronic conditions to aquatic biota, or adversely affect public health.	Same as AA.
Aesthetic Values:	Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.	Same as AA.

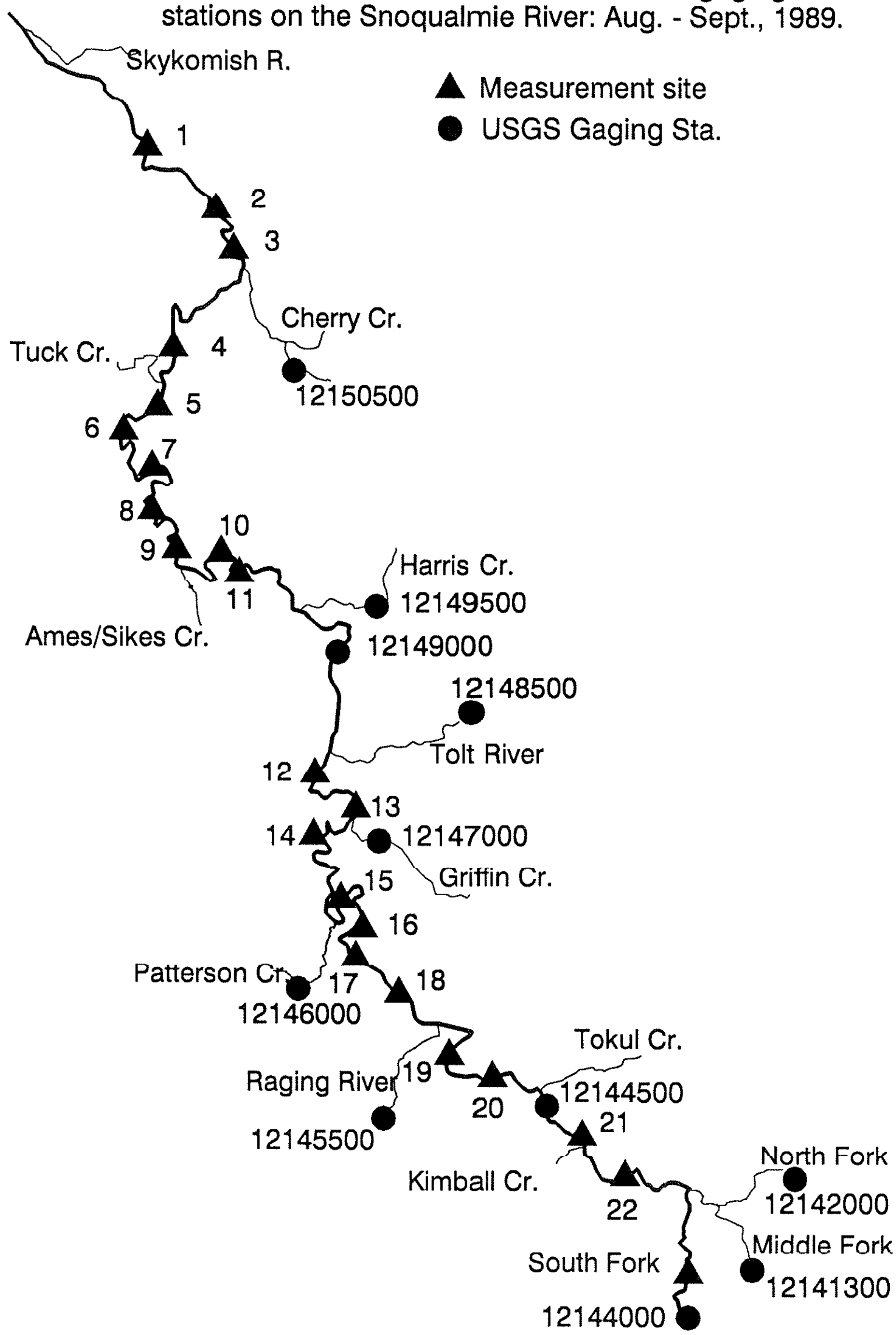


Figure 3. Cross-sectional measurement and USGS gaging stations on the Snoqualmie River: Aug. - Sept., 1989.

Table 3. USGS gaging stations in the Snoqualmie River basin used during the Ecology 1989 low flow study: July - September.

USGS Station Number	Name	River Mile	Drainage Area(mi^2)	Status
12144000	S. Fork Snoqualmie R. at North Bend	S.F. 2.0	81.7	Active
12141300	M. Fork Snoqualmie R. near Tanner	55.6	154	Active
12142000	N. Fork Snoqualmie R. near Snoqualmie Falls	N.F. 9.2	64	Active
12144500	Snoqualmie River near Snoqualmie	40.0	375	Active
12145500	Raging River near Fall City	R.R. 2.6	30.6	Active
12146000	Patterson Creek near Fall City	P.C. 1.9	15.5	Inactive
12147000	Griffin Creek near Carnation	G.C. 0.9	17.1	Inactive
12148500	Tolt River near Carnation	8.7	81.4	Active
12149000	Snoqualmie River near Carnation	23.0	603	Active
12149500	Harris Creek near Carnation	H.C. 1.7	8.4	Inactive
12150500	Cherry Creek near Duvall	C.C. 2.41	19.2	Inactive

During the baseline water quality sampling, discharge was directly measured at Kimball, Tokul, Patterson, Griffin, Ames/Sikes, Tuck, and Cherry Creeks using the incremental channel cross-section and velocity method (Buchanan and Somers, 1969).

Rhodamine WT and fluorometric tracing techniques (Hubbard, et al., 1982) were used to conduct a low level travel time study of the river over a four day period. A low level study provides basic time of travel data, but not definitive longitudinal dispersion characteristics. Dye slugs were monitored from:

- North Bend to Snoqualmie Falls
- below Tokul Creek to Fall City
- Fall City to Tolt River
- Tolt River to Duvall
- Duvall to Cherry Creek

Mean daily discharges were relatively stable over the four days: 444-407 cfs at Snoqualmie, 629-583 cfs at Carnation. Sample collection times were estimated using cross-section data collected earlier. These proved to be quite good estimates of dye cloud arrivals. Dye samples were collected mid-stream in virgin 125 mL polyethylene bottles, and measured at each site using a Turner® fluorometer. The fluorometer was corrected for background fluorescence using river water collected upstream of the dye drop site. Blank corrections were made prior to sampling, each time aperture settings were changed, and at other intervals during the monitoring. Some series of samples were reanalyzed at the laboratory to check temperature effects.

Effluent dispersion analyses were performed at the North Bend and Snoqualmie WWTPs outfalls. The monitoring attempt at the Duvall WWTP failed from lack of effluent discharge at the time. Specific cond ıctance was measured on transects upstream, and from several points downstream of the outfall. Effluent conductivity was measured and dilution calculated.

Ambient Water Quality Measurements

A water quality monitoring network of 18 mainstem and 16 tributary and point source stations was established in the study area (Figure 2). Water samples were collected on four occasions at three week intervals during the low flow period: July 24-25; August 15-16; September 5-6; and September 26-27. The four survey dates were selected during the project planning phase to accommodate laboratory and staff resources. No adjustments were made to sample a particular flow event - either 7Q10 or summer storm.

Grab samples were collected directly into sample bottles, by bucket, or Van Dorn bottle at mainstem and tributary sites. When a bucket or Van Dorn bottle was used, it was rinsed twice with on-site water prior to sample collection. Site descriptions and samples taken are listed in Tables 4 and 5. All samples were collected within two feet of the water's surface. Puget Sound Freshwater Protocols (Tetra Tech, University of Washington, and Battelle Laboratories, 1988)

Table 4. Locations and descriptions of baseline water quality monitoring stations on the Snoqualmie River tributaries and point sources.

Site Name	I.D. No.	River Mile	Description of Station
Above North Bend	M444020	S.F. 2.0	Approx. 50' downstream from Old Hwy. 90 bridge: R.B.&L.B.
Below North Bend	M444012	S.F. 1.2	Right bank access from S.E. 104th St.: mid-stream
Middle Fork near mouth	M453	45.3	From 428th Ave. S.E. bridge north of North Bend: mid-stream
North Fork near mouth	M449003	N.F. 0.3	From 428th Ave. S.E. bridge north of North Bend: mid-stream
Meadowbrook Bridge	M423	42.3	From Meadowbrook Ave. - Ecology Sta. 07D130: R.B.&L.B.
Above Snoqualmie WWTP	M412	41.2	From railroad bridge near Weyerhaeuser Mill site: R.B.
Below Snoqualmie WWTP	M407	40.7	From Hwy. 202 bridge above Snoqualmie Falls: R.B.&L.B.
Below Snoqualmie Falls	M397	39.7	Right bank access just above Tokul Cr.: R.B.
Above Raging River	M373*	37.3	R.B. access from Snoq. Falls Golf Course: mid-stream
Above Raging River	M363	36.3	1st survey only: L.B. boat launch at Raging River: L.B.
Below Fall City	M3535	35.3	Right bank access from Neal Rd. off Hwy. 203: R.B.
Above Patterson Creek	M326*	32.6	1st & 2nd surveys: from R.B. boat launch on Neal Road: R.B.
Above Patterson Creek	M323	32.3	3rd & 4th surveys: from R.B. off Highway 203: mid-stream
Point Sources/Tributaries			
North Bend WWTP	NO.BEND	S.F. 1.8	From chlorine contact chamber
Kimball Creek	T411005	41.1	Upstream 10' from Hwy. 202 bridge: mid-stream
Weyerhaeuser Log Pond	WEYCO	41.6	At outflow weir along Mill Rd.
Snoqualmie WWTP	SNOQWWTP	40.8	From chlorine contact chamber
Tokul Creek	T396	39.6	At confluence with Snoqualmie River: mid-stream
Raging River	T362	36.2	At confluence with Snoqualmie River: mid-stream
Patterson Creek	T312004	31.2	Under W. Snoqualmie River Rd. bridge: mid-stream
Btwn. Patterson & Griffin	M279	27.9	(By boat) upstream of Griffin Cr.: mid-stream
Btwn. Griffin & Tolt	M251	25.1	(By boat) 25' upstream of Tolt Hill Rd. bridge: R.B.&L.B.
Btwn. Tolt and Harris	M2301	23.0	From Carnation Farms Rd.- Ecology Sta. 07D050 : R.B.&L.B.
Below Harris Creek	M203*	20.3	1st & 2nd surveys: R.B. off Hwy. 203
Below Harris Creek	M1825	18.2	3rd & 4th surveys: L.B. from N.E. 100th St.
Novelty Bridge	M147	14.7	From N.E. 124th St. (Novelty Hill Rd.) bridge: R.B.&L.B.
Above Duvall	M107	10.7	(By boat) upstream WWTP revetted outfall: mid-stream
Below Duvall	M098	9.8	(By boat) 10' upstream Woodinville-Duvall Rd. Bridge: R.B.&L.B.
Below Cherry Creek	M058	5.8	(By boat) near county line: mi-stream
High Bridge	M027	2.7	(By boat) 25' upstream of Crescent Lake Rd.: R.B.&L.B.
Point Sources/Tributaries			
Griffin Creek*	T272007	27.2	1st survey: at Highway 203 crossing: mid-stream
Griffin Creek	T272	27.2	(By boat) at mouth: mid-stream
Tolt River	T249	24.9	At mouth from Dept. of Wildlife boat launch area: mid-stream
Harris Creek	T213017	21.3	At Hwy. 203 bridge at N.E. 87th St.: mid-stream
Ames/Sikes Lk. Creek	T175001	17.5	At N.E. 100th St. bridge crossing: mid-stream
Tuck Creek		T103	10.3(By boat) at mouth: mid-stream
Duvall WWTP	DUVALL	10.6	From chlorine contact chamber
Cherry Creek*	T067;T067004	6.7	At mouth; 2nd survey from Hwy. 203 bridge crossing: mid-stream

* Stream station location change
L.B. = left bank or left half of river
R.B. = right bank or right half of river

Table 5. The number of each type of analysis conducted at the baseline water quality monitoring network station on the Snoqualmie River during four survey runs: July - September, 1989.

Parameter Site Name	Temp	Cond	D.O.	pH	NO_3+ NO_2	NH_3	TP	SP	TSS	Sol. (4)	Cl-	BOD 5	BOD 20	COD	TOC	Hard	Alk	Chl a	FC	Ent.	%Kleb
Above North Bend	2	2	2	2	2	2	2	2	1	1	2	1			1	1	1		2		
Below North Bend	1	1	1	1	1	1	1	1		1	1		1		1	1	1		1	1	
Middle Fork nr. mouth	1	1	1	1	1	1			1		1				1				1		
North Fork nr. mouth	1	1	1	1	1	1			1		1				1				1		
Meadowbrook Bridge	3	3	3	3	2	2	2	2	2	1	2			2	1	2	2	1*	2	1	2
RR Bridge	3	3	3	3	1	1	1	1		1	1	1		2	1	1	1		1		1
Below Snoqualmie WWTP	3	3	3	3	2	2	2	2	2	1	2		1	2	1	1	1	1*	2	2	1
Below Snoqualmie Falls	1	1	1	1	1	1			1		1								1	1	
Above Raging River	1	1	1	1	1	1	1	1		1	1	1			1			1*	1	1	
Below Fall City	1	1	1	1	1	1	1	1		1	1		1		1	1	1	1	1		
Above Patterson Creek	2	2	1	2	1	1	1	1	1		1	1			1		1		1		
North Bend WWTP	4	4		4	1(4)	1(4)	1(4)	1(4)	(4)	1	1(4)	1		1(4)		1(4)	1(4)		2		
Kimball Creek	1	1	1	1	1	1	1	1	1		1	1		1	1				1		1
Weyerhaeuser Log Pond	4	4		4	1(4)	1(4)	1(4)	1(4)	(4)	1	1(4)	1		1(4)		1(4)	1(4)		2		
Snoqualmie WWTP	4	4		4	1(4)	1(4)	1(4)	1(4)	(4)	1	1(4)	1		1(4)		1(4)	1(4)		2		
Tokul Creek	1	1	1	1	1	1	1	1	1		1	1			1	1			1		
Raging River	1	1	1	1	1	1	1	1	1		1	1			1	1	1		1		
Patterson Creek	1	1	1	1	1	1	1	1	1		1	1			1		1		1		
Between Patterson & Griffin	1	1	1	1	1	1	1	1	1		1				1		1	1*	1		
Between Griffin & Tolt	2	2	2	2	2	2	2	2	1	1	2		1	1	1	1	1	1*	2	1	
Between Tolt & Harris	3	3	3	3	2	2	2	2	1	1	2			1	1	1	1	1*	2		
Below Harris Creek	1	1	1	1	1	1	1	1	1	1		1				1		1	1	1	
Novelty Bridge	2	2	2	2	2	2	2	2	2		2	2		2	2		2		2	1	
Above Duvall	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1*	1	1	
Below Duvall	2	2	2	2	1	2	1	1	1	1	2		1	1	1	1	1	1*	1	1	
Below Cherry Cr.	1	1	1	1	1	1	1	1	1		1				1		1	1*	1		
High Bridge	2	2	2	2	2	2	2	2	1	1	2	1		1	1	1	1	1*	2	1	
Griffin Creek	2	2	2	2	1	1	1	1	1		1	1			1		1		1		
Tolt River	2	2	2	2	1	1	1	1	1		1	1			1	1	1	1	1		
Harris Creek	2	2	2	2	1	1	1	1	1		1	1			1		1		1		
Ames/Sikes Cr. drain	2	2	2	2	1	1	1	1	1		1	1		1	1			1	1		
Tuck Creek	2	2	2	2	1	1	1	1	1		1	1		1	1				1		
Duvall WWTP	4	4		4	1(4)	1(4)	1(4)	1(4)	(4)	1	1(4)	1		1(4)		1(4)	1(4)		2		
Cherry Creek	2	2	2	2	1	1	1	1	1		1	1		1	1		1		1		

* Composite sample: half from each side of the river.
( ) Denotes samples taken during Class II Inspection.

were followed. Dissolved oxygen, pH, temperature, and conductivity were measured at all sites, and at two or three points across the river at some mainstem bridge stations using field monitoring units. Five to ten percent of the field samples of a survey event were replicated at random from a homogenized split, or side-by-side samples. Distilled, ionic resin filtered water was transferred into sample containers in the field and analyzed for selected parameters. Also, field blank samples for soluble reactive phosphorus were filtered with the regular survey samples.

Twenty-four hour automatic compositors were installed to collect effluent samples from four NPDES permitted point sources (Duvall, Snoqualmie, Weyerhaeuser, and North Bend). Grab samples and field measurements were taken of D.O., pH, temperature, and total residual chlorine. Discharge was monitored by instantaneous flow measurement and in-plant continuous flow recording devices. In addition, a Class II study was performed at each of the three municipal WWTPs. The Class II methods and results are described by Heffner (in preparation). Discharges from the Tokul Creek Fish Hatchery and the operation of the Carnation Research Farms land application of wastes were not monitored.

All samples were stored in the dark, on ice, and arrived at the Manchester Laboratory within 24 hours. Analyses were performed using standard procedures (APHA, 1985; USEPA, 1983; Huntamer and Smith, 1988), and Puget Sound Freshwater Protocols (Tetra Tech, University of Washington, and Battelle Laboratories, 1988). Dissolved oxygen saturation was calculated using the APHA (1985) formula with adjustments made for elevation. The lab analyses, primary analytical laboratory, and target detection limits are listed in Table 6. Laboratory quality assurance and quality control (QA/QC) procedures were extensive, (e.g. lab blanks, replicates, spikes, etc). QA/QC data were reviewed by Manchester Quality Assurance staff, and are available for inspection.

Field and laboratory data are stored on magnetic disk in a Puget Sound Water Quality Authority format.

Biological Parameters

Methods outlined by Hall and Moll (1975) and Slack *et al.*, (1973) were used for productivity determination. Dissolved oxygen concentration and water temperature were measured instream at hourly intervals for 24 hours. Productivity and respiration were estimated graphically using the rate of oxygen change corrected for the diffusion of oxygen between water and atmosphere. This method and calculations are outlined in Appendix B.

Primary production was measured at RM 9.5, 11.2, 23.5, 26.0, 36.5, 40.7, and 42.6. Sites were selected to assess longitudinal distribution of productivity and respiration along the study reach. Sites were also selected to bracket major population centers on the mainstem Snoqualmie River (Duvall, Carnation, Fall City, and Snoqualmie).

Table 6. Summary of target precision for field and laboratory determinations, method, and place of analysis.

Parameter	Detection Limit	Method	Location*
pH	+/- 0.1 SU	Field meter/electrode	F
Temperature	+/- 0.1°C	Thermometer/thermistor	F
Dissolved Oxygen	0.2 mg/L	Gas probe/Winkler titration	F
Specific Conductivity	0.5 umho/cm	Field meter/conductivity bridge	F
Chloride	0.1 mg/L	Ion chromatography	1
Hardness	1 mg/L	EDTA Titrimetric Method	1
Alkalinity	1 mg/L	Low potentiometic titration method	1
Solids (4)	1 mg/L	Gravimetric	1
Total Suspended Solids	1 mg/L	Gravimetric	1
5-day Biochemical O2 Demand	----	Incubation and titration	2
20-day Biochemical O2 Demand	----	Incubation and titration	2
Chemical Oxygen Demand	4 mg/L	Potassium dichromate oxidation	1
Total Organic Carbon	0.1 mg/L	Infrared detection	1
Nitrate and nitrite nitrogen	0.01 mg/L	Cadmium reduction	2
Ammonia nitrogen	0.01 mg/L	Phenate	2
Total phosphorous	0.002 mg/L	Persulfate digestion/ascorbic acid	2
Orthophosphate	0.002 mg/L	Persulfate digestion/ascorbic acid	2
Total Nitrogen	0.05 mg/L	Persulfate digestion/hydrazine reduction	2
Fecal Coliform	2/100 mL	Membrane filter	1
Enterococcus	1/100 mL	Membrane filter	1
% Klebsiella	+/- 2 %	Membrane filter	1
Chlorophyll *a*/pheophytin	0.1 μg/L	Fluorometric or spectrophotometric	1
Dry weight	0.1 gram	Gravimetric	1
Ash-free Dry Wt.	0.1 gram	Gravimetric	1

* Location identification code: F = Field measurement
1 = Ecology/USEPA Lab: Manchester Washington
2 = Aquatic Research Labs: Seattle, Washington

Measurements were made with Martek Mark XVI® submersible water quality instruments. Each unit was positioned approximately one meter below the water surface using an anchor and float. Instruments were calibrated using the Winkler method and then programmed to measure temperature and dissolved oxygen each hour. Instrument drift was assessed by measuring field D.O. and temperature at least twice daily. A small amount of drift was observed on three occasions (0.2-0.3 mg/L). Dissolved oxygen values were corrected for the drift using field Winkler measurements.

Triplicate samples of benthic macroinvertebrates were collected at three mainstem sites and two South Fork sites on two occasions (Figure 4). An area of approximately one square foot was sampled. The substrate was disturbed by kicking to a depth of several centimeters for two minutes. Dislodged organisms were swept downstream into a D-shaped net (600-um mesh) positioned directly below the sampling area. Larger rocks were scrubbed until clean and then removed from the net. Samples were preserved in 70 percent ethanol. In the lab, organisms were sorted, counted, and identified to the family level using the taxonomic keys of Pennak (1978) and Merritt and Cummins (1984).

Periphyton samples were collected on September 12th and 25th at two South Fork sites (RM 1.8 and 1.6) and three mainstem sites (RM 33.5, 22.9, and 9.9) along the Snoqualmie River. Riffle areas with similar habitat types (i.e. depth, velocity, substrate, and shading) were selected so that comparisons between sites could be made. Depth and flow were measured with a Swoffer® current meter.

Five rocks were selected at each site. Periphyton inside a 12.6 cm^2 plexiglass circular sampler was scrubbed from each rock with a stiff bristled brush and composited into a one liter sample bottle. The periphyton slurry was diluted to volume using pre-filtered Snoqualmie River water. The composite was homogenized by vigorous shaking and then separated into appropriate sample containers. A replicate composite sample was taken at each site.

Samples for laboratory analysis were stored on ice and delivered to the Ecology/ Environmental Protection Agency (EPA) Laboratory in Manchester, Washington, within 24 hours. Laboratory analyses were performed as per EPA (1983), APHA *et al.* (1985), and Huntamer and Smith (1986). Analytical measurements on periphyton samples included: total organic carbon (TOC), total suspended solids (TSS), total volatile suspended solids (TVSS), total phosphorus (TP), total nitrogen (TN), chlorophyll *a* (chl. *a*), and pheophytin. Results were converted from volumetric to areal measurements by dividing volumetric results by the area of the sample collected.

ASSESSMENT

Physical Characteristics

The survey was conducted in the period of July through September. Mean monthly discharges at the two Snoqualmie River mainstem stations and the Tolt River are compared to discharge

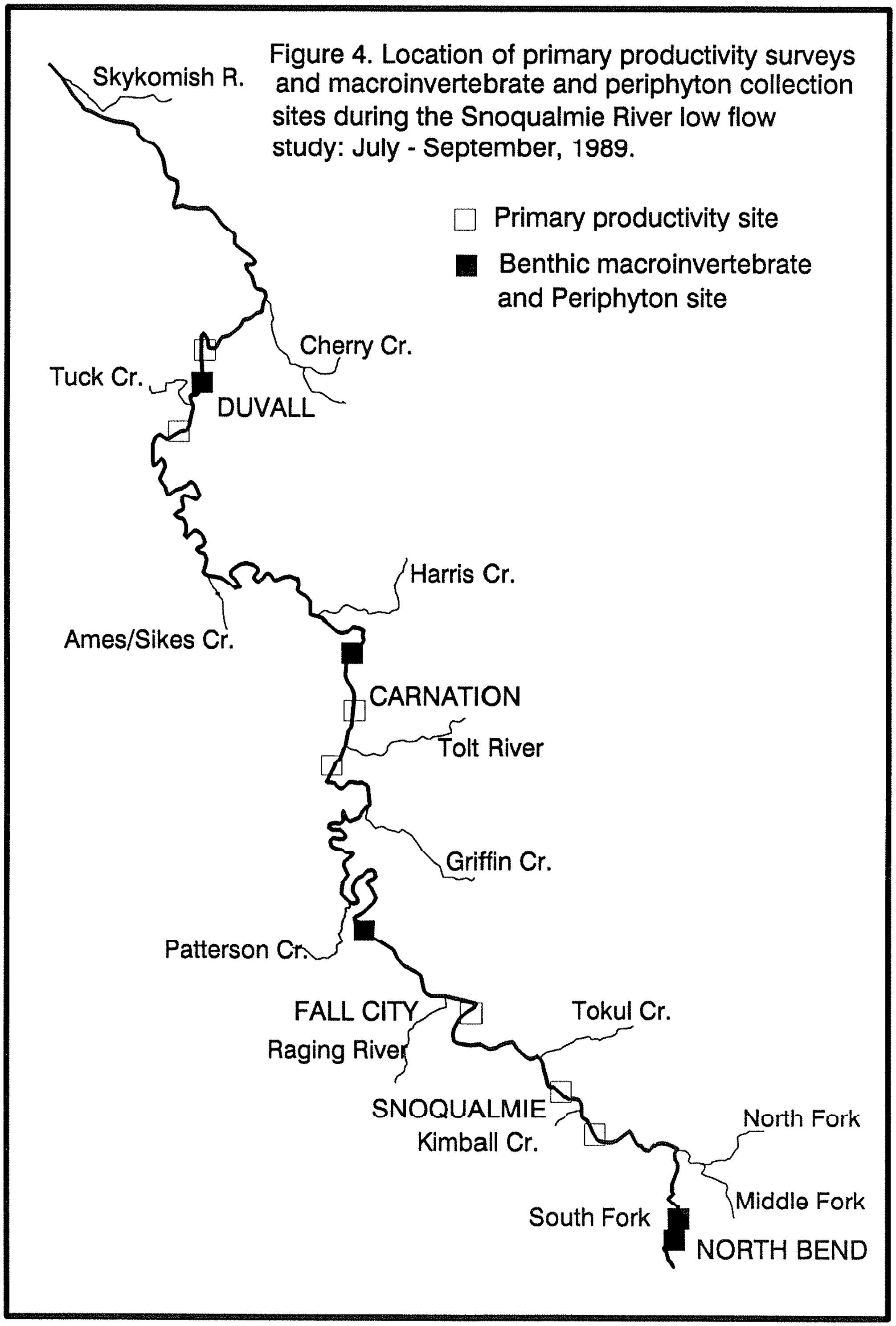


Figure 4. Location of primary productivity surveys and macroinvertebrate and periphyton collection sites during the Snoqualmie River low flow study: July - September, 1989.

statistics from the historical record in Table 7. The seven-day, ten year (7Q10) conditions were not observed during the survey period. However, discharge appeared to be within the normal low flow range.

Mean daily discharges at the two USGS gage stations on the mainstem Snoqualmie River, and daily precipitation recorded by US Weather Service (USWS) Stations at Snoqualmie Falls and Monroe are graphed in Figure 5. The rainstorm of August 20th - 21st, was significant in raising river discharges four-fold, and perturbing the low-flow progression. Biological systems and water quality may have been effected (see below -Chemical Water Quality & Biological Surveys). The storm intensity at Snoqualmie Falls averaged 0.042 inches/hour and the duration was 24 hours (USWS, 1989). According to work performed by URS (1977; Figure B-4), a storm of this magnitude at Snoqualmie Falls would be expected with about a 60 percent probability, or at a 1.67-year recurrence interval.

Mean velocity, depth, and cross-sectional area data taken at several sites along the river are presented in Table 8. Several hydrologic and channel features are of interest because of their impact on river water quality: the Three Forks area, the PP&LC Dam, Snoqualmie Falls, major pool and riffle areas, the Tolt River, and the diked and channelized areas near Duvall.

The Three Forks area lies between the towns of Snoqualmie and North Bend where the North and Middle Forks join at RM 44.9, and are joined by the South Fork at RM 44.4 (Figure 2). The channels are broad and fairly shallow in the area of the confluence during low flow periods. Levees are present, but major channelization is absent. Throughout the low flow period, half of the discharge of the mainstem was from the Middle Fork with the South Fork and North Fork contributing approximately equal portions of the remainder.

The PP&LC Dam structure and hydroelectric plant operation has a significant impact on daily discharge patterns along the river during low flow. The hourly discharge record of two USGS gages below the dam demonstrate the pattern induced by a typical daily storage and release operation at the dam (Figure 6). A 270 cfs decrease in discharge over six hours from peak to trough was not uncommon. The wave from a release (or trough during retention) took approximately six to seven hours to travel the 17 miles between the gages. These wave speeds are not the same as time of travel rates (see below). The waves are hydraulic phenomenon called translatory, abrupt or stage waves and are transfers of wave energy rather than discrete water volume transport (King, Wisler, and Woodburn, 1980; Chow, 1959).

PP&LC regulates the discharge over Snoqualmie Falls and through its two powerhouses that bypass the falls. PP&LC is required to maintain a minimum of 100 cfs over the falls during daylight hours only. The other two routes are through penstocks: one spillway exits through Powerhouse #1 at the base of the falls, the other exits through Powerhouse #2 at RM 40.1. When discharges are less than 500 cfs, the remainder (400 cfs or less) goes to Powerhouse #1; at discharges over 500 cfs, the remainder goes to Powerhouse #2.

Table 7. Snoqualmie River and Tolt River monthly and low flow discharge statistics compared to Ecology 1989 low flow study discharge observations. All flows in cfs.

Station	Snoqualmie at Snoqualmie		Snoqualmie at Carnation		Tolt River	
	Historical	1989	Historical	1989	Historical	1989
JULY						
Monthly Mean	1993	1286	2425	1587	300	236
Monthly Mean* Max.	4393		5629		820	
Monthly Mean* Min.	536		840		120	
AUGUST						
Monthly Mean	960	778	1141	1007	182	192
Monthly Mean* Max.	2263		2992		485	
Monthly Mean* Min.	477		492		75	
SEPTEMBER						
Monthly Mean	1342	503	1434	701	261	141
Monthly Mean* Max.	3937		5128		954	
Monthly Mean* Min.	429		493		73	
7-day,10-yr. low flow	346	409**	443	583**	72	126**
1-day,10-yr. low flow	240	391**	414	555**	70	120**

* Monthly Mean Max. = The highest monthly mean discharge reported for that month over the historical period of record.

Monthly Mean Min. = The lowest monthly mean discharge reported for that month over the historical period of record.

** Lowest flow in July through September of 1989 over a seven-day period and on one day.

Figure 5. Discharge and precipitation levels during the Snoqualmie River low flow study: July - September, 1989.
Data: USGS, 1989 provisional gaging data; NWS, 1989 climatological data.

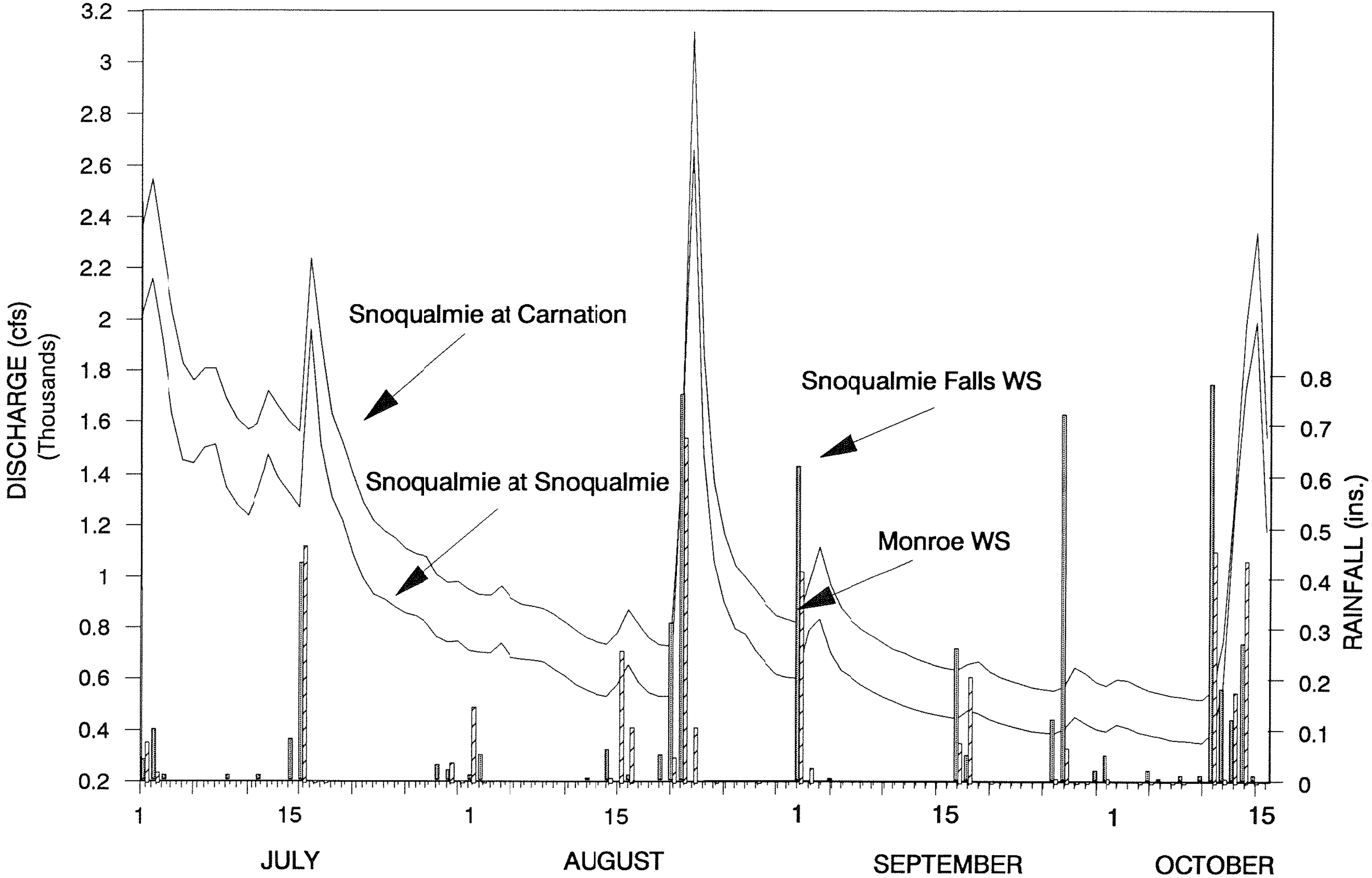
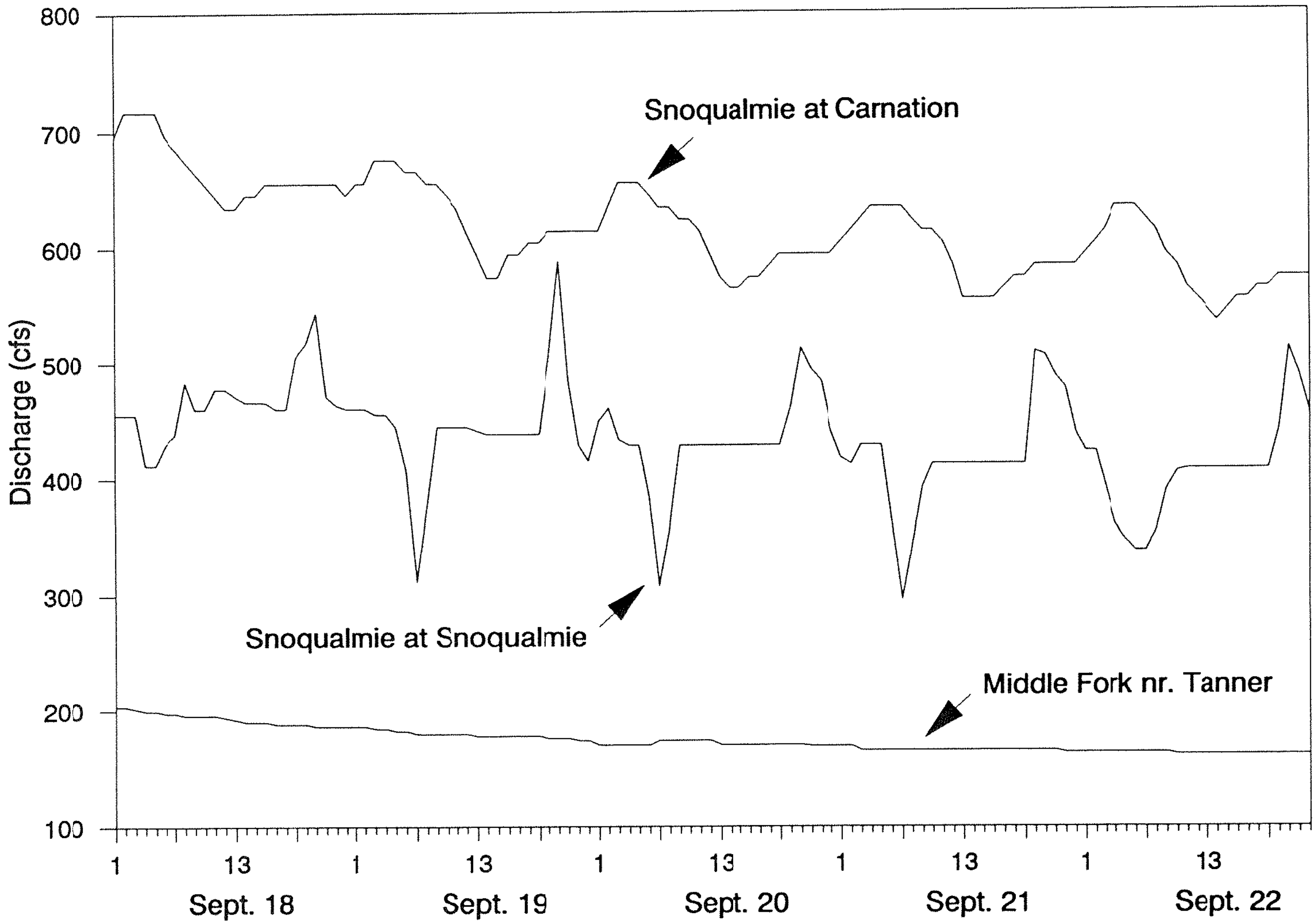


Table 8. Data from Snoqualmie River cross-section surveys: August 7 -17, 1989

Map No.*	RM mile	Description	Avg. vel. ft/sec	Avg. d. ft	Max. d. ft	Area ft^2	Width ft	Elevation ft	Disch. cfs
1	2.87	Near High Bridge	0.54	7.5	14.60	1,684	226	17	903
2	5.30	Near County Line	0.69	9.0	14.60	1,339	149	18.5	930
3	6.64	Near Cherry Cr.	0.78	8.3	12.90	1,250	150	19.5	978
4	9.40	Below Duvall	1.20	6.3	10.00	851	134	21	1,018
5	10.50	Duvall WWTP area	1.23	5.0	8.80	832	166	22	1,022
6	11.70	Above Duvall	1.85	3.7	5.30	562	151	23	1,038
7	13.55	Below N.E. 124th Br.	1.18	5.0	12.10	804	162	24	945
8	15.40	Above bridge - shallow	1.53	3.1	5.10	650	208	25	995
9	16.70	Below Ames - Deep	0.88	7.9	16.60	1,021	129	27	904
10	18.05	Near Ames - shallow	1.92	1.8	4.40	483	266	30	928
11	19.40	Below Carnation Farms	1.00	5.8	10.60	951	165	33	948
12	25.30	Above Tolt R.	0.24	9.9	15.60	2,094	211	58	508
13	27.10	Below Griffin Cr.	0.53	9.3	19.00	1,320	142	58.3	696
14	28.30	Above Griffin Cr.	0.98	2.6	4.10	701	268	58.6	687
15	31.75	Neal Rd. - channeled	0.84	5.7	11.10	815	144	60	685
16	32.80	Above Neal Rd. boat l.	1.06	3.6	4.70	646	180	62	681
17	34.10	Riffle abv. Patterson	1.65	2.8	4.10	401	141	65	664
18	35.35	Below Fall City	0.68	7.3	14.20	1,057	144	75	719
19	37.80	Abv. Fall City - pool	0.75	6.6	11.80	843	127	85	634
20	38.30	Blw. Snoq. Fall-riffle	2.95	1.2	3.40	205	168	87	604
21	**40.71	Abv. Falls nr.Hwy 202	0.25	7.80	11.00	1,512	195	390	378
22	**42.10	Abv. Falls Meadowbrook	0.37	5.10	8.90	1,009	197	398	378

* Figure 3.
** Measured September 22nd, 1989.

Figure 6. Typical daily flow fluctuations from the Snoqualmie Falls power facilities operations (USGS, 1989 provisional hourly flow data).



The PP&LC operation is undergoing review for its Federal Energy Regulatory Commission (FERC) license which expires in 1993. Some changes in operation have been proposed. These include maintenance of 100 cfs over the falls at all times, and at least 300 cfs at the base of the falls from the Powerhouse #1 and falls combined releases. PP&LC would also like to include reinstallation of 4.5 foot high flashboards, and replacement of generators in one powerhouse into the permit. The flashboards were removed in 1977. PP&LC will study the impact of the flashboards on pool heights and velocities behind the dam, and subsequent water quality changes in 1990 (Barnes, 1990). The change in generators may also effect D.O. and will be studied as well.

There were two major pool areas identified in the study area: 1) above the PP&LC dam at Snoqualmie Falls, and 2) above the confluence of the Tolt River debris flow. Typical depth and velocity data for the pools are represented in Table 8. The pools are the result of shallow gradients and channel obstructions: the PP&LC Dam and Tolt River debris flow. The pools have a significant effect on travel times and water quality during the low flow period (see below).

Major riffle areas occur below Snoqualmie Falls (RM 40.3) to RM 38, and below the Tolt River confluence (RM 24.9) to RM 21. Smaller riffles are located between the Raging River (RM 36.2) and Patterson Creek (31.2), and along the South Fork.

The Tolt River has a significant impact on the mainstem channel configuration and lower valley water quantities. Its role in mainstem pool and riffle formation has been mentioned earlier. In addition, Tolt River can constitute 20 percent of the water gaged at the USGS station at Carnation during the summer low flow season (Table 7). It is by far the largest tributary to the Snoqualmie River in the lower valley.

The channelized and diked reach of river from Duvall to High Bridge (RM 10.5 to 2.7) has a shallow gradient, and fairly uniform channel cross-section (Table 8). Other than shallow, swift water at RM 9.8 and RM 3.6, the reach was very much like a large slow moving canal.

Time of travel studies describe mass water movement through a river system. The USGS performed a time of travel study on the Snoqualmie River in August, 1966 (Puget Sound Task Force, 1970). The river was gaged at 1020 cfs at Snoqualmie, and 1470 cfs at Carnation, during the study. The average time of travel was 46 minutes per mile between Carnation and Novelty Hill, and 64 minutes per mile between Carnation and High Bridge. A time of travel between Snoqualmie Falls and Carnation was not calculated because the dye cloud was not detected below Fall City.

The time of travel dye study was conducted in late September when average discharges were 431 cfs at Snoqualmie, and 610 cfs at Carnation (USGS provisional data, 1990). The travel time through the lowest reach (RM 7.3 to RM 2.7) was estimated from velocity measurements. Average time of travel of the dye centroids through various reaches were estimated at:

North Bend to Snoqualmie Falls	14.8 hrs.	162 min./mi.
Tokul Creek to Fall City	6.2 hrs.	114 min./mi.
Fall City to Tolt River	26.1 hrs.	141 min./mi.
Carnation to Duvall	19.3 hrs.	106 min./mi.
Duvall to Cherry Creek	6.5 hrs.	101 min./mi.
Cherry Creek to High Bridge	13.1 hrs.	196 min./mi.

At the observed discharge, water from North Bend took roughly 3.5 days to reach High Bridge. The PP&LC Dam at the Falls, the pool behind the confluence with the Tolt River, and the diked, channelized, low-gradient reach from Duvall to High Bridge appeared to retard water movement greatly.

Under 7Q10 conditions, the time of travel would be expected to be further slowed. Velocities and cross-section data for a 7Q10 event were estimated based on the data collected during this survey and USGS field data sheets at their two gages (USGS, 1988). Using these data, it would take an estimated 4.2 days for water from North Bend to reach High Bridge during 7Q10 conditions.

Water Budget

We intended to use gaging station and cross-section measurement data to construct a detailed low flow period water budget of the study area (Joy, 1989). However, the translatory waves created by PP&LC operations at the Falls created a hydraulic system more complex than could be described using our data collection system. The unsteady flow introduced by the wave passage combined with the usual 5 - 10% error in performing discharge measurements prevented meaningful calculation of reach gains or losses of discharge. However, net discharge through major subunits of the study area were evaluated. Establishing a few temporary continuous gaging stations at critical points along the river would have provided better data for water budget definition.

The estimated water budgets at three points along the mainstem, within the study area are shown in Table 9. The low flow period of interest was determined to be July 21 to October 11 (Figure 5). Discharges at the USGS Snoqualmie Falls gaging station were less than 1000 cfs over this period except during the August 20-21 storm event. USGS gaging data, instantaneous tributary discharge measurements, and estimates based on historical records were used to construct the budget. Evaporation and precipitation were not considered. The contribution of groundwater to the budget was not estimated because no data were available.

Most differences in discharge among the three points along the mainstem could be attributed to tributary inflow (Table 9). The lower river between Carnation and High Bridge may have unidentified groundwater or sub-surface gains, since not all the discharge can be accounted. However, the estimated flow at High Bridge was indirectly derived and could have a large error.

Table 9. Estimated Snoqualmie River water budget for the period July 21 to Oct. 11 during the 1989 Ecology low flow survey.

Location	Discharge (cfs)		
	Mean		Standard error
North Fork @ bridge*	180	±	12
Middle Fork	300	±	22
South Fork	150	±	4
North Bend WWTP	0.37	±	
Weyerhaeuser Pond	0.01	±	0.004
Kimball Cr.	1.8	±	0.3
Snoqualmie WWTP	0.19	±	
Total Tributary	630	±	90
Snoqualmie at Snoqualmie	640	±	35
Tokul Cr.	29	±	1
Raging River	13	±	1
Patterson Cr.	7.2	±	0.1
Griffin Cr.	3.5	±	0.1
Tolt River	160	±	9
Total Tributary	210	±	36
Snoqualmie at Carnation	860	±	39
Harris Cr.	3	±	0.1
Ames-Sikes Cr.	4.3	±	0.4
Duvall WWTP	0.24	±	
Tuck Cr.	0.7	±	0.1
Cherry Cr.	7.1	±	1
Total Tributary	15	±	6
Snoqualmie at High Br.**	890	±	40

* Calculated from: N.F.bridge = (N.F.gage X 1.378) + 18.125 $r^2 = 0.97$ based on miscellaneous USGS low flow measurements.

** Calculated from: H.Bridge = (Carnation gage X 1.037) + 4.104 $r^2 = 0.98$ based on miscellaneous USGS low flow measurements.

Chemical Water Quality

Chemical water quality data at mainstem, point source, and tributary stations were primarily collected during four monitoring surveys. Field and laboratory results from these surveys are presented in Appendix A, Tables 1-4. Additional diurnal D.O. monitoring, water quality monitoring during cross-section measurements, and Snoqualmie WWTP receiving water data are also presented (Appendix A, Table 5-6).

Samples collected for quality assurance and quality control (QA/QC) are summarized in Table 10. Laboratory analyses were reviewed after comparison to acceptable QA/QC limits, measured by duplicate, method spikes and blank results (Smith, 1989).

Field blank water often had minute concentrations of chloride, total organic carbon (TOC), ammonia (NH_3-N), total phosphorus (TP), soluble phosphorus (SP), and nitrates and nitrites (NO_{2+3}). The source of these have not yet been determined. Corrections of data for field blank concentrations were not made.

Field replicate samples, and samples taken at difference points along station transects had higher variability than the blank background (Table 10). Total analytical precision of several parameters was determined from the pooled standard deviations of field replicates (Table 10). Soluble phosphorus, TP, and NH_3 had very good precision. Total nitrogen did not, and NO_{2+3}, chloride, and fecal coliform precisions were fair.

Temperature and pH

Temperatures exceeded the 18°C, Class A standard during the first survey at all sites monitored below RM 20.3 (Appendix A, Table 1-4). Continuous temperature monitoring devices were not installed until September when instream temperatures were significantly lower, so the frequency of excursions over the Class A standard at various points along the river earlier in the season are not known. Temperatures measured during cross-section measurements in August exceeded the criterion as far upstream as RM 32; temperatures greater than 20°C were not uncommon in the lower portion of the river (Appendix A, Table 5). None of the temperature measurements taken at the North Fork or Middle Fork exceeded the 16°C, Class AA standard.

The reason for the violation of standard was lack of riparian cover and slow moving water in the channelized lower reaches of the river. None of the tributaries or point sources was having as great a heating impact as direct solar heating of the river. However, the Tolt River appeared to have some moderating effect on mainstem temperatures (Appendix A, Tables 1-4). As earlier described, much of the mainstem river has undergone channelization and revetting so banks are high and lacking large trees or significant cover. Slow velocities and time of travel through a large portion of the river below RM 38 (see above - **Physical Characteristics**) increase the potential for elevated instream temperatures.

Table 10. Field blank and duplicate results summary. Pooled variance of duplicates presented as total error (field + analytical).

BLANKS ANALYSES

	NH_3-N ug/L	TP ug/L	SP ug/L	TN ug/L	NO_2+NO_3 ug/L	COD mg/L	TOC mg/L	CL- mg/L
1	15	15	4	50	74	<4	0.66	
2			2					
	15	5	6		127			
4			<1					
5	<10	5	2	50	20		0.31	
6	11	4	1	64	15		0.44	0.10
7	<10	4	3	50	10		2.26	0.10
8	10	1	2	79	10		3.64	0.10

DUPLICATE ANALYSES

	NH_3-N		TP		NO_2+NO_3	
	0.021	0.016	0.001	0.004	0.116	0.115
	0.012	0.013	0.001	0.003	0.233	0.240
	0.029	0.024	0.001	0.011	0.154	0.125
	0.037	0.014	0.015	0.014	0.119	0.119
	0.012	0.012	0.010	0.021	0.129	0.158
	0.016	0.025	0.011	0.011	0.146	0.147
	0.022	0.017	0.017	0.019	0.139	0.153
	0.018	0.018	0.010	0.012	0.141	0.146
Pooled Var. =		0.007		= 0.004		= 0.011

	TN		SP-P		CHLORIDE	
	0.117	0.093	0.002	0.002	1.01	1.10
	0.060	0.079	0.006	0.006	1.33	1.22
	0.065	0.237	0.001	0.002	0.98	0.99
	0.373	0.143	0.006	0.006	1.22	1.24
	0.188	0.116	0.005	0.004	1.33	1.33
	0.346	0.283	0.006	0.007	1.51	1.49
			0.003	0.004		
Pooled Var. =		0.088		= 0.001		= 0.04

Fecal Coliform

	26	17	33	45
	17	11	33	51
	6	31	26	35
	410	320	28	33
	10	11	55	45
	14	15	83	100
	9	12		
Pooled Var.		= 19.4		

The Raging River, Ames/Sikes Creek, Tuck Creek, and Cherry Creek had less riparian cover than the other tributaries, and as a result were generally warmer with a greater potential of exceeding the Class A standard (Appendix A, Tables 1-4). The temperature of the Raging River at the confluence with the Snoqualmie was 22.6°C on the first survey, and over 18°C on the next two surveys. Temperatures of the WWTP effluents were also elevated and will be discussed in **Point Source Survey**.

The pH levels in the mainstem were within the 6.5 - 7.5 range usually seen in western Washington rivers (Appendix A, Tables 1-4). The Snoqualmie Falls pool from RM 40.4 to RM 42.3 usually had lower pH than the reaches below and above it. The Raging River had the highest pH on all surveys (8.7 - 9.4 s.u.). The cause for these patterns is unknown at this time.

<u>Dissolved Oxygen</u>

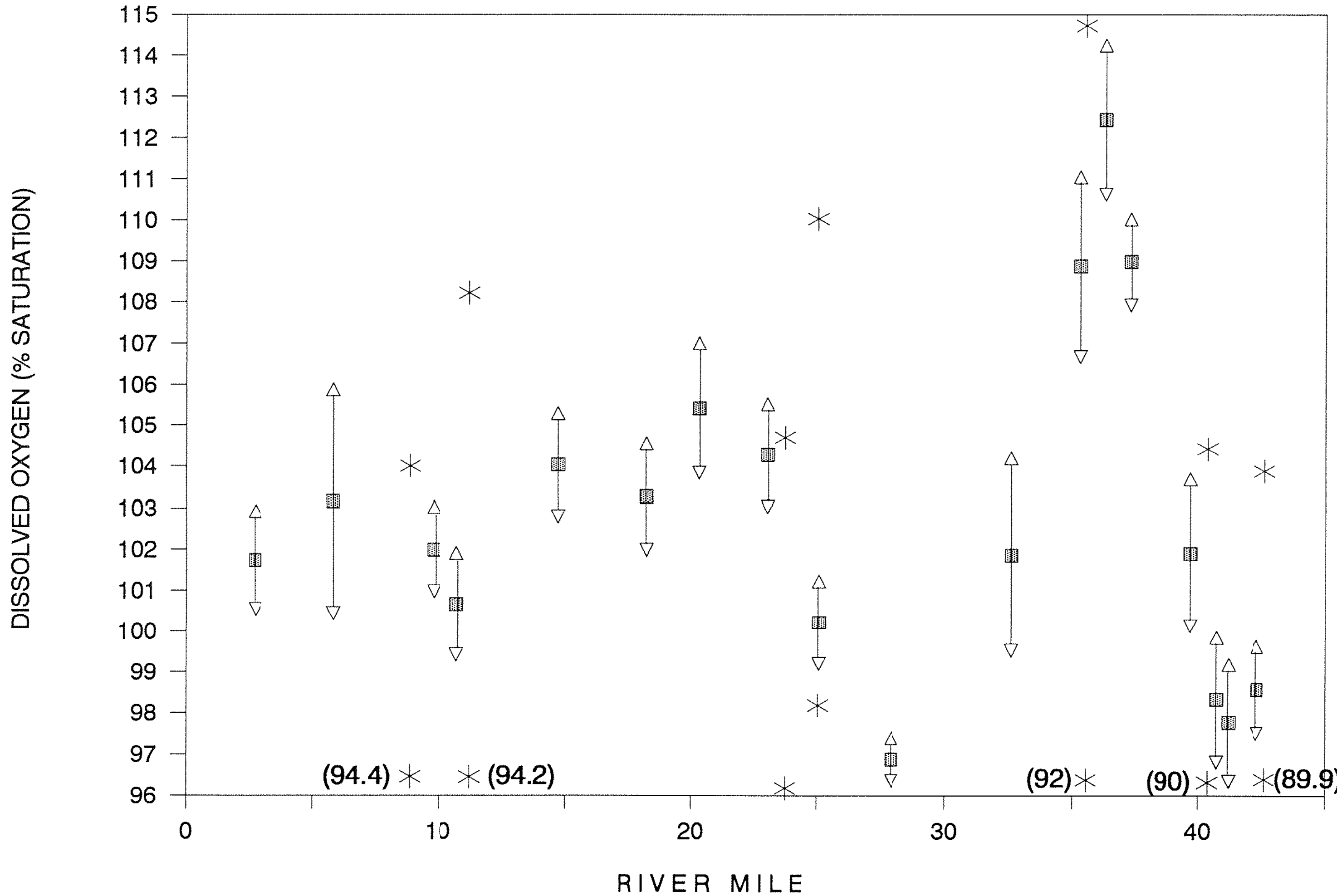
Reaeration, productivity, waste loading and channel characteristics of upstream reaches influence the diurnal D.O. pattern at a particular monitoring station. Interpretation of the D.O. regime of the river requires analysis of results from several types of monitoring: routine grab sampling, diurnal monitoring and intra-reach comparisons. The general D.O. regime observed during the study is discussed in this section, but the **Primary Production** and **Model Simulation** sections also have related discussions.

All mainstem station D.O. results met applicable Class A standards, and the North Fork and Middle Fork met Class AA standards (Appendix A, Tables 1-4). D.O. values collected during the four main routine surveys from mainstem stations ranged from 9.3 mg/L to 11.4 mg/L; percent D.O. saturation values ranged from 92% to 116% percent. Ranges observed during the diurnal monitoring were 8.9 mg/L to 11.3 mg/L with saturation values of 90% to 115%. The range of D.O.s observed during the cross-section work were similar to the others: 9.1 mg/L to 10.6 mg/L with 96% to 114% saturation. Only minor variations in D.O. concentrations were observed from samples taken at different depths, or over a transect at a single station (Appendix A, Table 1-5).

The average D.O. profile of the mainstem of the river from the four routine survey runs is presented in Figure 7, as percent D.O. saturation. Since samples at each station were taken at approximately the same time of day, temporal patterns influence the profile. Ranges from the 24-hour diurnal D.O. monitoring sites are also shown in Figure 7, to demonstrate the temporal range.

A significant D.O. loss was observed in the routine survey data in the reach between the Three Forks Area (RM 44.4) and the Falls (RM 40.4). However, the diurnal results indicate the D.O. pattern in the pool above the Falls was established at the head of the pool and translated downstream. A smaller net D.O. loss was observed through the pool than indicated by the routine survey data (Figure 8). A sediment oxygen demand (SOD) may be present within the pool area. Data collected in 1987 (PEI, 1987) suggested a significant difference between surface and bottom D.O. concentrations. Further monitoring of the condition may be warranted.

Figure 7. D.O. saturation profiles (mean +/- S.E.) for four low flow monitoring surveys on the Snoqualmie River and diurnal ranges at selected sites (✳): July - September, 1989.



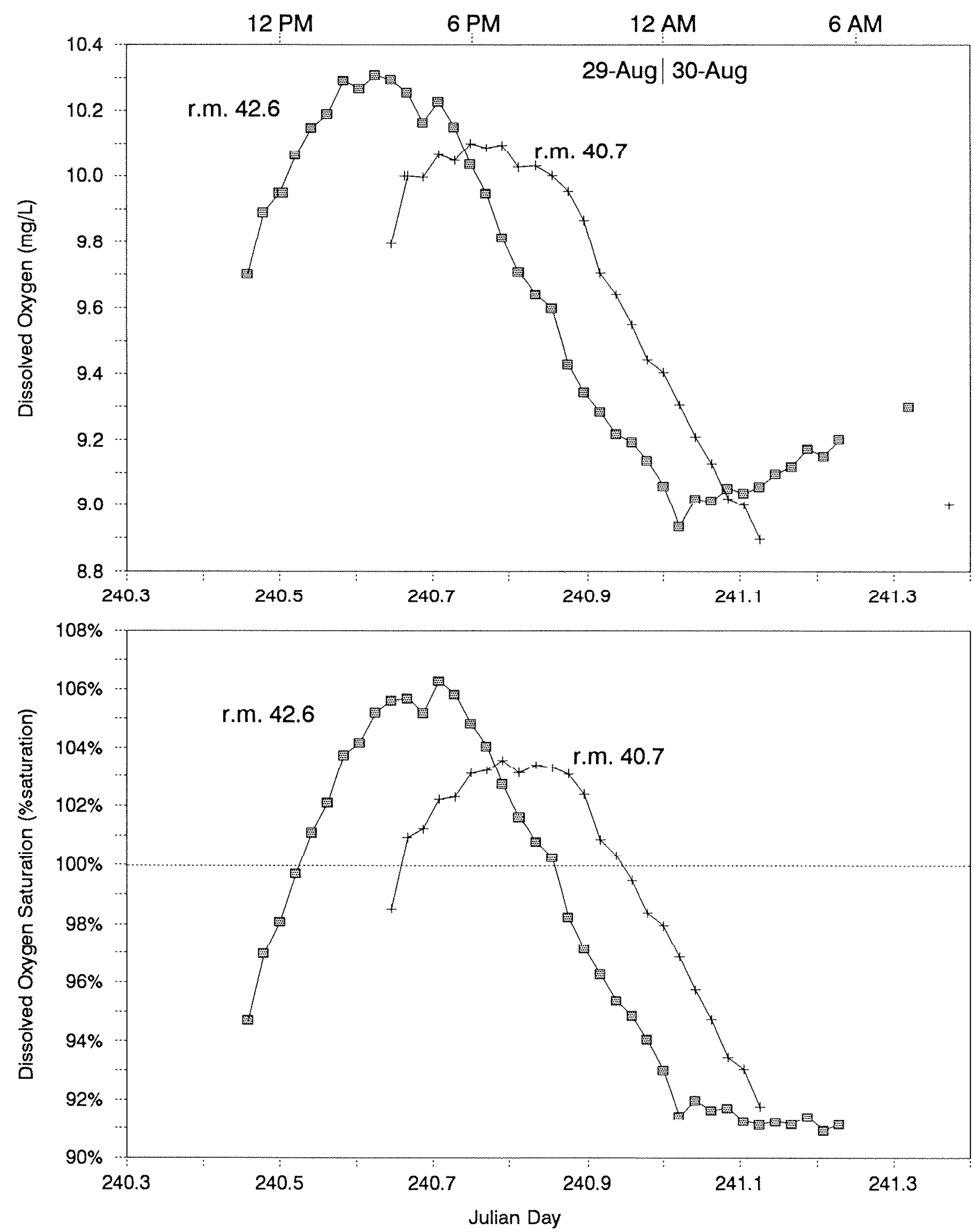


Figure 8. Diurnal dissolved oxygen concentrations at r.m. 42.6 and r.m. 40.7 on August 29 and 30, 1989.

The profile indicates the river typically gained D.O. in the largest high velocity reach: Snoqualmie Falls (RM 40.3) to the Raging River (RM 36.2). D.O. diurnal monitoring results suggested this reach also had the widest diurnal D.O. range and highest net primary productivity of the reaches monitored.

The area between Fall City (Rm 36) and the Tolt River (Rm 24.9), and between N.E. 124th (RM 14.7) and Duvall (RM 10.7) show net D.O. losses, according to the routine monitoring results. Diurnal results indicated these areas may be net gaining areas.

The reach below the Tolt River (Rm 24.9 to 23.0) appeared to be a D.O. gaining reach from the routine monitoring data. However, diurnal results indicated it had a low productivity and low respiration rate and little net D.O. change despite its relatively turbulent channel character. Also, the reach below the Duvall WWTP appeared to be net D.O. losing based on diurnal results, when routine monitoring indicated a D.O. gaining reach.

Tributary samples had relatively low biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentrations. The Class A D.O. standard was met on all monitoring occasions at the tributaries. Dissolved oxygen values ranged from 8.1 mg/L to 11.9 mg/L (Appendix A, Tables 1-4). Point source often had elevated concentrations of BOD and nitrogenous biochemical oxygen demand (NBOD), but loads were usually insignificant relative to the river volume present during the study (see-**Point Source Surveys**). Instream concentrations of these parameters were also low. These factors contributed to a generally good low flow D.O. regime throughout the study area.

Nutrients

The nutrient samples were collected and loads calculated in the Snoqualmie River to evaluate the productivity of the river, and the relative impacts of various nutrient sources. Also, ammonia (NH_3-N) acts as a nutrient, but can be toxic to aquatic organisms under certain pH and temperature conditions. Nutrient data were collected during the four routine monitoring surveys and the Snoqualmie WWTP receiving water survey, and are presented in Appendix A, Tables 1-4 & 6.

Total phosphorus (TP), soluble phosphorus (SP), nitrate and nitrite (NO_2+NO_3-N), total inorganic nitrogen (TIN), total nitrogen (TN) and NH_3-N average mainstem station concentrations are summarized in Table 11. Average instream loads at mainstem stations are shown in Figure 9.

There was a general increase in nutrient concentrations on the mainstem from Meadowbrook Bridge (RM 42.3) to High Road Bridge (RM 2.7). The Tolt River (RM 24.9) appeared to temporarily lower instream concentrations of several nutrients. Average NH_3-N, TP, and SP concentrations all peaked upstream of Griffin Creek (RM 27.9), and at the N.E. 124th Bridge (RM 14.7). Concentrations of TIN and NO_2+NO_3-N peaked above Griffin Creek

Table 11. Summary of nutrient concentration data at Snoqualmie River sites and tributary/point source sites for the four monitoring surveys during the 1989 low flow study: July - September, 1989. Values are $\mu g/L$, mean ± standard deviation.

River Mile	Location	Total P	Soluble Phos.	NH_3-N	NO_2+NO_3-N	Total Inorganic N	Total N
SF 2.0	Abv. No. Bend	10 ± 9	3.4 ± 0.8	10.8 ± 4.8	247 ± 20	258 ± 20	240 ± 90
SF 1.2	Blw. No. Bend	14 ± 9	11 ± 5	9.3 ± 2.9	241 ± 14	250 ± 17	250 ± 80
45.3	Middle Fork	5 ± 2		5.0 ± 0.0	54 ± 9	59 ± 9	
NF 0.3	North Fork	4 ± 3		11.0 ± 5.8	158 ± 14	169 ± 14	
42.30	Meadowbrook Br.	7 ± 5	3.0 ± 1.0	15.5 ± 9.7	127 ± 11	143 ± 15	120 ± 50
41.20	Railroad Br.	6 ± 4	2.3 ± 1.5	16.4 ± 3.0	121 ± 5	137 ± 5	120 ± 60
40.70	Blw. Snoq. WWTP	11 ± 7	4.6 ± 2.9	18.3 ± 7.1	129 ± 12	147 ± 15	220 ± 120
39.70	Abv. Tokul Cr.	12 ± 7	5.0 ± 1.8	15.4 ± 4.6	131 ± 15	146 ± 18	
37.30	Abv. Raging R.	13 ± 7	4.8 ± 2.2	11.8 ± 1.5	133 ± 16	144 ± 16	160 ± 110
35.35	Blw. Fall City	11 ± 6	3.2 ± 2.2	18.0 ± 11.0	121 ± 6	139 ± 11	140 ± 80
32.60	Abv. Patterson	21 ± 28	3.3 ± 2.1	20.0 ± 14.0	132 ± 13	152 ± 19	150 ± 70
27.90	Abv. Griffin Cr.	15 ± 3	5.0 ± 2.6	26.0 ± 12.0	149 ± 3	176 ± 15	200 ± 120
25.10	Abv. Tolt River	11 ± 5	2.6 ± 1.1	21.0 ± 5.0	140 ± 16	161 ± 18	190 ± 170
23.01	Blw. Carnation	12 ± 10	3.9 ± 4.4	14.1 ± 6.9	132 ± 11	146 ± 14	190 ± 100
18.25	Btw. Harris/Ames	26 ± 40	2.8 ± 1.8	17.2 ± 2.6	139 ± 7	157 ± 10	200 ± 110
14.70	N.E.124th Br.	17 ± 9	7.0 ± 4.3	29.4 ± 15.3	135 ± 18	164 ± 23	290 ± 200
10.70	Abv. Duvall WWTP	13 ± 2	4.0 ± 1.4	23.5 ± 6.8	140 ± 9	163 ± 6	200 ± 90
9.80	Blw. Duvall	16 ± 2	4.9 ± 2.8	24.9 ± 3.0	132 ± 8	157 ± 8	190 ± 80
5.80	Blw. Cherry Cr.	15 ± 2	5.0 ± 2.6	27.3 ± 5.0	146 ± 16	173 ± 11	350 ± 300
2.70	High Bridge	14 ± 6	4.7 ± 1.8	27.1 ± 4.9	127 ± 18	154 ± 18	380 ± 310
Tributaries/Point Sources							
41.10	Kimball Cr.	16 ± 3	4 ± 2	18 ± 8	340 ± 50	360 ± 60	360 ± 110
39.60	Tokul Cr.	42 ± 9	21 ± 6	41 ± 11	400 ± 70	440 ± 70	490 ± 60
36.20	Raging River	9 ± 5	4 ± 2	15 ± 6	86 ± 39	100 ± 40	200 ± 60
31.20	Patterson Cr.	63 ± 17	37 ± 7	30 ± 5	740 ± 30	770 ± 30	920 ± 130
27.20	Griffin Cr.	22 ± 8	8 ± 2	31 ± 13	340 ± 100	370 ± 100	460 ± 250
24.90	Tolt River	5 ± 4	2 ± 1	14 ± 10	125 ± 20	140 ± 20	100 ± 60
21.30	Harris Cr.	43 ± 23	20 ± 15	16.0 ± 4.2	610 ± 140	630 ± 140	720 ± 120
17.50	Ames/Sikes Cr.	870 ± 1400	100 ± 30	190 ± 120	670 ± 70	860 ± 130	1400 ± 400
10.30	Tuck Cr.	190 ± 180	21 ± 5	51 ± 26	40 ± 20	90 ± 50	350 ± 30
6.70	Cherry Cr.	37 ± 11	9 ± 3	41 ± 15	470 ± 40	520 ± 60	720 ± 220
SF 1.8	North Bend WWTP	4700 ± 2200	3100 ± 1900	540 ± 320	2600 ± 4000	3100 ± 4200	
41.70	Weyco Log Pond	60 ± 14	80 ± 120	78 ± 66	23 ± 19	100 ± 60	
40.80	Snoq. WWTP	5900 ± 900	3300 ± 370	815 ± 730	2300 ± 1200	3100 ± 570	8800 ± 3800
10.60	Duvall WWTP	8500 ± 6200	5600 ± 3100	10800 ± 7300	320 ± 240	1170 ± 7100	

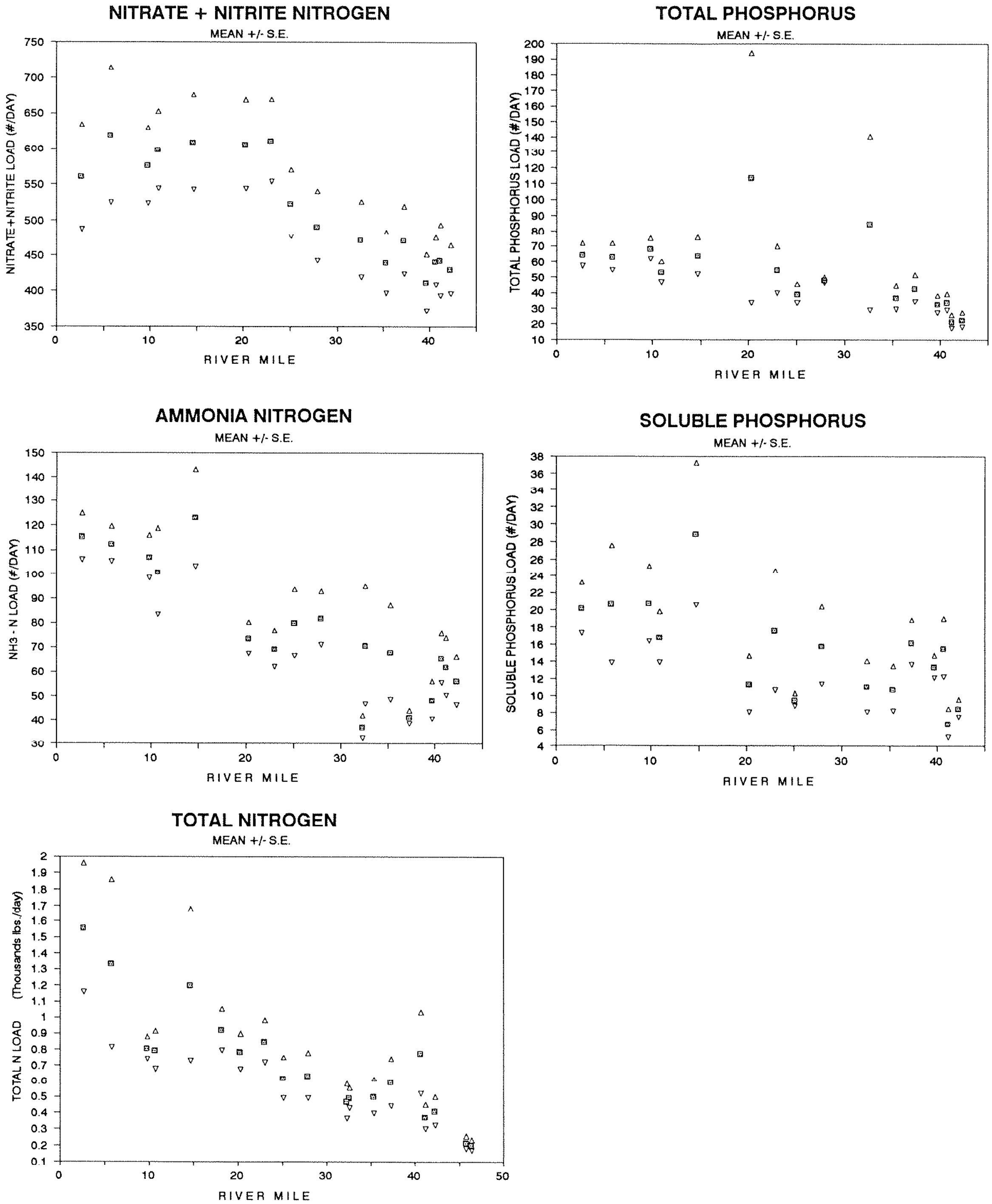


Figure 9. Nutrient loads during four monitoring surveys on the Snoqualmie River at various sites: July - September, 1989.

(RM 27.9), then again at the county line (RM 5.8). TN concentrations gained below theSnoqualmie WWTP (RM 40.7), declined at Fall City (RM 36) and steadily gained from the Tolt River downstream to High Road Bridge. Organic nitrogen (ON=TN-TIN) was present in detectable amounts from Snoqualmie (RM 40.7) to Fall City (RM 36), and from below Carnation (RM 23.01) to High Road Bridge (RM 2.7).

Un-ionized NH_3-N was not present in toxic concentrations in samples from any of the mainstem or tributary sites. NH_3-N concentrations were too low at the pH and temperature conditions observed during the sample to create high concentrations of un-ionized NH_3-N. The WWTP NH_3-N issues will be discussed under **Point Source Surveys**.

Nitrogen and phosphorus concentrations are often used as indicators of a water body's productivity or trophic status. In addition, the ratio of nitrogen to phosphorus is used in identifying a limiting nutrient for water column algal growth when factors such as light, temperature, and residence time are adequate. This ratio has been especially helpful in lake studies (Vollenweider, 1968; Welch, 1980). Mills *et al.* (1985) suggest the following "eutrophication potential" scale for river systems when both TN and TP are present at certain concentrations:

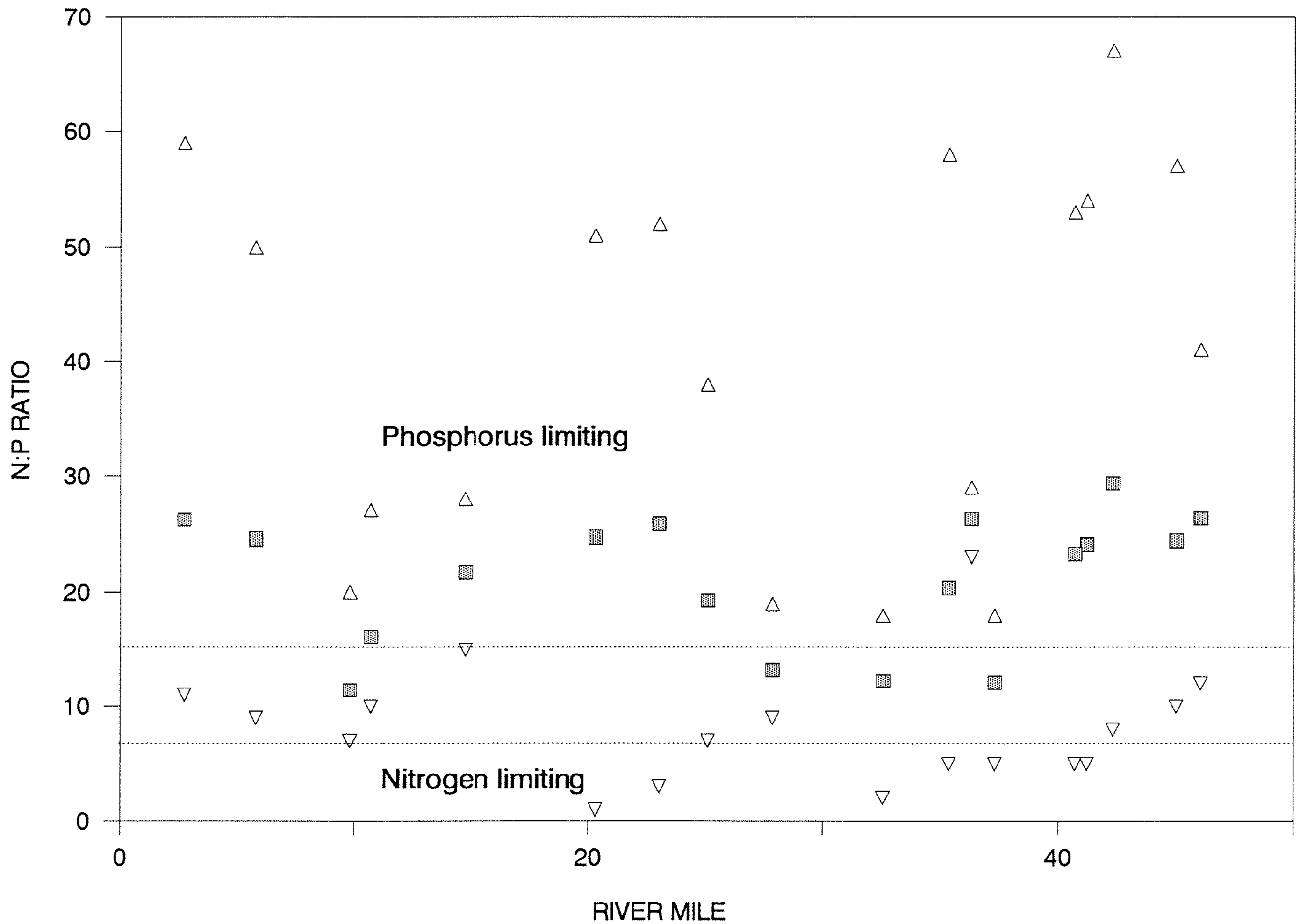
P (μg/L)	N (μg/L)	Significance
13	92	Problem threshold
130	920	Problem likely to exist
1300	9200	Severe problems possible

Mainstem TN and TP concentrations during the low flow Snoqualmie study were present at or below the "problem threshold" category; concentrations never reached the "problem likely to exist" level. Excursions into the threshold category were most prevalent during the second and fourth surveys (Appendix A, Tables 1-4). The August 21 storm event between the second and third surveys may have interrupted some type of nutrient progression e.g. chemical or biological conversion of settled organic N and P to inorganic forms. During the fourth survey, 12 of 17 stations (71%) had TN and TP concentrations at the threshold level. The threshold category was reached at RM 9.8, below Duvall during all four surveys. Stations below North Bend (S.F. 1.2), above Griffin Creek (RM 27.9), below Cherry Creek, (RM 5.8) and at High Bridge (RM 2.7) reached the threshold category during the first three surveys. Concentrations of TN and TP did not reach the threshold category during any of the surveys at Meadowbrook Bridge (RM 42.3), Weyerhaeuser Railroad Bridge (RM 41.2), and below the Tolt River (RM 23.01).

TN:TP ratios at mainstem Snoqualmie River stations generally indicated a phosphorus limited system (Figure 10). Nitrogen was potentially limiting only during the second survey - from the Weyerhaeuser Railroad Bridge (Rm 41.2) to Neal Road boat launch (RM 32.6).

Chlorophyll *a* samples collected at several sites during each of the four surveys usually had concentrations below the detection limit (Appendix A, Tables 1-4). In addition, primary

Figure 10. Nitrogen to phosphorus ratios (▩ Mean △ Maximum ▽ Minimum) during the Snoqualmie River low flow study: July - September, 1989.



productivity surveys performed in some areas of the river also suggested the presence of little or no free-floating phytoplankton in the river (see - Primary Productivity). It may be that the river moves too quickly for phytoplankton to develop, that light or temperature is limiting, or some other interference or delay in growth is at work. However, it appears that the Snoqualmie River has enough phosphorus and nitrogen to stimulate growth if other factors are favorable. Mass balance calculations in some reaches indicated nutrients were being used or retained within the system by macrophytes, periphyton, or sediments. Macrophyte beds were present in some of the littoral areas of pools in the lower river. Areas of significant periphyton were also noted (see - Periphyton).

Instream nutrient loads increased steadily downstream from Meadowbrook Bridge (RM 42.3) to High Bridge (RM 2.7). The following average net increases were observed between these two stations during the four surveys (mean ± standard deviation):

- Total phosphorus: 40 ± 20 lbs./day
- Soluble phosphorus: 10 ± 6 lbs./day
- Ammonia nitrogen: 70 ± 9 lbs./day
- Nitrate & nitrate: 200 ± 100 lbs./day
- Total nitrogen: 1000 ± 600 lbs./day

Major tributaries and point sources were monitored to evaluate their nutrient loading impact on the river. Average loads for these sources are summarized in Table 12.

Of the sources monitored, the three WWTPs were the most significant for TP and SP loading. For example, North Bend WWTP doubled the South Fork TP load; Snoqualmie WWTP contributed 20% - 30% of the instream load monitored at RM 40.7, and Duvall WWTP accounted for 10% - 30% of the load monitored at RM 9.9.

The tributaries were usually the most significant sources of nitrogen species although TN cannot be fully evaluated from the study data. Except for two samples taken from the Snoqualmie WWTP, TN was only monitored at tributary stations. The Tolt River, Tokul Creek (RM 39.6), and Patterson Creek (RM 31.2) contributed the largest TIN and TN loads. Ames/Sikes Creek was the largest monitored source of organic nitrogen, although the WWTPs appeared to be significant sources of TN and organic nitrogen based on mainstem monitoring results (Table 12). Duvall WWTP and the Tolt River were the most significant source loads of NH_3-N, followed by Tokul Creek, and Ames/Sikes Creek (RM 17.5). The high nitrogen loads estimated for the Tolt River relative to other sources may be surprising. The concentration of nitrogen in the Tolt River was generally very low, but the discharge volume was an order of magnitude greater than any other source (Tables 9 and 11).

Nutrient loads from these sources were influenced by various factors. For example, on the third survey, samples from Ames/Sikes Creek (Station T175001) had very elevated TP and NH_3-N concentrations. Livestock were upstream in the ditch at the time of sampling and probably were a major factor in the nutrient increase by disturbing streambed sediments and depositing fresh

Table 12. Average nutrient loads from Snoqualmie River tributaries and point sources over four monitoring surveys: July - September, 1989. All values lbs./ day, mean ± standard deviation.

River Mile	Location	Total P	Soluble P	NH_3 - N	NO_2+3 - N	Total Inorganic N	Total N
41.1	Kimball Cr.	0.15 ± 0.04	0.04 ± 0.01	0.2 ± 0.1	3 ± 1	3 ± 1	3.2 ± 0.7
39.6	Tokul Cr.	6.6 ± 0.5	3.2 ± 0.7	6.8 ± 2.6	66 ± 21	73 ± 23	78 ± 11
36.2	Raging River	0.6 ± 0.3	0.2 ± 0.1	1.0 ± 0.5	6 ± 3	7 ± 4	13 ± 3
31.2	Patterson Cr.	2.5 ± 0.9	1.4 ± 0.4	1.2 ± 0.3	29 ± 3	30 ± 3	36 ± 6
27.2	Griffin Cr.	0.4 ± 0.1	0.1 ± 0.1	0.6 ± 0.2	6 ± 2	7 ± 2	8 ± 5
24.9	Tolt River	4 ± 4	1.6 ± 0.8	12 ± 9	109 ± 33	122 ± 34	80 ± 34
21.3	Harris Cr.	0.7 ± 0.3	0.3 ± 0.2	0.3 ± 0.1	10 ± 1	10 ± 1	12 ± 2
17.5	Ames/Sikes Cr.	21 ± 33	2.1 ± 0.6	4.1 ± 2.7	15 ± 3	19 ± 4	30 ± 11
10.3	Tuck Cr.	0.7 ± 0.5	0.1 ± 0.0	0.2 ± 0.1	0.15 ± 0.07	0.4 ± 0.1	1.4 ± 0.4
6.7	Cherry Cr.	1.2 ± 0.5	0.3 ± 0.2	1.4 ± 0.8	16 ± 7	18 ± 8	26 ± 17
SF 1.8	North Bend WWTP	9 ± 4	6 ± 4	1.1 ± 0.6	5 ± 8	6 ± 8	
41.7	Weyco Log Pond	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.001 ± 0.001	0.01 ± 0.01	
40.8	Snoq. WWTP	10 ± 4	6 ± 2	1.2 ± 0.7	4 ± 2	5 ± 2	7.1 ± 3.9*
10.6	Duvall WWTP	11 ± 8	7 ± 4	14 ± 9	0.4 ± 0.3	14 ± 9	

* From samples taken during Snoqualmie WWTP receiving water survey.

manure. The Duvall WWTP NH_3-N concentration on the first survey was an order of magnitude lower than the other three survey concentrations as system efficiencies changed. Hatchery effluent may have contributed to the nutrient loads present in Tokul Creek depending on the number and size of fish being reared, and the method and frequency of raceway cleaning.

From the mainstem monitoring data (Figure 9), non-point sources of TP, SP, and TN were suspected as the cause of increased loads between: Fall City (RM 35.3) and upstream of Griffin Creek (RM 27.9); Tolt River (RM 24.9) and Carnation Research Road (RM 23.01); Ames/Sikes Creek (RM 17.5) to the N.E. 124th Bridge (RM 14.7); and below Cherry Creek (RM 5.8) to High Road Bridge (2.7). Livestock may be one source of these loads. Many times over the study period, livestock were seen on the banks of the river or in the shallows. Also, some landowners were piling manure mixed with sawdust at the top of the river bank. At least one discharging culvert with the odor of manure was identified. It was located just upstream of the N.E. 124th Bridge (RM 14.7) station. Septic tank leachate, fertilizer application, subsurface run-off from farms, homes, and golf courses could also be contributing to these loads.

Bacterial Indicators

Fecal coliform and enterococcus samples were collected to assess compliance with water quality standards and criteria for protection of recreational characteristic uses (Table 2). The sample results are summarized in Table 13.

As with other parameters discussed, bacterial water quality in the Snoqualmie River was worse during the second and fourth surveys. The August 21 storm event between the second and third surveys may have interrupted a favorable environment for bacteria populations of low flows and warm temperatures. On the first survey, none of the samples exceeded the Class A fecal coliform standards. Six of the 20 stations (30%) had fecal coliform samples exceeding the 100 organisms/100 mL standard on the second survey; the 200 organisms/100 mL standard was exceeded at one station. One sample exceeded the 100 organisms/100 mL standard on the third survey. Six of the 20 stations (30%) had fecal coliform samples exceeding the 100 organisms/ 100 mL standard on the fourth survey; the 200 organisms/100 mL standard was exceeded at three stations. North Fork and Middle Fork samples met Class AA fecal coliform standards on all sampling occasions.

All mainstem fecal coliform standard violations occurred in the lower valley between Neal Road boat launch (RM 32.6) and High Bridge Road (RM 2.7). Violations of the standards were most frequent at: Neal Road boat launch (RM 32.6 - 32.3); above Griffin Creek (RM 27.9); the N.E. 124th Bridge (RM 14.7); and the four sites from above Duvall (RM 10.9) to High Bridge Road (RM 2.7).

Samples from Ames/Sikes Creek, Cherry Creek, Kimball Creek, Griffin Creek, and Patterson Creek exceeded fecal coliform standards during three or more surveys (Table 13). The Cherry Creek and Patterson Creek problems have been more completely documented by work performed

Table 13. Fecal coliform and enterococcus densities from samples collected during the four 1989 low flow surveys on the Snoqualmie River: July - September. All values colonies/100 mL, mean ± standard deviation.

River Mile	Location	Fecal Coliform	Enterococcus	Class A * Violations
SF 2.0	Abv. No. Bend	27 ± 17	17	
SF 1.2	Blw. No. Bend	24 ± 12	15 ± 7	
45.3	Middle Fork	10 ± 1		
NF 0.3	North Fork	21 ± 18		
42.3	Meadowbrook Br.	21 ± 14	9 ± 5	
41.2	Railroad Br.	23 ± 14		
40.7	Blw. Snoq. WWTP	23 ± 11	18 ± 19	
39.7	Abv. Tokul Cr.	30 ± 9	14 ± 12	
37.3	Abv. Raging R.	17 ± 14	4 ± 1	
35.35	Blw. Fall City	13 ± 6	5 ± 4	
32.6	Abv. Patterson	77 ± 56		2
27.9	Abv. Griffin Cr.	152 ± 63		2
25.1	Abv. Tolt River	71 ± 37	9 ± 7	1
23.01	Blw. Carnation	44 ± 24	10 ± 10	
18.25	Btw. Harris/Ames	42 ± 20	<1	1
14.7	N.E. 124th Br.	130 ± 112	9 ± 13	1
10.7	Abv. Duvall WWTP	109 ± 85	8 ± 9	2
9.8	Blw. Duvall	101 ± 75	10 ± 14	1
5.8	Blw. Cherry Cr.	134 ± 105	1 ±	1
2.7	High Bridge	84 ± 46	5 ± 5	2
TRIBUTARIES/POINT SOURCES				
46.3	North Bend WWTP	383 ± 680		1
41.7	Weyco Log Pond	6 ± 2		
41.1	Kimball Creek	1448 ± 1393		4
40.8	Snoqualmie WWTP	14 ± 9		
39.6	Tokul Creek	10 ± 4	7 ± 7	
36.2	Raging River	31 ± 29	16 ± 13	
31.2	Patterson Creek	207 ± 82		3
27.2	Griffin Creek	238 ± 137		4
24.9	Tolt River	15 ± 11	3 ± 2	
21.3	Harris Creek	50 ± 32		
17.5	Ames/Sikes Creek	6546 ± 8031		4
10.6	Duvall WWTP	16750 ±22384		4
10.3	Tuck Creek	74 ± 38		1
6.7	Cherry Creek	533 ± 455		4

* Number of fecal coliform densities exceeding 100 colonies/100 mL, or WWTP NPDES permit limits.

by the Tulalip Tribes (Tulalip Tribes, 1988). Tokul Creek, the Raging River, the Tolt River, and Harris Creek met standards on all surveys.

Ames/Sikes Creek delivered the largest fecal coliform load of the monitored tributaries and point sources. The bacterial quality and fecal coliform permit compliance of the WWTP effluents will be discussed in **Point Source Surveys**. Cherry Creek, Patterson Creek, Duvall WWTP, and Kimball Creek also contributed significant loads. Although the Tolt River had low concentrations of fecal coliform bacteria, it contributed a significant coliform load during the last three surveys relative to the other monitored tributaries and point sources due to its discharge volume.

Monitoring data and mass balance calculations suggest significant nonpoint sources of fecal coliform loading along the mainstem: between Fall City (RM 35.3) and Griffin Creek (RM 27.2); below Harris Creek (RM 18.3) to Duvall (RM 10.7); and below Duvall (RM 9.8) to High Road Bridge (RM 2.7). Again, livestock in the river are one obvious source, as are bank-side manure storage piles. Septic tank leachate may also contribute. Careless placement of manure guns may be contributing to fecal loading as well. This practice was observed during a reconnaissance flight over the river in May 1989.

Enterococcus bacteria criteria have been proposed by the USEPA for freshwater bathing beaches (USEPA, 1986). They are health risk criteria based on epidemiological studies correlating enterococcus concentrations to gastrointestinal illness incidence from exposure while swimming (Dufour, 1983). The State of Washington has not adopted these criteria, but they are useful for water quality screening purposes, especially since numerous swimmers were seen throughout the study area.

A geometric mean enterococci density of 33 per 100 mL is the suggested limit for an illness rate of eight cases per 1000 swimmers. (The limit would be 10 per 100 mL for a six cases per 1000 illness rate.) However, 33 per 100 mL density should be based on five or more samples collected over 30 days. A suggested enterococci density criterion based on a single sample in moderately used waters is 89 per 100 mL (USEPA, 1986).

Enterococcus bacteria sample results from selected mainstem and tributary sites are summarized in Table 13. None of the average densities exceeded the 33 per 100 mL criterion. Highest enterococci densities were observed on the fourth survey. None of the densities exceeded the 89 per 100 mL single sample criterion. Only two sites had individual samples exceeding the 33 per 100 mL density criterion: below the Snoqualmie WWTP, and the Raging River. The station below Duvall WWTP (RM 9.8) showed a density of 31 per 100 mL on the fourth survey.

The enterococcus bacteria results indicate swimmers in the Snoqualmie were usually subjected to a low risk of illness from water contact. Future monitoring could focus on the following popular swimming areas: Raging River confluence, N.E. 124th Bridge, and Duvall between the WWTP and the bridge at the proposed park beach (RM 9.9).

Point Source Surveys

Results of samples taken at all three WWTPs and the Weyerhaeuser Mill Pond outlet during each of the four river surveys are summarized in Appendix A, Tables 7-10. In addition, intensive survey results performed in the vicinity of the Snoqualmie WWTP outfall are presented in Appendix A, Table 6. Effluent dispersion evaluations were successfully completed at North Bend and Snoqualmie WWTP (Figure 11). Dispersion work at Duvall was unsuccessful. Most of the work performed at the WWTPs will be covered in another document (Heffner, in preparation), and only summary data are included here.

<u>North Bend WWTP</u>

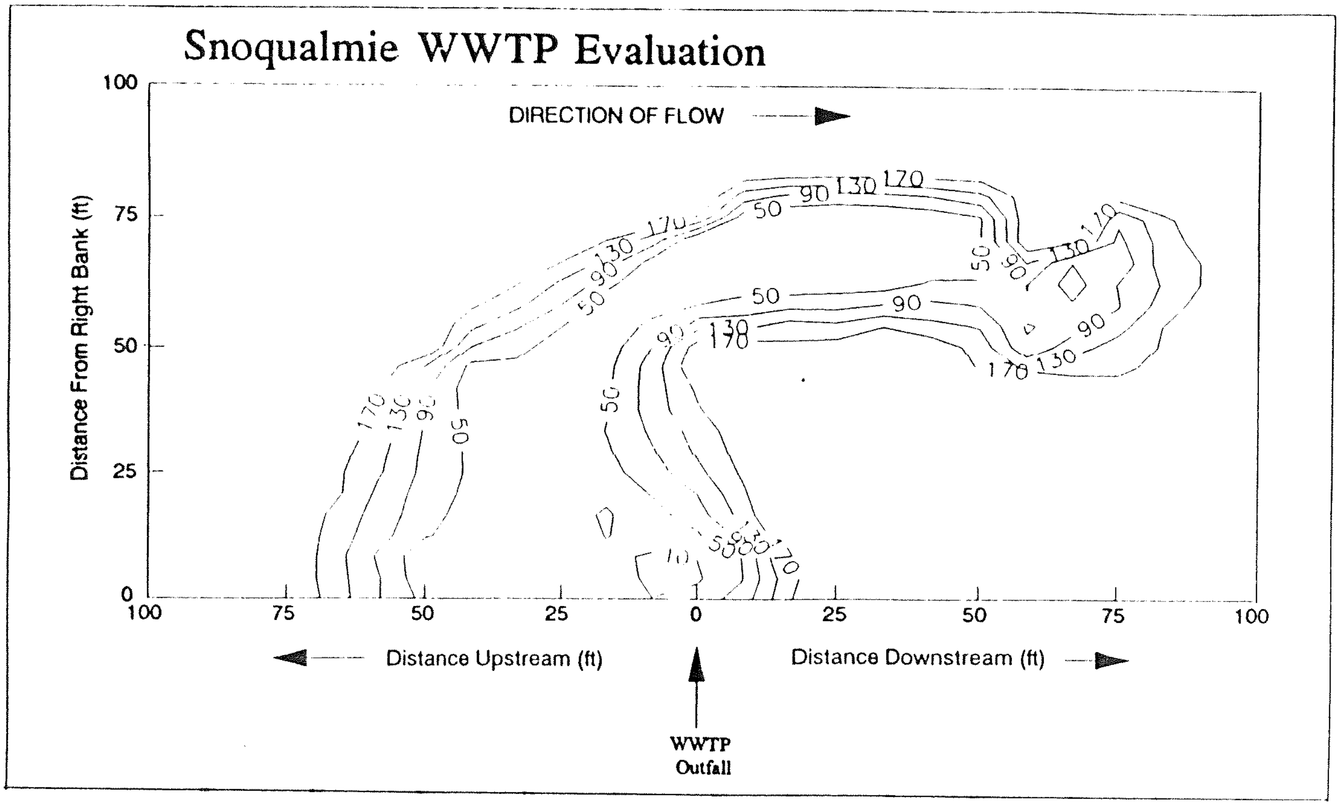
The North Bend WWTP is an oxidation ditch type secondary system with two secondary clarifiers and two chlorine contact chambers. The design average flow is 0.4 million gallons a day (mgd). The current NPDES permit limits for the facility are previously presented in Table 1.

The North Bend WWTP effluent discharges from a right bank outfall into the South Fork of the Snoqualmie River. During the low flow survey period, the outfall was exposed above the river level. Throughout late-July, August and September, the effluent was discharging into a five to eight feet wide slough formed by a transverse gravel bar. Effluent in the slough travelled upstream approximately 90 feet, to the head of the bar before mixing into the river.

Mixing of the effluent was tracked using conductivity measurement, and is illustrated in Figure 11. Conductivity measurements indicated a greater increase in downstream conductivity than would be expected from the effluent alone. Dilution based on conductivity at an area of complete mixing was only 30 or 40:1 when 500:1 was expected, based on discharge volumes. Some left to right bank conductivity variation was observed upstream of the effluent slough: 55 umhos/cm, right bank and 52 umhos/cm all the way across the river 200 feet below the outfall. The water quality station (M444012 at S.F. RM 1.2) also had higher conductivities than would be expected from the North Bend WWTP effluent alone during all four monitoring runs (Appendix A, Tables 1-4). Further tests may be warranted to locate the source.

Current mixing zone recommendations for distance from shore, length, and width were not being met because of the bank discharge into the slough. Calculated whole river to effluent dilution ratios observed during the four monitoring surveys ranged from 320:1 to 580:1.

Effluent volumes were at 60% of the design flow capacity on the dates monitored. Effluent quality met all permit limits and excellent treatment was provided during the first two monitoring surveys (Appendix A, Table 10). During the last two surveys, TSS concentrations were elevated above permitted weekly and monthly average levels. BOD and fecal coliform also exceeded their permitted concentrations on the last survey.



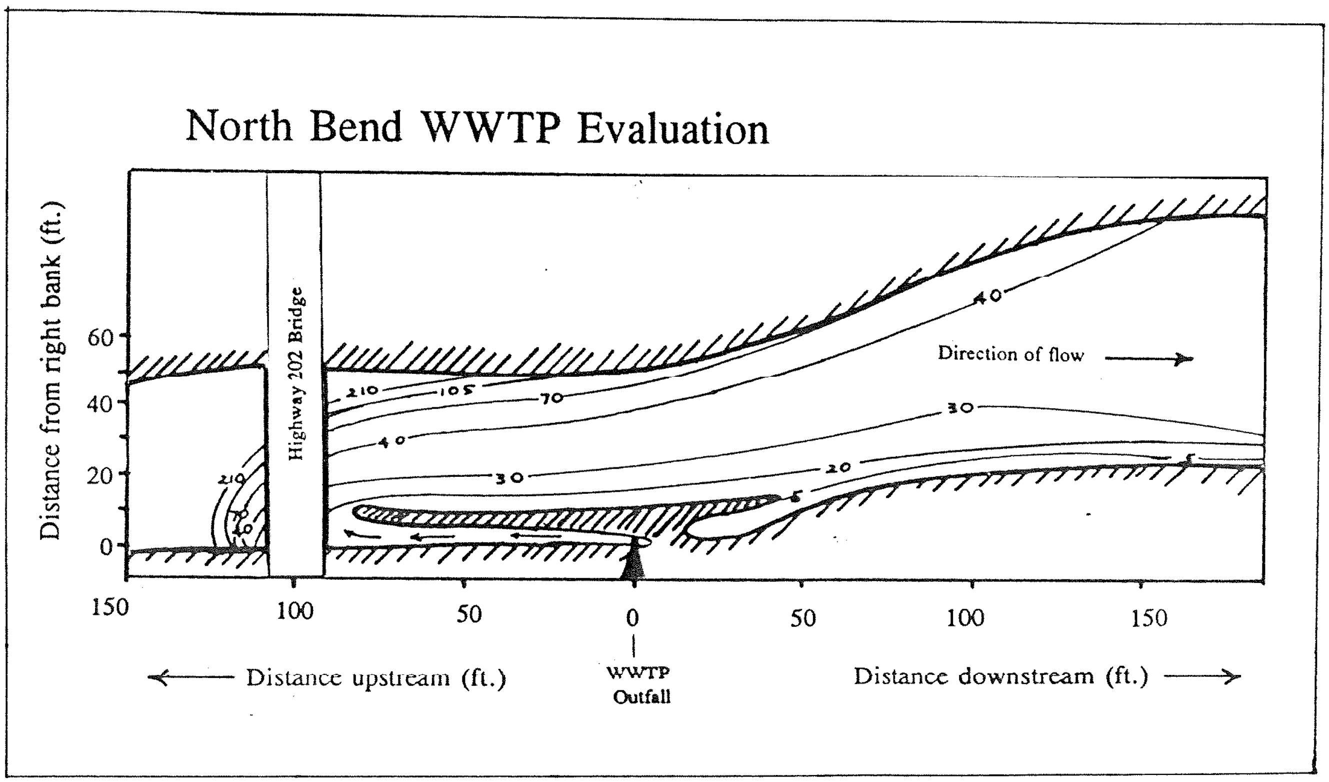


Figure 11. Dispersion of effluent at Snoqualmie and North Bend WWTP outfalls. Isopleths represent dilution factor based on conductivity measurement transects.

The effluent NH_3-N concentrations were low; un-ionized NH_3-N toxicity would not have been a problem at the outfall. Chlorine residuals (TRC) were between 0.2 and 0.6 mg/L, and exceeded the 0.011 mg/L and 0.019 USEPA criteria in the slough, but not in the main channel. The maximum temperature observed of 19.3°C would not have created Class A water quality criteria violations.

Several metals were detected in the effluent samples (Appendix A, Table 10). Copper, silver and zinc concentrations in one or more effluent samples exceeded USEPA acute and chronic toxicity criteria (USEPA, 1986). Lead and mercury concentrations in one or more effluent samples exceeded chronic toxicity criteria, but lead was also detected in sample blanks (USEPA, 1986).

Heffner (in preparation) reported that six organic compounds were detected in the effluent samples collected: α-chlordane, gamma-BHC, bromoform, dibromochloromethane, chloroform and bromodichloromethane. Only the 0.092 μg/L α-chlordane exceeded aquatic toxicity criteria; the 0.0043 11μg/L, 24-hour average criterion was exceeded (USEPA, 1986).

Heffner (in preparation) reported the effluent displayed low toxicity in the effluent bioasssays. Tests using 100% effluent showed no effect on three types of organisms.

Samples taken from stations placed above (S.F. RM 2.0) and below (S.F. RM 1.2) the WWTP indicated the effluent had some impacts on water quality during the four monitoring surveys (Appendix A, Tables 1-4). Dissolved oxygen and phosphorus concentrations and loads had the most significant gains. The rise in total phosphorus at the lower station put the TN and TP concentrations into the "problem threshold" eutrophication category mentioned earlier (see- Nutrients). The increased nutrients were also probably responsible for the periphyton chlorophyll *a* reaching "nuisance" level concentrations (see - Periphyton). The increase in periphyton may have contributed to the D.O. gains observed through primary production. Conductivity and chloride concentrations rose slightly. However, TSS, TOC, fecal coliform, and nitrogen species were similar or showed decreases in concentrations. Benthic macroinvertibrate populations did not appear to be effected by the presence of the effluent (see- Benthic macroinvertebrates).

A preliminary evaluation of an "ideal" mixing zone for the North Bend WWTP at design capacity was performed using the formula in Fischer *et al.* (1979). An outfall with a single port diffuser at mid-channel was assumed. Model results suggest the dilution ratio at the mixing zone boundary, 300 feet downstream, would probably not meet the 100:1 guideline at the 7Q10 flow of 78 cfs. The plume would likely exceed both the 15 percent of volume and stream width guidelines as well (Ecology, 1985). The whole river to effluent dilution ratio would be 127:1, but the 15 percent of river volume dilution ratio would be 19:1. Current residual chlorine would exceed USEPA acute aquatic toxicity criteria greater than 30 feet downstream under these circumstances. Current copper and mercury effluent metal concentrations also would not meet aquatic toxicity criteria. (The scenario also assumes negligible background concentrations upstream of the outfall, and a 30 foot downstream zone is allowed to meet acute toxicity criteria.) The effluent α-chlordane concentration would probably not meet aquatic life chronic toxicity, and a 10^{-6} human health risk criteria (0.46 mg/L) at the edge of the mixing zone under 7Q10 conditions.

Weyerhaeuser Mill Log Pond

The Weyerhaeuser (Weyco) log pond receives stormwater runoff from the mill site and some of the log handling area. Sanitary wastes from the mill facility are routed to the Snoqualmie WWTP. The NPDES permit limits were previously presented in Table 1, and are storm event directed. Pond effluent discharges over a weir to a culvert and under Mill Road to a marshy area between the road and the river before reaching the river at RM 41.7. The weir was too large and leaky to accurately measure the low flows encountered, but estimates are provided in Appendix A, Table 9.

Discharge volume and effluent contaminants from the log pond were insignificant over the course of the study (Appendix A, Table 9). All permit parameters were well within permit limits. Metals concentrations were low. Organic priority pollutant samples were not collected because of low discharge volume. The effluent nutrient quality of the log pond was more similar to the tributaries than the WWTPs. Samples from mainstem stations placed above (RM 42.3) and below (RM 41.2) the log pond did not show any significant impact on water quality (Appendix A, Tables 1-4).

A ground water survey between the road and the river was not conducted. However, no significant increase in river discharge was detected in that reach of the river during cross-section work (Table 8, transects 21 and 22). To better evaluate this permitting discharge, a wet season survey should be conducted.

Snoqualmie WWTP

The Snoqualmie WWTP is a two-cell aerated lagoon with a chlorine contact chamber. Wastewater is processed from the City of Snoqualmie, the Snoqualmie Falls Resort area, and the Weyco mill sanitary facilities. Design average flow is 0.26 mgd. The NPDES permit limits were previously presented in Table 1, and are typical for lagoon systems.

Effluent is discharged into the Snoqualmie River from the right bank at RM 40.8. The outfall was exposed above the water's surface during the entire study period. Dispersion of the effluent was tracked using specific conductivity measurements; results are illustrated in Figure 11. An eddy carries the effluent about 50 feet upstream before the main river current turns the plume downstream. Effluent dilutions of 10:1 to 50:1 were found to extend offshore about 75 feet and downstream 50 feet. Effluent in the initial dilution area was concentrated in the upper 3 feet of the water column. Effluent influenced conductivity could not be detected 100 feet downstream of the outfall (a dilution greater than 200:1).

Velocities are very slow throughout the entire pool where the WWTP outfall is located. During the dispersion survey, mean channel velocities in the pool were estimated at 0.62 feet/second (fps) at an average river discharge of 640 cfs. Cross-sectional measurement and velocity data verified the estimated slow velocity between the WWTP outfall and Highway 202 bridge (RM 40.7); mean velocity was 0.25 fps at a discharge of 380 cfs (Table 8, transect 20).

Current mixing zone recommendations for distance from shore were not being met because of the bank discharge. Calculated whole river to effluent dilution ratios based on USGS Snoqualmie gage and WWTP discharge data during the four monitoring surveys ranged from 4270:1 to 1200:1.

Effluent volumes were at 53% to 88% of the design flow capacity on the dates monitored. During three of the four surveys, TSS concentrations were elevated above permitted monthly average levels. One of these TSS samples exceeded the weekly average limit as well (Appendix A, Table 8). The estimated BOD concentration on the first survey exceeded the monthly average permitted concentration. Several problems were experienced with the BOD analyses from this facility, so the degree of BOD permit compliance needs further investigation. Influent pH levels were sporadically high (9.7 and 11.3), but the cause was not isolated. Effluent pH was within permit limits.

The effluent NH_3-N concentrations were low; un-ionized NH_3-N toxicity would not have been a problem at the outfall. TRC concentrations were between 0.5 and 1.2 mg/L. The concentrations could have exceeded the 0.011 and 0.019 mg/L USEPA criteria until effluent dilution in the main channel reached about 63:1 and 110:1, respectively. In Figure 11, a 3700 square foot area in the vicinity of the outfall was potentially effected. The maximum effluent temperature observed of 27.7°C would have exceeded the Class A standard within a smaller area near the outfall. At a 14.7°C ambient river temperature, a 1.28°C increase would be allowed.

Several metals were detected in the effluent samples (Appendix A, Table 8). Copper concentrations in all four effluent samples exceeded USEPA acute and chronic toxicity criteria (USEPA, 1986). Cadmium and silver concentrations in one effluent sample exceeded chronic and acute toxicity criteria (USEPA, 1986). Lead and zinc were detected at levels above the chronic aquatic toxicity criteria, but they were also found in the sample blank (Appendix A, Table 8).

Heffner (in preparation) reported that very few organic compounds were detected at quantifiable concentrations in the effluent samples. Traces of phthalate esters, chloroform, 4-methylphenol, benzyl alcohol, benzoic acid, phenol, and 1,4 dichlorobenzene were detected. Methylene chloride and acetone detected in the volatile fraction are common sampling equipment contaminants and are usually not related to effluent concentrations.

The effluent displayed low toxicity in the effluent bioassays (Heffner, in preparation). Tests using 100 percent effluent resulted in no effects in the three bioassays.

Comparisons of samples taken above (RM 41.2) and below (40.7) the Snoqualmie WWTP showed few effects that could be attributed to the effluent. Phosphorus increases were observed downstream, especially nearer the right bank; some TN increases were also present (Appendix A, Table 1-4). During the special WWTP receiving water survey, the upstream portion of the river was contributing over 95 percent of the load of most nutrient and oxidizable materials (Appendix A, Table 6). Phosphorus was the exception. The phosphorus loading may have been a significant factor in stream productivity in the reach downstream of the Fall and the Raging River (see - Primary Productivity).

A mixing zone evaluation of an "ideal" outfall was performed in the manner described for the North Bend WWTP (see above). At current facilities design flow conditions, model results indicate the 100:1 dilution ratio guideline under 7Q10 conditions of 346 cfs would probably be easily met within a few feet downstream of the port outlet. However, the plume would probably be very close to the 15 percent of stream width limit when the 100:1 dilution ratio was reached. At the 7Q10, the whole river to effluent dilution ratio is 860:1, and a 15 percent of river volume dilution ratio of 129:1. Little temperature effect would be seen in the mixing zone. Residual chlorine toxicity would still be a problem at the diffuser port. The highest silver and cadmium effect metal concentrations detected during the study would require dilutions of 18:1 and 16:1, respectively to meet chronic aquatic toxicity criteria (at 30 mg/L $CaCO_3$ hardness) within this mixing zone under 7Q10 conditions. This scenario assumes negligible background concentrations upstream of the outfall, and that a minimal mixing zone is allowed to meet acute toxicity criteria.

Duvall WWTP

The Duvall WWTP is an oxidation ditch type secondary system with two secondary clarifiers and two chlorine contact chambers similar to North Bend WWTP design. The design average flow is 0.2 mgd. The current NPDES permit limits for the facility were already presented in Table 1.

The Duvall WWTP effluent discharges from a right bank, rock armored outfall into the Snoqualmie River. A mixing and dispersion study of the effluent was not successfully performed. A high conductivity indicating effluent was detected at the rock revetment, but was not detected a few feet below the outfall. This indicated very little effluent was being discharged through the outfall at the time. Other opportunities to conduct the study did not arise, but a study should be performed when outfall options are discussed in the future.

The current outfall does not conform to mixing zone guidelines for distance from shore and width because of the bank discharge location (Ecology, 1985). Whole river to effluent ratios calculated from WWTP measurements and river discharge estimates dilution during the four monitoring surveys ranged from approximately 5200:1 to 2700:1.

Effluent volumes were at 74 to 83 percent of the design flow capacity on the dates monitored. Effluent quality was generally poor during the monitoring visits, and operational problems were evident by poor permit limit compliance (Appendix A, Table 7). TSS concentrations were elevated above permitted weekly and monthly average levels on all four survey occasions. Fecal coliform densities also exceeded their permitted limits on all surveys. Like Snoqualmie WWTP, several problems were experienced with the BOD analyses from this facility, so the degree of BOD permit compliance needs further investigation.

The effluent NH_3-N concentrations were low on the first survey, but were high on the last three surveys. Un-ionized NH_3-N toxicity would have been a problem at the outfall on second and fourth surveys. A minimum of 16:1 dilution would have been necessary to meet aquatic chronic toxicity criteria (USEPA, 1986). TRC concentrations were between <0.1 and 1.3 mg/L, and most probably exceeded the 0.019 mg/L USEPA one hour average aquatic toxicity criteria at the outfall; a minimum of 68:1 dilution would have been required. The maximum effluent temperature observed at the chlorine contact chamber was 21.2°C. At that time the river already exceeded the 18°C Class A standard so only a 0.3°C increase was allowed (WAC 173-201-045 (2) (c)(iv)). Violation would have been contained within a limited area near the outfall until 10:1 dilution was achieved.

Several metals were detected in the effluent samples (Appendix A, Table 7). Copper, silver and zinc concentrations in one or more effluent samples exceeded chronic toxicity criteria (USEPA, 1986). Lead and mercury concentrations in some effluent samples exceeded chronic toxicity criteria (USEPA, 1986). Lead and zinc were also detected in some sample blanks.

Heffner (in preparation) reported that few organic compounds were detected in the effluent samples: chloroform and phthalate ester. Only total phthalate esters (estimated 23 μg/L) exceeded aquatic toxicity criteria; the 3 μg/L, chronic toxicity criterion was exceeded (USEPA, 1986).

The effluent displayed some toxicity in the effluent bioassays (Heffner, in preparation). Acute toxicity was observed in the rainbow trout and fathead minnow tests. Chronic toxicity was observed in the *Ceriodaphnia dubia* and fathead minnow tests. Metal and ammonia concentrations present in the effluent were possible agents of toxicity.

Samples taken from stations placed above (RM 10.7) and below (RM 9.8) the WWTP had few significant differences during the four monitoring surveys (Appendix A, Table 1-4). Concentrations and loads of TOC, fecal coliform and NO_2+NO_3-N species were not significantly different between stations. The WWTP was a significant source of NH_3-N loading relative to other monitored sources, but only slight increases between the stations were observed during the last two surveys. TSS loading showed a between station increase only during the last survey. Phosphorus concentrations and loads had the most significant gains. The rise in total phosphorus at the lower station put the TN and TP concentrations into the "problem threshold" eutrophication category mentioned earlier (see - Nutrients). The primary productivity work performed in this reach indicated a heterotrophic community (see - Primary Productivity), with diurnal D.O. monitoring indicating a net D.O. loss through the reach. It is unclear if the benthic macroinvertebrate populations were effected by the presence of effluent as much as the poor habitat at RM 9.8 (see - Benthic macroinvertebrates). An upstream control station was not available to better define such effects.

A mixing zone evaluation of an "ideal" outfall was performed in the manner described for the North Bend and Snoqualmie WWTPs (see above). If a mid-channel outfall were constructed, the same model indicates the dilution ratio would probably meet the 100:1 guideline at an estimated 7Q10 flow of 455 cfs, and current design average effluent volume, well before the mixing zone boundary 300 feet downstream. At the 7Q10, the whole river to effluent dilution would be 1470:1, with a 15 percent of river volume dilution ratio of 221:1. Current residual chlorine, ammonia, silver, and mercury effluent concentrations would have the most difficulty meeting criteria within an ideal mixing zone under 7Q10 conditions. This scenario assumes negligible background concentrations upstream of the outfall, and that a minimal mixing zone is allowed to meet acute toxicity criteria.

Biological Surveys

Primary Productivity

Numerous investigators have measured the diurnal rise and fall of dissolved oxygen (D.O.) to estimate productivity of biological communities in flowing waters (Odum 1956; McIntire *et al.* 1964; Thomas and O'Connel 1966; Hall and Moll 1975). Single and two-station dissolved oxygen rate of change curves for the seven stations monitored are presented in Appendix B, Figures 2 and 3. All curves from this survey, with one exception, followed a typical diurnal trend. The exception was the two-station analysis between RM 42.6 and 40.7. According to Hall and Moll (1975), the two-station analysis works ideally with a travel time of two hours or less. The travel time between RM 42.6 and 40.7 was approximately 4 hours, thus further analyses were not conducted for this curve. The two-station method was also attempted for sites bracketing Carnation. This analysis was dropped due to lack of stream homogeneity between sampling points and increased river discharge from the Tolt River.

Productivity and respiration estimates are given in Table 14 and illustrated in Figure 12. Volumetric estimates (g/m^3/day) were converted to areal estimates (g/m^2/day) by multiplying by depth. This correction is necessary because shallow sites are more responsive to D.O. change simply due to smaller volumes of overlying water. Most literature values are similarly corrected for depth to facilitate comparisons between sites and studies.

Highest productivity and respiration rates using the single-station analyses were observed at RM 36.5. Lowest productivity and respiration were measured at RM 23.5. Net productivity was near zero or in deficit at the majority of sites. Highest net productivity was found at RM 36.5. A suitable habitat and nutrient availability for a good periphyton standing crop may be probable causes.

The ratio of total primary productivity to total community respiration (P/R) was determined for each site. This ratio is often used to classify the trophic state of a community. Green plants

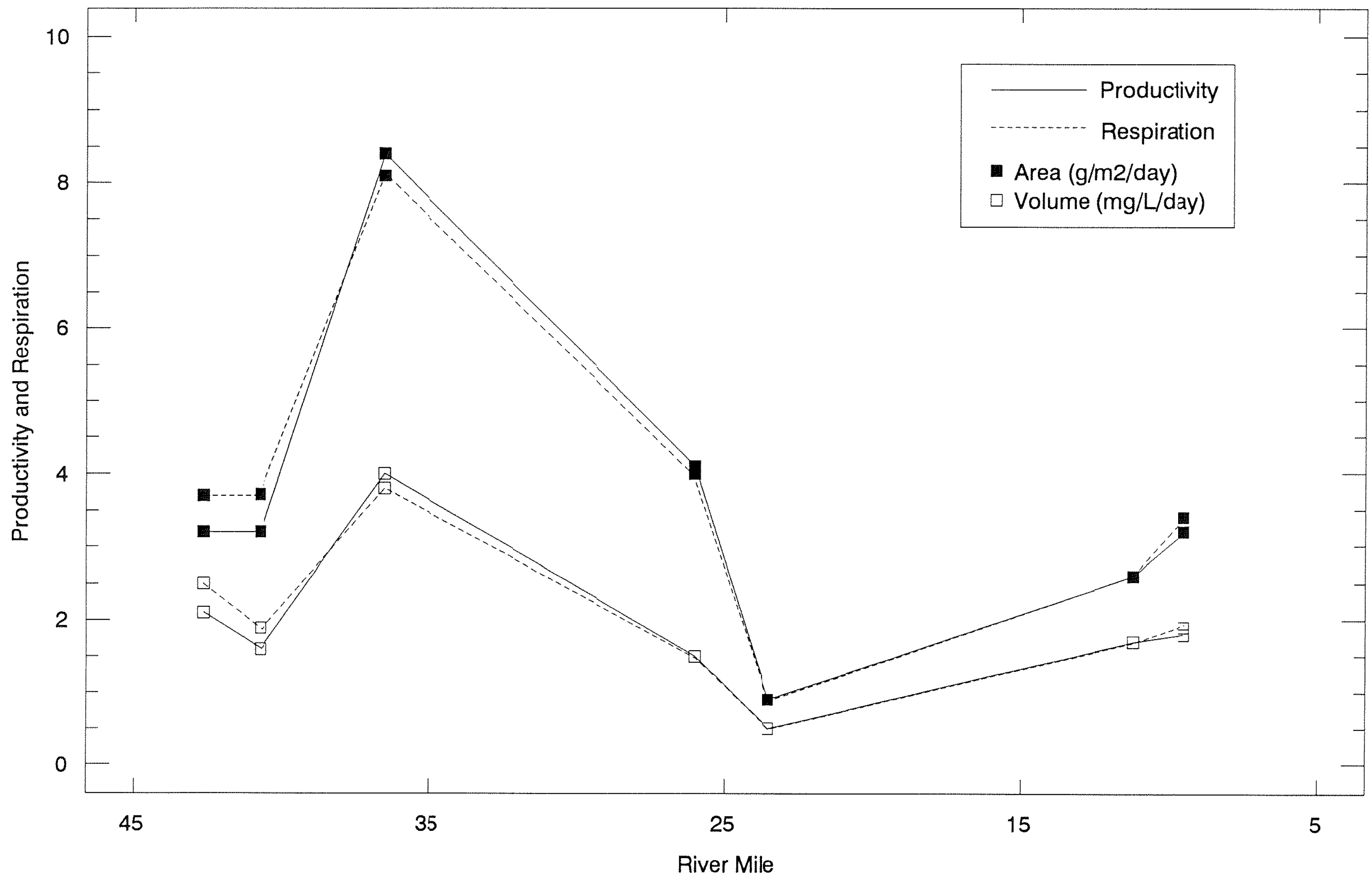


Figure 12. Productivity and respiration rates for sites along the Snoqualmie River on 8/29 for RM 42.6 and 40.7 and 9/13-14/89 for other sites. Values were determined with the single-station method.

and algae are autotrophs because they synthesize organic molecules from inorganic precursors (H_2O and CO_2) via photosynthesis. Heterotrophs do not have this ability and can only survive by taking in available organic molecules. Generally, communities are considered autotrophic when P/R is greater than one and heterotrophic when P/R is less than one (Odum 1956). Results of single-station analyses yielded P/R ratios ranging from 0.8 to 1.0, indicating an intermediate characterization between autotrophic and heterotrophic status.

Two-station analysis was successfully conducted for the river segment between RM 11.2 and 9.5 on two separate surveys (Table 14). Estimates of gross productivity were somewhat similar to those found using the single-station method. However, two-station community respiration values were two to three times higher than those found using the single station method. Therefore, the P/R ratios of 0.4 and 0.5 indicated dominance of a heterotrophic community at this site.

Differences in results using the two analyses are attributed to the fact that a single-station method is influenced by upstream productivity and respiration, while the two-station method is not. According to Hall and Moll (1975), when upstream and downstream diurnal curves are similar the single-station method can be used as an approximation of the two-station analysis. According to our results, D.O. regimes along the Snoqualmie study reach are not similar, therefore the two-station technique is recommended for future productivity work on the Snoqualmie River.

Results of light-dark bottle experiments (Appendix A, Table 11) indicated no measurable phytoplankton (pelagic) productivity at any station. Differences in light and dark bottle D.O. were usually 0.00 or 0.05 mg/L, the latter being the detection limit of the Winkler test. Nearly all the chlorophyll *a* samples collected during the four baseline monitoring surveys were below detection limit (Appendix A, Tables 1-4). Retention time in the river is probably too short to sustain a viable phytoplankton population, although the Snoqualmie River has some features that would support significant phytoplankton communities: large and slow reaches, with quiet bays and side arms where algae can develop continuously (Hynes 1970).

Productivity estimates for the Snoqualmie River using both single- and two-station methods fell in the lower range of values reported by other investigators for larger rivers (Odum 1956: Thomas and O'Connell 1966; Deb and Bowers 1983). Comparison among streams indicates that highest gross productivity rates are typically found in the recovery zones of streams polluted with organic wastes (Odum 1956). Organic pollution increases autotrophic productivity due to nutrient loading and eventually leads to productivity magnification up the food web.

<u>Periphyton</u>

A summary of periphyton data collected on two occasions at five sites in the study area is presented in Table 15. A complete set of raw chemical data can be found in Appendix A, Table 12.

Table 14. Diurnal oxygen curve results for gross productivity and community respiration for sites on the Snoqualmie River.

Sampling Site	River Mile	Date	Mean Depth (m)	Mean Velocity (fps)	K Gas transfer coefficient (g/m²/hr)	Gross Productivity (g/m²/day)	Community Respiration (g/m²/day)	Net Productivity (g/m²/day)	P/R
Above Meadowbrook Bridge	42.6	8/29-30	1.5	0.37	0.21	3.3	3.6	-0.3	0.9
		9/21-22	1.5	0.37	0.21	4.1	4.6	-0.5	0.9
Highway bridge above Snoq. Falls	40.7	8/29-30	2.0	0.25	0.52	3.2	3.6	-0.4	0.9
Upstream of Fall City	36.5	9/13-14	2.1	0.68	0.48	8.4	8.1	0.3	1.0
Upstream of Carnation	26.0	9/13-14	2.7	0.24	0.27	4.1	4.0	0.1	1.0
		9/28-29	2.7	0.24	0.27	6.8	6.8	0.0	1.0
Downstream of Carnation	23.5	9/13-14	0.6	0.43	0.67	0.9	0.9	0.0	1.0
Upstream of Duvall	11.2	9/14-15	1.5	1.23	0.78	2.6	2.6	0.0	1.0
		9/27-28	1.5	1.23	0.78	2.9	2.8	0.1	1.0
River segment* between RM 11.2-9.5	9.5-11.2	9/14-15	1.6			1.9	5.3	-3.4	0.4
		9/27-28	1.6			4.6	9.5	-4.9	0.5
Downstream of Duvall	9.5	9/14-15	1.8	1.20	0.67	3.2	3.4	-0.2	0.9
		9/27-28	1.8	1.20	0.67	2.6	2.7	-0.1	1.0

* Values in box determined using the two-station method.

Table 15. Results of periphyton surveys conducted on the Snoqualmie River (September 12 and September 25, 1989).

Sampling Site	River Mile	Date	Depth (ft)	Velocity (fps)	TOC (mg/M^2)	TSS (mg/M^2)	TVSS (mg/M^2)	TP (mg/M^2)	TN (mg/M^2)	TN/TP Ratio	Chl. a** (mg/M^2)
S.F Snoqualmie River upstream of North Bend WWTP outfall	SF 1.8	9/12/89	1.6	1.01	2,700	30,000	10,000	42	207	4.96	155.6
		Repl.	1.6	0.93	3,600	33,000	11,000	69	212	3.09	68.3
		9/25/89	1.6	0.74	3,300	44,000	16,000	86	376	4.39	40.9
		Repl.	1.4	1.06	5,200	41,000	15,000	136	567	4.15	29.5
S.F. Snoqualmie River downstream of North Bend WWTP outfall	SF 1.6	9/12/89	1.6	1.55	3,200	30,000	11,000	67	392	5.84	123.8
		Repl.	1.6	1.23	5,000	35,000	16,000	110	480	4.36	138.0
		9/25/89	1.5	1.46	6,300	35,000	17,000	178	585	3.29	28.7
		Repl.	1.1	1.60	6,000	38,000	17,000	176	570	3.24	78.7
Downstream of Fall City corner of W. River Rd	33.5	9/12/89	1.6	1.09	1,500	144,000	8,000	140	254	1.81	42.8
		Repl.	1.9	1.21	1,600	113,000	7,000	105	294	2.79	37.4
		9/25/89	1.5	1.10	2,200	270,000	14,000	205	348	1.70	32.3
		Repl.	1.7	1.36	1,300	95,000	6,000	140	88	0.63	23.1
200 m below Carnation Farms Rd.	22.9	9/12/89	1.7	1.72	1,700	21,000	5,000	36	273	7.68	9.4
		Repl.	1.8	1.56	2,700	43,000	13,000	51	235	4.58	44.6
		9/25/89	1.5	1.64	3,000	22,000	9,000	103	242	2.35	37.7
		Repl.	1.7	1.38	2,800	21,000	9,000	57	158	2.77	20.8
200 m upstream of Duvall Bridge	9.9	9/12/89	1.8	1.63	3,500	37,000	10,000	104	322	3.11	PNQ
		Repl.	1.3	1.10	3,400	24,000	7,000	93	319	3.45	55.4
		9/25/89	1.4	2.20	4,800	43,000	17,000	156	378	2.43	66.5
		Repl.	1.3	1.05	4,800	70,000	15,000	173	316	1.83	53.8

Columns TOC through Chl. a** are grouped under the heading PARAMETERS.

Repl. = Replicate value
PNQ = Present but not quantified
** = Chlorophyll corrected for pheophytin

The five periphyton collection sites were located in areas of cobble substrate in riffles (Figure 4). Periphytic growth was also observed in several other areas of the river. Prior to the August 21 storm event, extensive growths of fragile brown mats of periphyton were noted on coarse sands and small gravel shallow areas between Fall City (RM 35) and Griffin Creek (RM 27.2), and between Carnation (RM 23) and Duvall (RM 10.7). Wood debris in mid-channel, and snags close to shore also provided habitat for periphyton communities.

Instream periphyton standing crop at the five sites monitored (expressed as chl. *a*) ranged from 9.4 mg/m^2 at RM 22.9 to 155.6 mg/m^2 at SF 1.8. Generally, chl. *a* concentrations were higher in the South Fork compared to the mainstem and higher on September 12 compared to September 25.

Figure 13 presents chl. *a* standing crop for each site and date. On September 12, chl. *a* biomass in the South Fork was approximately two or three times greater than at downstream mainstream sites. Variability within replicates was relatively high at SF 1.8 and RM 22.9, probably due to patchy distributions and/or variability in sampling methods. There was difficulty in maintaining sample homogeneity while filling individual sample bottles. On September 25, chl. *a* in the South Fork was more than 50% lower than the biomass found two weeks earlier. Changes in temperature, light, current velocity, or nutrients may have altered periphyton standing crops in the South Fork between the two sampling surveys. At mainstem sites, biomass was closer to that found on the previous trip. Variability within replicates was high on September 25th at most sites, particularly SF 1.6.

Periphyton standing crop above a critical range of 100-150 mg chl. *a*/m^2 had been considered representative of nuisance conditions by some investigators (Horner *et al.* 1983; Welch *et al.* 1988). Biomass in this range has been associated with dense filamentous coverage which produces an adverse aesthetic effect. Three or four samples collected in the South Fork on September 12 were above 100 mg chl. *a*/m^2 (Figure 13). Samples at mainstem sites were well below this critical range. Chl. *a* values from an earlier study of the Raging River and other Pacific Northwest rivers and creeks were very comparable to results in this study (Table 16).

A two-way factorial analysis of variance was conducted on chl. *a* biomass to determine if significant differences were present between sampling sites or dates (Figure 14). A significant difference in chl. *a* biomass was not found between the two sampling dates. However, a statistically significant difference was found between several sites. The site at SF 1.6 was significantly higher than a RM 33.5 and 22.9; SF 1.8 was significantly higher than RM 22.9.

Sampling depth and velocity data were tested by analysis of variance to determine if biomass differences were related to differences in habitat (Figure 14). Sampling depth was found to be significantly greater on September 12, however, differences between sites were non-significant. Because a significant difference in chl. *a* biomass was not found between sampling dates, it appears that the differences in depths between dates were not affecting chl. *a* biomass. Velocities at SF 1.8 were significantly lower than at SF 1.6, RM 22.9, and RM 9.9. If this trend was affecting chl. *a*, then a similar trend would be expected for the biomass data. Since

Table 16. Chlorophyll *a*. biomass in the Snoqualmie River compared to other Washington streams and rivers.

		Chlorophyll *a*. (mg/m^2)		
Location	N	Mean	Maximum	Range
Upper Spokane River (Patmont *et al.*, 1987)	5	-	-	3-34
Lower Spokane River (Patmont *et al.*, 1987)	21	-	-	61-600
Raging River (Horner *et al.*, 1986)	10	55	92	-
Issaquah Creek (Horner *et al.*, 1986)	10	166	267	-
Lyre River (Horner *et al.*, 1986)	1	345	-	-
Sammamish River (Horner *et al.*, 1986)	1	108	-	-
Snoqualmie River (present study)				
SF 1.8	4	74	156	30-156
SF 1.6	4	92	138	29-138
33.5	4	34	43	23-43
22.9	4	24	45	9-45
9.9	3	58	66	54-66

N = Sample size

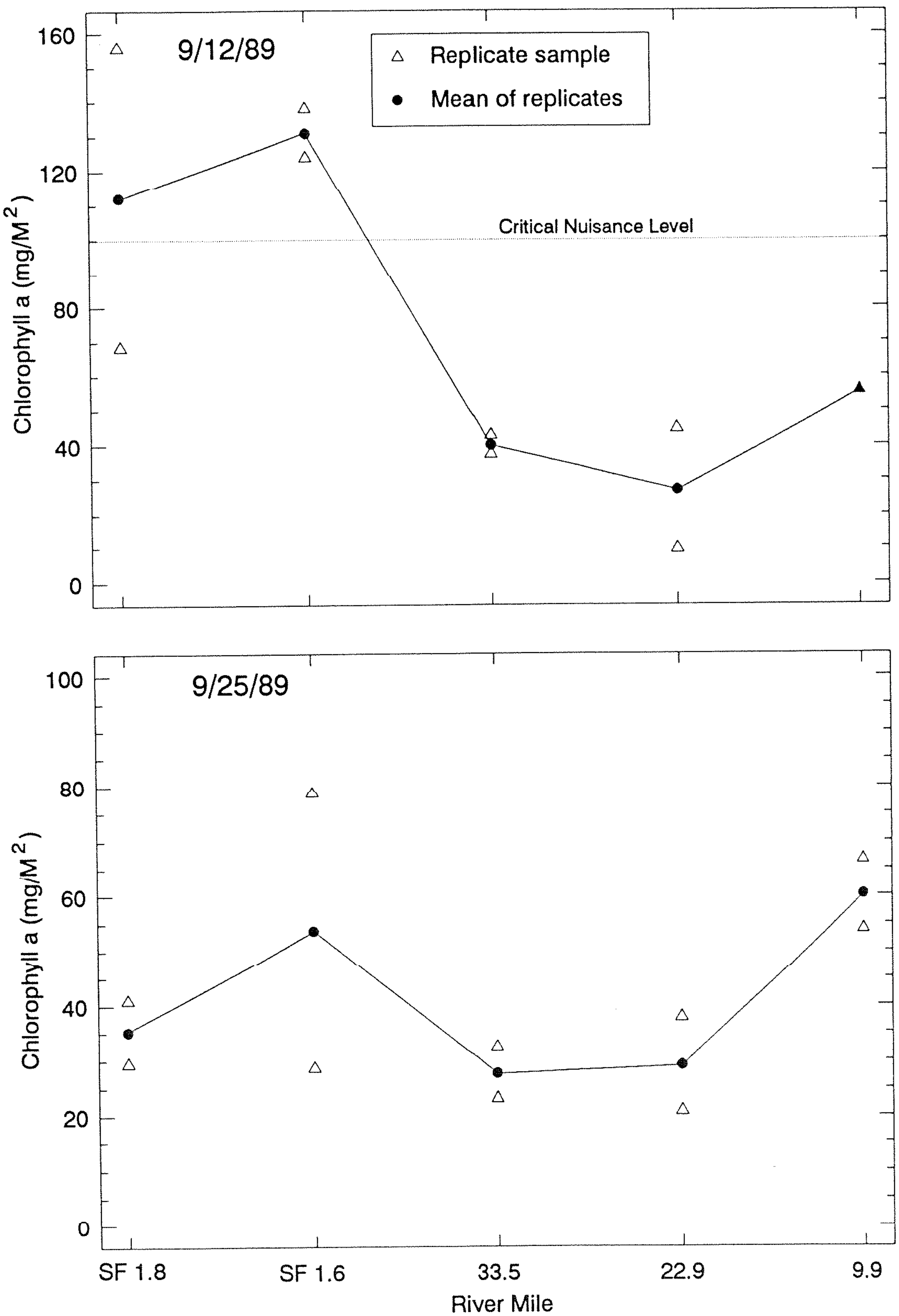


Figure 13. Periphyton biomass based on chlorophyll a concentrations at Snoqualmie River sampling sites.

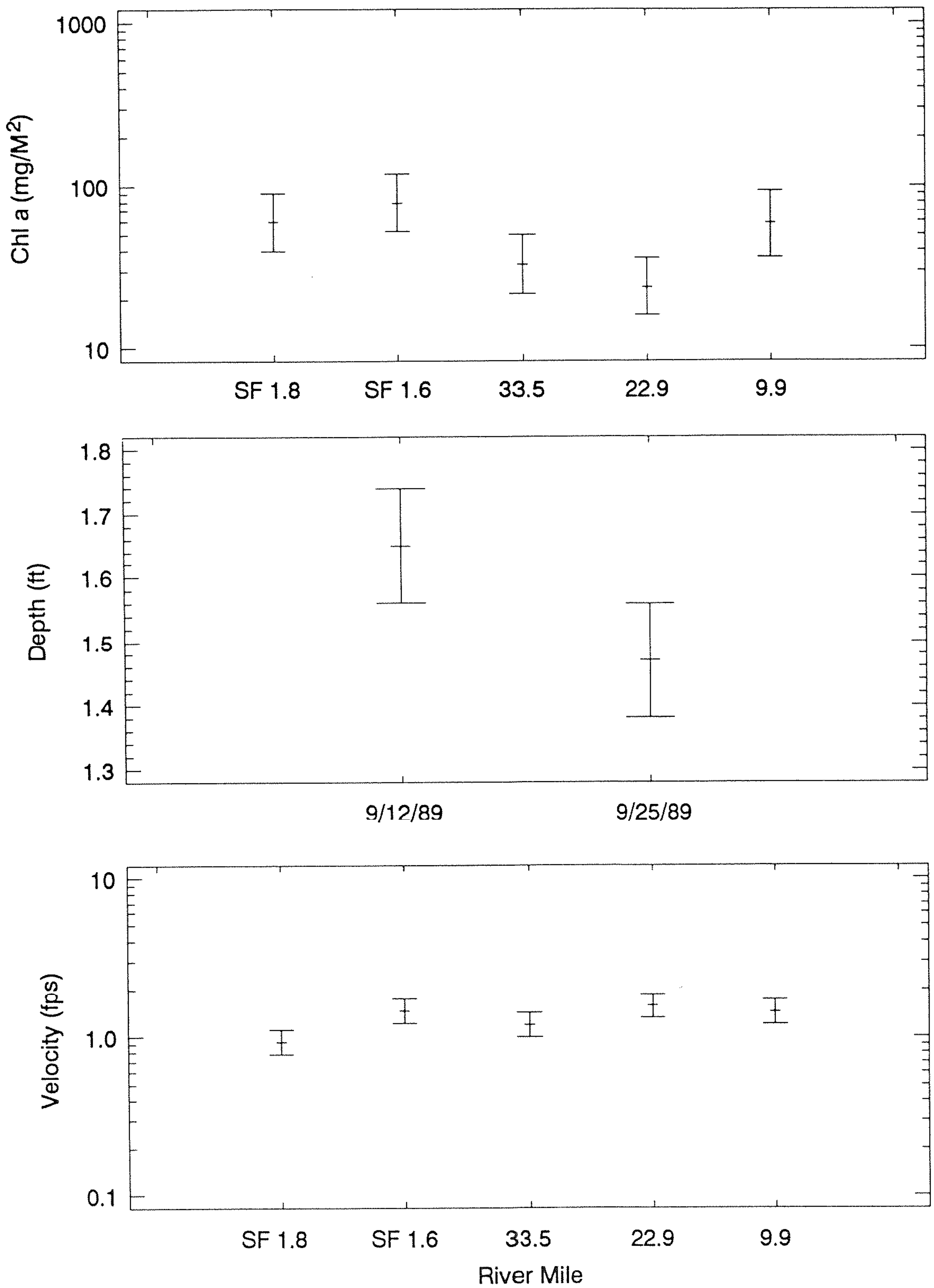


Figure 14. Results of two-way factorial analysis of variance for periphyton chlorophyll a biomass, sampling depth, and velocity. Means are bracketed by 95 percent confidence intervals (Fisher's Least Significant Difference).

the biomass at SF 1.8 was not statistically different from SF 1.6 and RM 9.9, it appears that differences in velocity were not a determinant of chl. *a* biomass.

Total volatile suspended solids (TVSS), a measure of organic solids, is often used to measure periphyton biomass. Much like the chl. *a* results, TVSS biomass was generally greatest at SF 1.8 and 1.6 on both dates (Table 15). Replicate variability was high at some sites. The TVSS biomass appeared to follow the same longitudinal trend as chl. *a* biomass. However, a linear correlation between the two data sets was non-significant. A decrease in chl. *a* biomass and an increase in TVSS from the first to second surveys probably resulted in the lack of correlation. A die-off of periphyton and deposition of non-algal organic matter could explain this finding. The measure of TVSS represents the organic content of a sample, which includes all biological components (i.e., periphyton, invertebrates, bacteria, and organic detritus), and therefore may overestimate viable algal biomass. Chl. *a* analysis provides a more direct measure of the algal fraction of a community and thus is more commonly used to evaluate periphyton biomass.

Like the other measures of biomass, TOC was generally highest in the South Fork (Table 15). The longitudinal trend was almost identical between sampling dates, though TOC was slightly higher on September 25th. A significant linear correlation was found between TOC and TVSS, but not between TOC and chl. *a*.

The two South Fork sites (0.2 miles apart) were located to assess the near-field impacts of North Bend WWTP discharge. The site (S.F. 1.6) immediately downstream of the WWTP discharge had the highest mean chl. *a*, TVSS, and TOC biomass compared to other survey sites. Additional nutrients from WWTP effluent probably foster greater plant growth in this area.

Periphyton tissue was analyzed for TN and TP to help assess whether phosphorus and/or nitrogen supplies are most likely to limit plant growth. Periphyton samples at all sites exhibited ratios of TN/TP and TN/TOC which have been associated with moderate nitrogen deficiency in phytoplankton (Table 15). Ratios of TP/TOC indicated little or no deficiency of phosphorus. This finding is puzzling for the Snoqualmie River because nitrogen is usually only limiting in highly enriched freshwaters. One explanation is that nutrient results may have been biased by non-algal organic components in the sample. Additionally, the ratios used to assess nutrient limitations were based on literature values derived for phytoplankton which may be different for periphyton.

In summary the highest periphyton standing crop measured was located in the South Fork, immediately downstream of the North Bend WWTP outfall. Nutrients from WWTP effluent probably stimulate greater plant growth in this area. Because chl. *a* measures only the algal component of a sample and it did not significantly correlate with TVSS and TOC, it is probably the best measure of periphyton biomass for the Snoqualmie River. Only three of 19 periphyton chl. *a* samples exceeded 100 mg/m^2, a value used by some investigators as a lower threshold for indicating nuisance algal conditions. Biomass of chl.*a* from Snoqualmie River sampling sites appears to be in the lower range of values reported by other investigators in the Pacific

Northwest. Periphyton chl. *a* values from the Raging River, a tributary of the Snoqualmie River were very comparable to results found in this study (Table 16).

Benthic Macroinvertebrates

A summary of benthic macroinvertebrate data showing mean abundance and diversity for each site and date is presented in Table 17; complete data are available in Appendix A, Table 13.

On August 16th, mean abundance ranged from 282 to 738 organisms/ft^2, and mean diversity ranged form 2.20 to 2.79. On September 22nd, abundance ranged from 418 to 572 organisms/ft^2 and diversity ranged from 2.35 to 2.82. Abundance and diversity were higher for samples collected during September at all sites except RM 9.9, where abundance was higher in August.

On August 16th, an upstream to downstream trend of increasing abundance was observed. Sample variability was low during August at all sites except RM 33.5. In September, abundance showed no trend and sample variability was high for all sites except RM 9.9.

A two-way factorial analysis of variance were conducted on invertebrate abundance data to determine if significant differences were present between: 1) sampling dates or sampling sites, and 2) flow and depth. Results of these analyses indicated few significant differences and are summarized in Appendix A, Tables 14 and 15.

A period of five weeks separated the two sampling events. During this time, a major storm event increased river discharge from 700 cfs to 2,600 cfs at the USGS station downstream of Snoqualmie Falls (RM 40). High variability in benthic macroinvertebrate abundance during September may be a result of this storm. Patchier distributions would be expected until invertebrate communities could recolonize and stabilize following such an event. The storm may also have caused the observed decline in invertebrate abundance at RM 9.9. The river channel at RM 9.9 was relatively narrow and deep, and substrate more sandy compared to other sites. The numbers of free-swimming *Baetidae* decreased at RM 9.9 from a mean of 149 per square foot on August 16th to only 15 per square foot on September 22nd (Figure 18). More sedentary organisms such as *Oligochaeta* (segmented worms) did not show a similar decrease in abundance between dates. Upstream stations did not show similar decreases in *Baetidae* abundance, indicating that these sites may have been less affected by the storm event.

The Shannon-Weaver diversity index is a measure of the evenness with which organisms are distributed among taxa. Wilhm and Dorris (1968) have shown the Shannon-Weaver index to be a reliable indicator of pollution in riffle sections of streams with high invertebrate production and obvious sources of contamination. Based on their work, the following general diversity guidelines were suggested for distinguishing the state of a stream (Welch 1980):

Table 17. Summary of benthic macroinvertebrate data for the Snoqualmie River 1989.

Site	River Mile	Date	Sample Size	Depth (ft)	Velocity (fps)	Abundance (no./m²)	Shannon-Weaver Diversity	Percent EPT*	Percent *Diptera*	Percent *Oligochaeta*	No. of Taxa
S.F. Snoqualmie River upstream of North Bend WTP outfall	S.F. 1.8	8/16/89	3	1.3	1.61	282	2.60	39.8	39.3	6.2	15
		9/22/89	3	1.5	1.57	547	2.66	49.0	39.3	4.6	16
S.F. Snoqualmie River downstream of North Bend WTP outfall	S.F. 1.6	8/16/89	3	1.2	1.93	293	2.56	71.0	17.8	7.6	12
		9/22/89	3	1.6	1.67	418	2.70	64.7	26.1	5.3	13
Downstream of Fall City (corner of West River Rd)	33.5	8/16/89	3	1.4	1.81	321	2.79	52.8	40.4	2.5	17
		9/22/89	3	1.6	1.63	512	2.82	79.6	13.8	1.4	17
200 m below Carnation (Farms Rd. Bridge)	22.9	8/16/89	3	1.8	1.80	424	2.32	48.9	45.3	1.8	17
		9/22/89	3	1.4	2.11	572	2.64	65.7	28.8	0.9	16
200 m upstream of Duvall Bridge	9.9	8/16/89	3	1.5	1.70	738	2.20	35.6	48.9	10.0	14
		9/22/89	3	1.2	1.69	444	2.35	18.9	51.6	19.0	15

* *Ephemeroptera*, *Plecoptera*, and *Trichoptera*.

Heavy Pollution	D <	1.0
Moderate Pollution	D =	1.0 - 3.0
Clean water	D >	3.0

The range in diversity of all samples collected in the Snoqualmie River was from 1.8 to 3.25, with a mean of about 2.6: an indication of fair to good water quality. The diversity values showed similar longitudinal trends during both sampling surveys, but the differences were not statistically significant because of high variability within each triplicate. Mean diversity was highest (2.8) at RM 33.5 and lowest (2.2 and 2.4) at RM 9.9 during both surveys. The range of diversities was similar between dates.

Composition of the major invertebrate taxa is presented in Figure 15. The most dominant organisms at all sites were *Diptera* (flies) and *Ephemeroptera* (mayflies). *Trichoptera* (caddisflies) were generally more common during September than August. Proportions of *Trichoptera* were highest at RM 33.5 during both surveys. *Diptera* and *Oligochaeta* (segmented worms) were found in highest proportion at RM 9.9 during both surveys. *Plecoptera* (stoneflies) were found in low proportions at all sites, but were most common at the two South Fork sites on both surveys. The invertebrate composition at RM 9.9 appeared to be the most different from other sites, particularly during the second survey. This is attributed to a greater degree of sandy substrate and vegetation at this site.

The two South Fork sites (0.2 miles apart) were used to assess the near-field impact of North Bend WWTP discharge. Mean abundance and diversity at the two sites were similar on both sampling dates (Table 17). Figure 18 showed evidence of an effluent discharge, but these results are opposite the expected trends. Thus, waste loading from North Bend WWTP does not appear to adversely affect benthic macroinvertebrate communities in the South Fork.

<u>Fish Tissue and Habitat</u>

Four largescale suckers (*Catostomus macrocheilus*) and four whitefish (*Prosopium williamsoni*) were collected from the Snoqualmie River just above the confluence with the Tolt River. Whole tissue samples were composited from the suckers, and fillet tissue samples were composited from the whitefish. Fish were analyzed for six to eight metals, and nineteen pesticide or persistent organic compounds (Appendix A, Table 16). Results are summarized in Table 18. Cadmium, chromium, copper, lead, zinc, mercury, and two pesticides, aldrin and p,p'DDE, were detected in one or both of the samples.

The estimated aldrin concentrations in both fish samples were similar to low levels detected in other fish taken around the state in 1989 (Hopkins, in preparation). Metals concentrations and the low DDE concentration detected in the sucker sample are typical of Western Washington drainages (Hopkins, Clark, Schlender and Stinson, 1985).

None of the concentrations exceeded U.S. Food and Drug Administration consumption criteria, or U.S. Dept. of Fish and Wildlife guidelines for the protection of wildlife. The 15 μg/kg aldrin

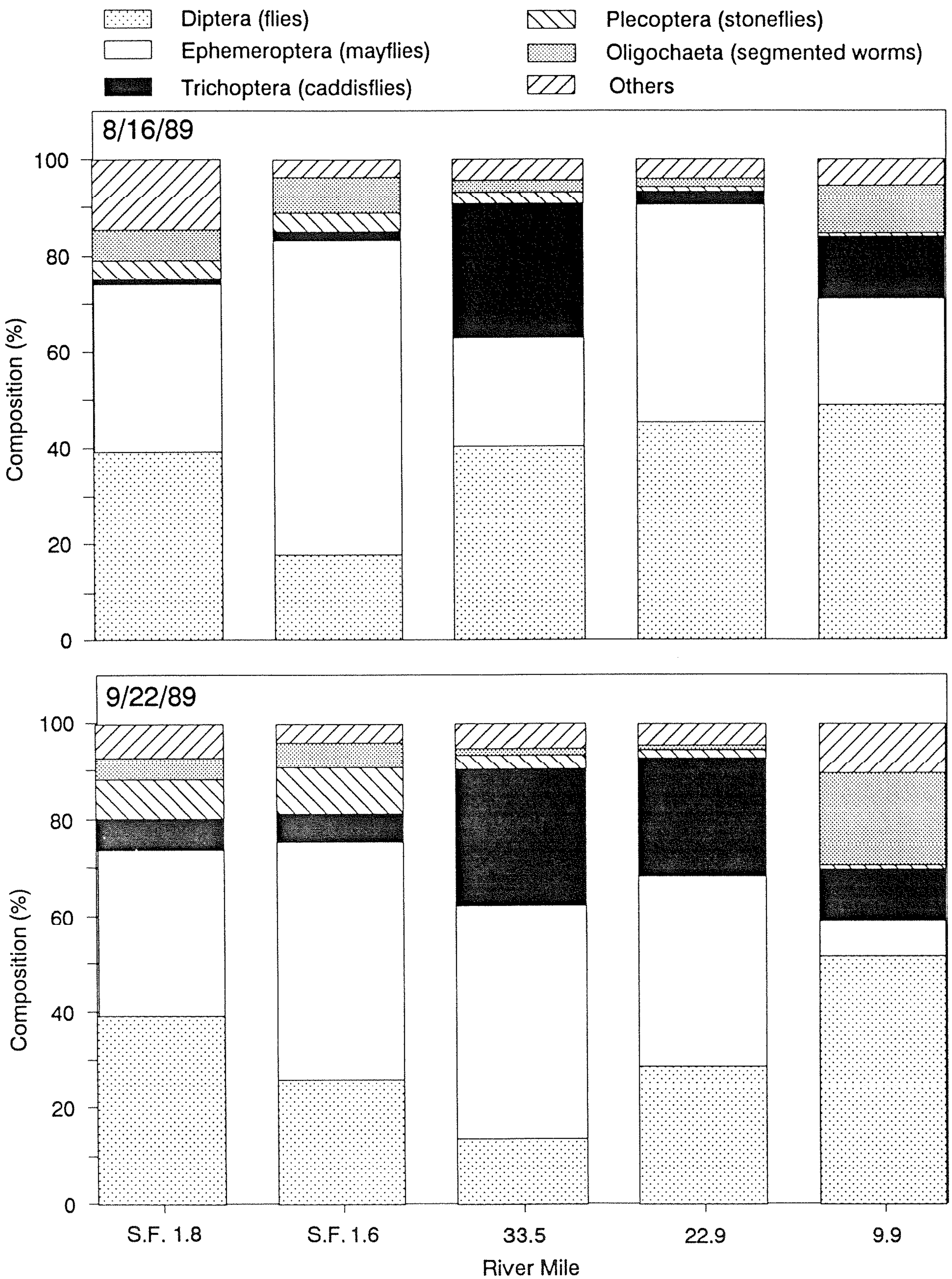


Figure 15. Composition of major benthic macroinvertebrate taxa at Snoqualmie River sampling sites.

Figure 16. Comparisons between water quality data from two Ecology ambient monitoring stations on the Snoqualmie River.

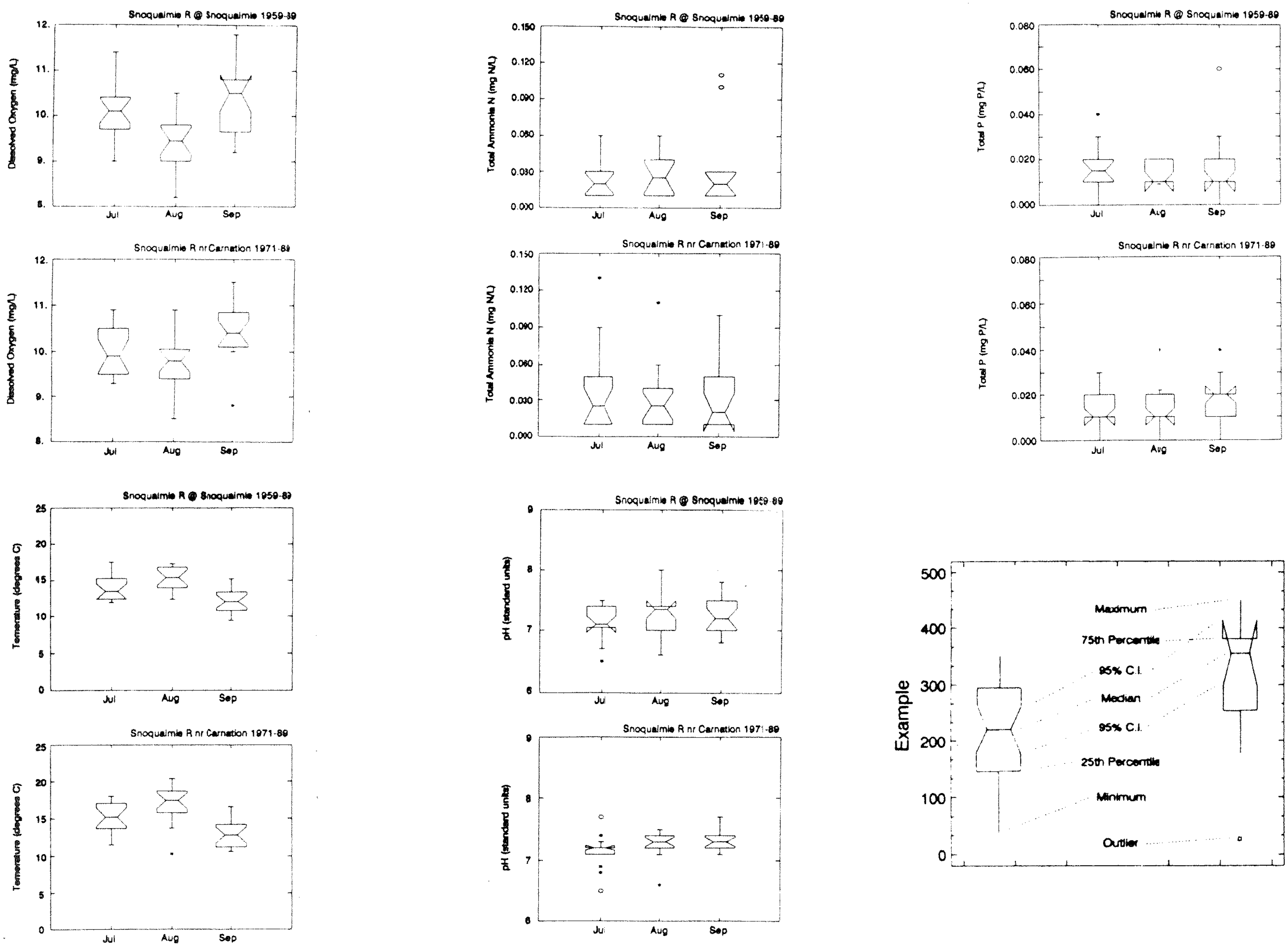


Table 18. Snoqualmie River fish tissue analysis data from Hopkins (in preparation). Fish were collected on Oct. 17, 1989, near Carnation, just above the Tolt River.

Analysis	Largescale sucker*		Largescale sucker		Mountain Whitefish**	
Tissue Type	whole		whole(dup.)		fillet	
Number in composite	4		4		4	
Length (cm)	35.8-45.2		35.8-45.2		20.3-22.7	
Weight (gm)	649-1130		649-1130		99-115	
Percent solids	26		26		27	
Percent lipids	4		3.7		4.3	
Arsenic (mg/kg)	0.20	U	0.40	U	0.39	U
Cadmium (mg/kg)	0.07		0.063		0.004	U
Chromium (mg/kg)	1.02		1.08		0.63	
Copper (mg/kg)	1.28		1.22		0.74	
Lead (mg/kg)	0.09	UJ	0.10	UJ	0.02	J
Selenium (mg/kg)					0.2	U
Zinc (mg/kg)	17.3		18.9		15.9	
Mercury (mg/kg)					0.07	
Aldrin ($\mu g/kg$)	5.2	UJ	5.5	UJ	15	B
Dieldrin ($\mu g/kg$)	7.3	U	7.3	U	15	U
a-Chlordane ($\mu g/kg$)	73	U	73	U	73	U
p,p' DDE ($\mu g/kg$)	3.4	J	3.6	J	7.3	U
o,p DDE ($\mu g/kg$)	7.3	U	7.3	U	7.3	U
p,p' DDD ($\mu g/kg$)	7.3	U	7.3	U	7.3	U
o,p DDD ($\mu g/kg$)	7.3	U	7.3	U	7.3	U
p,p' DDT ($\mu g/kg$)	7.3	U	7.3	U	7.3	U
o,p DDT ($\mu g/kg$)	7.3	U	7.3	U	7.3	U
Hexachlorobenzene	7.3	U	7.3	U	7.3	U
PCB (Arochlor 1260)	150	U	150	U	150	U

* *Catostomus macrocheilus*
** *Prosopium williamsoni*
U = Undetected at stated concentration
J = Estimated value
UJ = Trace detected but not quantifiable
B = Analyte in blank samples as well

concentration in the whitefish fillet sample exhibited the highest potential human health risk of the chemicals detected. A health risk analysis based on an aldrin carcinogenic potency factor of 11.4 (USEPA, 1985), and an average daily consumption of 12.3 g/day over 70 years gave a 3 X 10^{-5} carcinogenic risk. This is below the recommended 10^{-3} action level, but greater than the 10^{-7} no-action level.

General aquatic habitat was classified along the Snoqualmie River by the Washington Department of Wildlife (WDW) in August 1979. An open file of maps with habitat information is maintained by the Seattle Regional Office (Pacific Northwest River Basins Commission, 1980), and is also available on the WDW Pacific Northwest Environmental Database (Knutson, 1989). The Washington Department of Fisheries (WDF) also has fish habitat information (Williams, Laramie, and Ames, 1975).

Information on the most important areas of fish habitat was taken from these two sources and are summarized in Table 19. During the 1989 low-flow study, no additional information was systematically collected. The following general observations were made over the course of the study concerning aquatic habitat:

- Several salmon were seen spawning and salmon redds were common in the reach from the Tolt River (RM 24.9) to the Carnation Farms (RM 21).

- Riffle areas with cobble substrate appropriate for benthic macroinvertebrate collection were difficult to find on the mainstem below RM 34, and became nearly impossible to find below RM 21. The one site at RM 9.8 (construction rubble) was marginal compared to sites located upstream.

- Riparian cover was poor in the revetted and heavy channelized areas below RM 35. However, even in areas of these bank protection efforts, thickets and tree falls were present to provide some cover.

The WDW and WDF databases should be consulted for general habitat information when sites for water quality modifications are considered. Since they appear to be limited along the mainstem river, the few identified fish spawning and rearing habitats should be protected against degradation.

COMPARISON TO HISTORICAL DATA

General assessments of Snoqualmie River water quality have relied on data from two ambient stations: 07D130, Snoqualmie at Snoqualmie, and 07D070, Snoqualmie at Carnation. The ambient monitoring data collected for 18 years by Ecology at two stations within the study area have characterized the river as having generally good water quality. Water Quality Index (WQI) scores (Table 20) have been calculated at two year intervals. The WQI gives a numerical score after data are evaluated against criteria scales (Singleton, 1980). Scores below 20 indicate the water body represented by the monitoring site meets 'fishable-swimmable' criteria and Clean

Table 19. Brief summary of Snoqualmie River fish habitat information.

Area	River Mile	Comment	Reference*
Confluence	0 to 3	Unchannelized area of some gravels for spawning. Good riparian cover: good salmonid rearing area.	PNRBC, 1980
Lower Mainstem	3 to 12	Cherry, Tuck, and Peoples creeks support good to excellent spawning areas.	WLA, 1975
Carnation to Duvall	12 to 25	One of the few high quality mainstem spawning areas for all salmon species located between Harris Cr. and the Tolt R. Harris and Ames Cr. support coho and chum.	PNRBC, 1980 WLA, 1975
Tolt River	--	Excellent spawning and rearing habitat above channelized area	PNRBC, 1980 WLA, 1975
Fall City to Carnation	25 to 36	Good spawning gravels located just downstream of Patterson Cr. Excellent spawning area for a mile below the Raging River. Griffin and Patterson creeks support good spawning and rearing habitat.	PNRBC, 1980 WLA, 1975
Fall City to Snoqualmie Falls	36 to 40	High quality spawning gravels located in many placed here. Raging River and Tokul Creek support spawning and rearing habitat.	PNRBC, 1980 WLA, 1975
Above Snoqualmie Falls	40 on up	Good trout habitat in all forks areas.	PNRBC, 1980

* PNWBC, 1980: Pacific Northwest Basins Commission, 1980
WLA, 1975: Williams, Laramie, and Ames, 1975

Table 20. Water quality index (WQI) scores for the Snoqualmie River water quality stations in the Ecology ambient monitoring network. Scores based on 5 years of data previous to the WQI analysis date.

Station	Year	Parameter Scores								Overall
		Temperature	Oxygen	pH	Bacteria	Trophic	Aesthetics	Sus. Solids	NH_3	Rating
Snoqualmie	1988	12	7	8	12	7	6	4	0	6
at Carnation	1986	10	8	11	16	6	13	6	0	9
	1984	12	8	11	16	5	13	9	0	9
	1981	13	7	8	15	4	7	9	0	7
	1980	14	8	8	10	4	6	--	0	8
Snoqualmie	1988	7	8	5	8	8	6	4	0	5
at Snoqualmie	1986	7	8	6	10	4	11	5	0	4
	1984	8	8	7	11	4	10	7	0	5
	1981	7	8	7	17	3	6	5	0	5
	1980	7	8	7	12	3	6	--	0	5

Water Act goals. The scores for the two Snoqualmie River stations give the impression that Class A standards are met, that there is little threat to water quality, and few water quality problems exist from North Bend to Carnation. Also, comparing some of the monthly historical data (Ecology, 1990) between the two stations (Figure 16), only a few changes downstream are apparent: slightly higher temperatures, more consistent pHs, and a wider range of NH_3-N concentrations.

The 1989 survey stations M423, Meadowbrook Bridge, and M2301, between Tolt River and Harris Creek, were located at the two ambient monitoring stations 07D130 and 07D070, respectively. Data collected at these stations (Tables 11 and 13, Appendix A Tables 1-4) fell within the monthly ranges shown for the historical record in Figure 16.

The data generated at these stations have not reflected some of the existing and potential water quality problems identified in the basin during this study. For example, the elevated nutrient levels in the South Fork below the North Bend WWTP are diluted at the Meadowbrook Bridge station by the relatively high water quality of the North and Middle Forks. Elevated fecal coliform, temperature, and nutrient concentrations in areas of the lower Snoqualmie River do not appear at the Carnation station because of the Tolt River's influence on the channel morphology and water quality. Some of the nonpoint and point source problems observed were not usually continuous, but sporatic events. Also, some of the impacts from these sources were not as apparent outside of a short reach immediately downstream.

Data from the study indicated water quality in portions of the Snoqualmie River Basin was impaired during the low flow season. Fecal coliform densities exceeded Class A criteria, temperatures were elevated by solar heating of highly exposed and slow moving water, and nutrient loadings may be reaching a critical point for nuisance periphyton growths and algal potential. The expected population growth in the basin could aggravate these problems. Monitoring the basin's water quality to ensure compliance with standards, or warn of developing problems will require various strategies. Some improvement in depicting the long-term overall water quality of the Snoqualmie River may be made by moving the ambient monitoring site from Carnation to below Duvall or to High Bridge (Figure 2). However, even at these sites some sources causing local water quality violations will be missed. Only periodic intensive monitoring of a basin or sub-basin is suitable for defining more localized problems.

Modeling the Snoqualmie River Basin for current and potential cumulative point and nonpoint source impacts can help in water quality management decisions, including monitoring station placement. The model simulations can be used to evaluate the relative importance of current sources to various water problems, predict their impact areas, and estimate what impacts may occur under future scenarios.

Two modeling efforts for the Snoqualmie River are presented next. First, the model QUAL2E was used to simulate 1989 low flow water quality conditions in the study area, and under two future scenarios. Second, the results of using a simple mixing model to examine ammonia toxicity within each WWTP dilution zone at proposed future design capacities is discussed. The structure, assumptions, coefficients, and findings for both models are included.

SNOQUALMIE RIVER QUAL2E MODEL

Model Structure

QUAL2E is a one-dimensional, steady-state numerical model capable of simulating a variety of conservative and non-conservative water quality parameters (Brown and Barnwell, 1987). The model has been widely used to assess multiple point source impacts on well-mixed river systems. We selected the model because it is: appropriate for our low flow point source study; adequate for modeling the water quality parameters of interest; readily available to us, and its operation and usefulness is well-documented.

The water quality parameters selected for modeling were: dissolved oxygen (D.O.), total phosphorus (TP), ammonia (NH_3-N), and fecal coliform (FC). Individual parameters and their associated variables and interactions are listed in Table 21.

QUAL2E divides the river into reaches, sections of river, each having fairly uniform hydraulic characteristics. Based on our field work, we defined twenty-four reaches for the Snoqualmie River from the confluence with the Skykomish River, river mile (RM) 0, to North Bend, RM 46.4 (Figure 17). Each reach was further divided into computational elements of 0.2 miles throughout the modeled river. For simplicity, and to fit within the physical limits of the model, only the South Fork and Middle Fork contained headwater elements. The North Fork was defined in the model as a point source to the Middle Fork, and all natural tributaries to the river were also defined as point sources. This was appropriate since tributary data for the 1989 study were primarily collected at the confluence with the mainstem.

The model was calibrated to the mean values generated from the 1989 survey data. Simulations were then run to evaluate water quality under the following scenarios:

- Seven-day, once in ten years (7Q10) low flow conditions in the river with existing WWTPs at full design capacity

- The river at 7Q10 with Fall City and Carnation WWTPs added to the existing WWTPs, and all at proposed or estimated design capacities

These will be referred to as Scenario 1 and 2. None of the current impacts from tributary or nonpoint sources were modified in the two scenarios. After reviewing the amount of data available, we decided an adequate model verification run could not be performed at this time. As some measure of model accuracy, sensitivity analyses and monte carlo simulations were

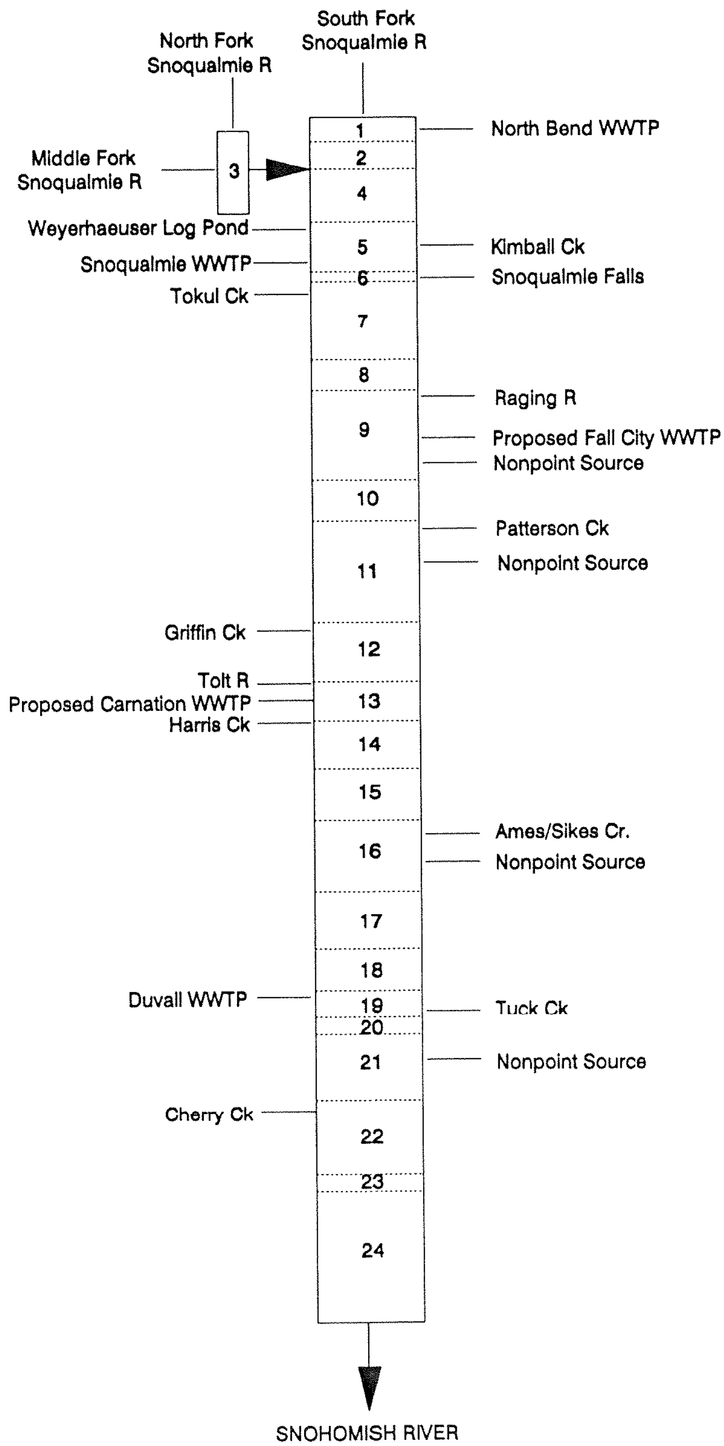


Figure 17. Schematic diagram of model reaches and loading sources for QUAL2E modeling of the Snoqualmie River system.

Table 21. Water quality parameters modelled and associated coefficients and inputs determined for the Snoqualmie River QUAL2E simulations.

Parameter	Modeling Technique	Coefficients	Inputs
Dissolved Oxygen	QUAL2E D.O. subroutine without algal input	Reaeration - formula selection - channel depth, velocity, & slope, BOD decay, SOD/ "respiration-photosynthesis"	Headwater, WWTP, tributary, and nonpoint: D.O, CBOD, NH3, Organic N, temperature, Reach temperature, Dam function
Total Phosphorus	Arbitrary non-conservative	First order settling rate	Headwater, WWTP, tributary, and nonpoint: TP conc.
Ammonia	QUAL2E nitrogen subroutine without algal uptake	Organic N to NH3 rate tributary, NH3 to NO2 rate NO2 to NO3 rate	Headwater, WWTP, and nonpoint: NH3 and ON concentrations
Fecal Coliform	QUAL2E coliform selection	FC decay rate	Headwater, WWTP, tributary, and nonpoint: FC conc.
Chloride	Conservative mineral	None	Headwater, WWTP, tributary, and nonpoint: Cl conc.
Temperature	Fixed by Reach	None	None

performed using QUAL2E-UNCAS (Brown and Barnwell, 1987). The results are in the Uncertainty Analyses Section below.

QUAL2E Coefficients, Inputs, and Calibration

Data from the 1989 low flow study were used to calibrate the QUAL2E model. For the most part, average concentrations were determined for individual stations along the mainstem river, tributaries, and point sources from the data collected during the four monitoring survey runs. Reaction rates, coefficients, and nonpoint inputs that were not determined from literature values were calculated from these field data averages. Data for some 7Q10 tributary and reach inputs, and future wastewater loading scenarios were extrapolated from existing data, or estimated from facility proposals. A brief description of the major modeling factors follows.

River and Tributary Flow Balance

River and tributary flows for the calibration period (Jul-Oct 89) were based on the water budget (Table 9) calculated earlier, and are shown in Tables 22 & 25. For the design condition of 7Q10 in Scenarios 1 and 2, the profile of river flows was calculated to match computed 7Q10 flows at USGS stations 12144000 (South Fork at North Bend), 12144500 (Snoqualmie River at Snoqualmie), and 12149000 (Snoqualmie River at Carnation). Design flows for individual tributaries without calculated 7Q10 statistics (USGS, 1990) were estimated to balance 7Q10 flows based on computed differences between the three stations listed above. Residuals in the flow balance were apportioned based on relative flows for other stations using published USGS data, and flows measured during July-October 1989 by Ecology for sources not monitored by USGS.

Reach velocities and channel depths in Table 25 were extrapolated to 7Q10 conditions from channel cross-section data (Table 8), USGS field data (USGS, 1988), and survey discharge measurements taken during the 1989 study (Appendix, Tables A1 - A6). Power function relationships (Mills *et al*, 1986) of discharge to velocity, and discharge to depth were developed for eight reaches with two or more channel measurements, and then applied to 7Q10 discharges. The power functions developed were applied to the other sixteen reaches, matching similar channel morphologies.

Temperature Calibration

The QUAL2E climatology modeling subroutine was not engaged for our simulations. Important inputs for the subroutine were not available. Instead, a mean temperature for each reach was assigned based on the field data.

Field data indicated river temperature increases linearly between RM 46.2 and 40.7 at a relatively rapid rate, and also between RM 40.7 and 0.0 at a slower rate (Figure 18). The temperature profile in the river for model calibration was estimated by the best fit linear regression through each of these river mile ranges.

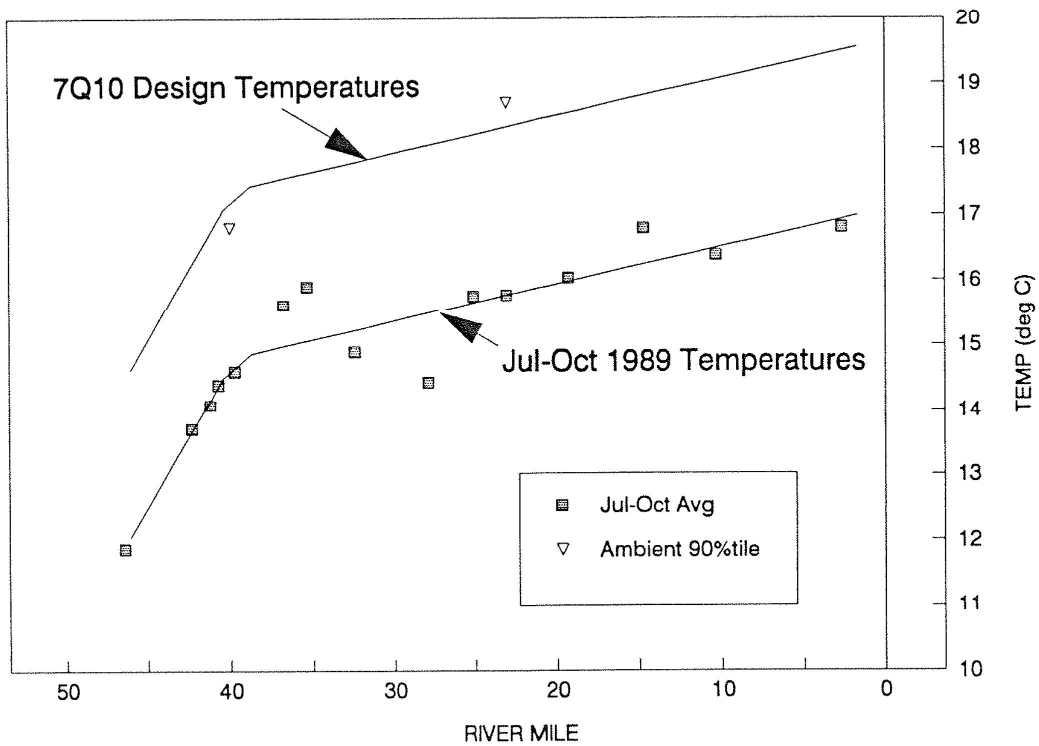


Figure 18. Snoqualmie River temperature profiles.

For 7Q10 design conditions, the temperature profiles were estimated by adjusting the measured July-October 1989 profile upwards to fit the 90 percentile temperatures observed at Ecology ambient monitoring stations at RM 23 and RM 40. Data for the period of record during the months of August through October were used. The resulting calibration and 7Q10 design profiles of temperature are also shown in Figure 18.

Point Source/Tributary Inputs

The point sources and tributaries monitored during the study were all included in the calibration simulations (Figure 17). Mean concentrations for each source were taken from Tables 11 and 13, and calculated from data in Appendix A, Tables A1 - A11. All are summarized in Table 22. For some WWTP inputs, permit limits were not being met during the study. The impacts from those violations are reflected in the calibration inputs, and as a conservative assumption in the Scenario 1 inputs (Table 23). Fall City and Carnation WWTPs are only in the facility planning stage at this time, so no discharge was applied to them during the calibration run.

Estimates of Scenario 2 WWTP discharge design capacities were obtained from the NWRO staff (J. Glynn and D. Wright, personal communication), and from consulting firm staff working on various community facility plans (G. Minton, A. Kindig, and J. Yoshida, personal communications). Effluent BOD and fecal coliform concentrations were set at the general weekly maximum permit limits (Table 22). Average secondary treatment effluent nutrient concentrations in the literature (Mills, Porcella, Ungs *et al*, 1985) were used for the future scenarios (Table 24). In some cases this resulted in major increases or decreases over effluent concentrations observed during the 1989 survey and used in the calibration and Scenario 1 inputs, e.g. Duvall and North Bend WWTPs NH_3-N concentrations.

Tributary concentrations were not changed from calibration inputs, although flows were adjusted to 7Q10 volumes. The Weyerhaeuser log pond discharge was adjusted to 0.02 cfs and not to current maximum design because its primary use is as a stormwater retention pond; some concentrations were adjusted as well (Tables 23 & 24). The Tokul Creek hatchery effluents were not directly included in the 7Q10 assessments. The 1989 study data from Tokul Creek taken below the Tokul Creek hatchery discharge were not changed to accommodate fish stock or treatment changes. The water quality impact of hatchery may require closer investigation for future TMDL processes. The positions of the Carnation (RM 23.8) and Fall City (RM 35.6) WWTPs outfall were randomly placed along likely reaches each community might use, and secondary effluent concentrations were applied.

Nonpoint Source Inputs

The evaluation of the 1989 study data indicated there were more nutrient and bacteria loads to the river than could be accounted for from the monitored tributary and point sources. This was indicated in the model simulations as well. The chloride profile with measured point source and tributary loads is a typical example showing the simulation results were too low compared to the

Table 22. Point source, tributary and nonpoint source (NPS - see text) inputs used in the calibration of the Snoqualmie River QUAL2E model of average water quality conditions during the 1989 field surveys.

1989 CALIBRATION SIMULATIONS

SOURCE	FLOW cfs	D.O. mg/L	BOD mg/L	CHL mg/L	TPO_4 µg/L	FC #/100mL	ORG-N µg/L	NH_3-N µg/L	NO_3-N µg/L
NORTH BEND WWTP	0.370	6.0	39.7	24.5	4700.	383.	5700.	540.0	2600.
NORTH FORK	175.1	10.1	1.0	0.85	4.	21.	0.000	11.00	158.
WEYCO POND	0.010	6.0	6.9	7.4	60.	6.	0.000	78.00	23.
KIMBALL CREEK	1.800	10.2	1.0	2.1	16.	1448.	0.000	18.00	340.
SNOQUALMIE WWTP	0.190	6.0	52.2	29.5	5900.	14.	5700.	815.0	2300.
TOKUL CREEK	29.00	10.9	1.0	1.6	42.	10.	50.00	41.00	400.
RAGING RIVER	13.00	10.7	1.0	5.3	9.	31.	100.0	15.00	86.
FALL CITY WWTP	0.000	0.0	0.0	0.0	0.	0.	0.000	0.000	0.
NPS	0.300	2.0	90.0	220.0	4000.	3E5	30E3	15E3	5000.
PATTERSON CREEK	7.200	9.6	1.0	2.3	63.	207.	150.0	30.00	740.
NPS	0.160	2.0	90.0	220.0	4000.	3E5	30E3	15E3	5000.
GRIFFIN CREEK	3.500	11.0	1.0	1.8	22.	238.	90.00	31.00	340.
TOLT RIVER	156.6	11.1	1.0	0.9	5.	15.	0.000	14.00	125.
CARNATION WWTP	0.000	0.0	0.0	0.0	0.	0.	0.000	0.000	0.
HARRIS CREEK	3.000	10.6	1.0	2.0	43.	50.	90.00	16.00	610.
AMES/SIKES	4.300	9.1	1.0	3.5	870.	6546.	540.0	190.0	670.
NPS	0.080	2.0	90.0	220.0	4000.	3E5	30E3	15E3	5000.
DUVALL WWTP	0.240	6.0	51.9	36.2	8500.	16750.	5700.	10800	320.
TUCK CREEK	0.700	8.3	1.0	2.6	190.	74.	260.0	51.00	40.
NPS	0.300	2.0	90.0	220.0	4000.	3E5	30E3	15E3	5000.
CHERRY CREEK	10.300	9.8	1.0	2.7	37.	533.	200.0	41.00	470.

D.O. = dissolved oxygen
BOD = BOD_5
CHL = total chloride
TPO_4 = total phosphate phosphorus as P
FC = fecal coliforms
ORG-N = total organic nitrogen as N
NH_3-N = total ammonia-nitrogen as N
NO_3-N = nitrate-nitrogen as N

Table 23. Point source, tributary and nonpoint source (NPS - see text) inputs used in the QUAL2E model simulation of the Scenario 1 water quality conditions in the Snoqualmie River.

CURRENT WWTP PERMIT/7Q10 SIMULATIONS

SOURCE	FLOW cfs	D.O. mg/L	BOD mg/L	CHL mg/L	TPO_4 µg/L	FC #/100mL	ORG-N µg/L	NH_3-N µg/L	NO_3-N µg/L
NORTH BEND WWTP	0.620	6.0	66.2	24.5	4700.	400.	5700	540.0	2600.
NORTH FORK	75.99	9.9	1.0	0.85	4.	21.	0.00	12.00	158.0
WEYCO POND	0.010	6.0	6.9	7.4	60.	15.	0.00	78.00	23.00
KIMBALL CREEK	0.950	9.7	1.0	2.1	16.	1448.	0.00	18.00	340.0
SNOQUALMIE WWTP	0.400	6.0	66.2	29.5	5900.	400.	5700	815.0	2300.
TOKUL CREEK	14.12	9.8	1.0	1.6	42.	10.	50.0	41.00	400.0
RAGING RIVER	7.180	8.8	1.0	5.3	9.	31.	100.	15.00	86.00
FALL CITY WWTP	0.000	0.0	0.0	0.0	0.	0.	0.00	0.000	0.000
NPS	0.300	2.0	90.0	220.0	4000.	3E5	30E3	15E3	5000.
PATTERSON CREEK	6.900	9.9	1.0	2.3	63.	207.	150.	30.00	740.0
NPS	0.160	2.0	90.0	220.0	4000.	3E5	30E3	15E3	5000.
GRIFFIN CREEK	1.750	9.8	1.0	1.8	22.	238.	90.0	31.00	340.0
TOLT RIVER	66.55	9.9	1.0	0.9	5.	15.	0.00	14.00	125.0
CARNATION WWTP	0.000	0.0	0.0	0.0	0.	0.	0.00	0.000	0.000
HARRIS CREEK	1.460	10.0	1.0	2.0	43.	50.	90.0	16.00	610.0
AMES/SIKES	2.090	9.5	1.0	3.5	870.	6546.	540.	190.0	670.0
NPS	0.080	2.0	90.0	220.0	4000.	3E5	30E3	15E3	5000.
DUVALL WWTP	0.310	6.0	66.2	36.2	8500.	400.	5700	10800	320.0
TUCK CREEK	0.340	9.4	1.0	2.6	190.	74.	260.	51.00	40.00
NPS	0.300	2.0	90.0	220.0	4000.	3E5	30E3	15E3	5000.
CHERRY CREEK	5.000	9.6	1.0	2.7	37.	533.	200.	41.00	470.0

D.O. = dissolved oxygen
BOD = BOD_5
CHL = total chloride
TPO_4 = total phosphate phosphorus as P
FC = fecal coliforms
ORG-N = total organic nitrogen as N
NH_3-N = total ammonia-nitrogen as N
NO_3-N = nitrate-nitrogen as N

Table 24. Point source, tributary and nonpoint source (NPS - see text) inputs used in the QUAL2E model simulation of the Scenario 2 water quality conditions in the Snoqualmie River.

FUTURE WWTP DESIGN/7Q10 SIMULATIONS

SOURCE	FLOW cfs	D.O. mg/L	BOD mg/L	CHL mg/L	TPO_4 $\mu g/L$	FC #/100mL	ORG-N $\mu g/L$	NH_3-N $\mu g/L$	NO_3-N $\mu g/L$
NORTH BEND WWTP	1.240	6.0	66.2	24.5	7000.	400.	7000.	4000.	4000.
NORTH FORK	75.99	9.9	1.0	0.8	4.	21.	0.000	12.	158.
WEYCO POND	0.020	6.0	6.9	7.4	80.	15.	100.	170.	20.
KIMBALL CREEK	0.950	9.7	1.0	2.1	16.	1448.	0.000	18.	340.
SNOQUALMIE WWTP	1.550	6.0	66.2	29.5	7000.	400.	7000.	4000.	4000.
TOKUL CREEK	14.12	9.8	1.0	1.6	42.	10.	50.	41.	400.
RAGING RIVER	7.180	8.8	1.0	5.3	9.	31.	100.	15.	86.
FALL CITY WWTP	0.620	6.0	66.2	30.1	7000.	400.	7000.	4000.	4000.
NPS	0.300	2.0	90.0	220.0	4000.	3E5	30000	15000	5000.
PATTERSON CREEK	6.900	9.9	1.0	2.3	63.	207.	150.	30.	740.
NPS	0.160	2.0	90.0	220.0	4000.	3E5	30000	15000	5000.
GRIFFIN CREEK	1.750	9.8	1.0	1.8	22.	238.	90.	31.	340.
TOLT RIVER	66.55	9.9	1.0	0.9	5.	15.	0.000	14.	125.
CARNATION WWTP	0.510	6.0	66.2	30.1	7000.	400.	7000.	4000.	4000.
HARRIS CREEK	1.460	10.0	1.0	2.0	43.	50.	90.	16.	610.
AMES/SIKES	2.090	9.5	1.0	3.5	870.	6546.	540.	190.	670.
NPS	0.080	2.0	90.0	220.0	4000.	3E5	30000	15000	5000.
DUVALL WWTP	1.390	6.0	66.2	36.2	7000.	400.	7000.	4000.	4000.
TUCK CREEK	0.340	9.4	1.0	2.6	190.	74.	260.	51.	40.
NPS	0.300	2.0	90.0	220.0	4000.	3E5	30000	15000	5000.
CHERRY CREEK	5.000	9.6	1.0	2.7	37.	533.	200.	41.	470.

D.O. = dissolved oxygen
BOD = BOD_5
CHL = total chloride
TPO_4 = total phosphate phosphorus as P
FC = fecal coliforms
ORG-N = total organic nitrogen as N
NH_3-N = total ammonia-nitrogen as N
NO_3-N = nitrate-nitrogen as N

mean mainstem concentrations (Figure 19). Fecal coliform, NH_3-N, and TP simulation results were also low at similar points along the river below RM 40. Therefore, four nonpoint source inputs were generated to help calibrate the model to the field data.

Livestock access to the river and poor manure handling practices were nonpoint sources clearly and routinely observed during the study. Several researchers have also characterized chemical components in manure. So, to simplify the input to the model, we tried to generalize all unaccounted increases in chloride, NH_3-N, TP, and fecal coliform as manure run-off sources (NPS) at four locations: RM 34.5, RM 30.5, RM 15.0, and RM 8.0. Only the RM 15.0 location had a suspected source observed during the 1989 study. The other three were located where increases in the mainstem concentrations were indicated by field data. The NPS inputs are to simulate all types of dispersive sources that were not directly observed during the study, e.g. on-site sewage systems, construction activities, field run-off, and fertilizer applications. As it turned out, the use of manure as the NPS input improved the model simulations at those locations adequately so that other input characterization was unnecessary. However, chloride and ammonia field data suggest an additional nonpoint source may be located near the confluence of the three forks (RM 44.4). Fecal coliform and total phosphorus did not appear to be affected, so neither the NPS nor other source input was applied there.

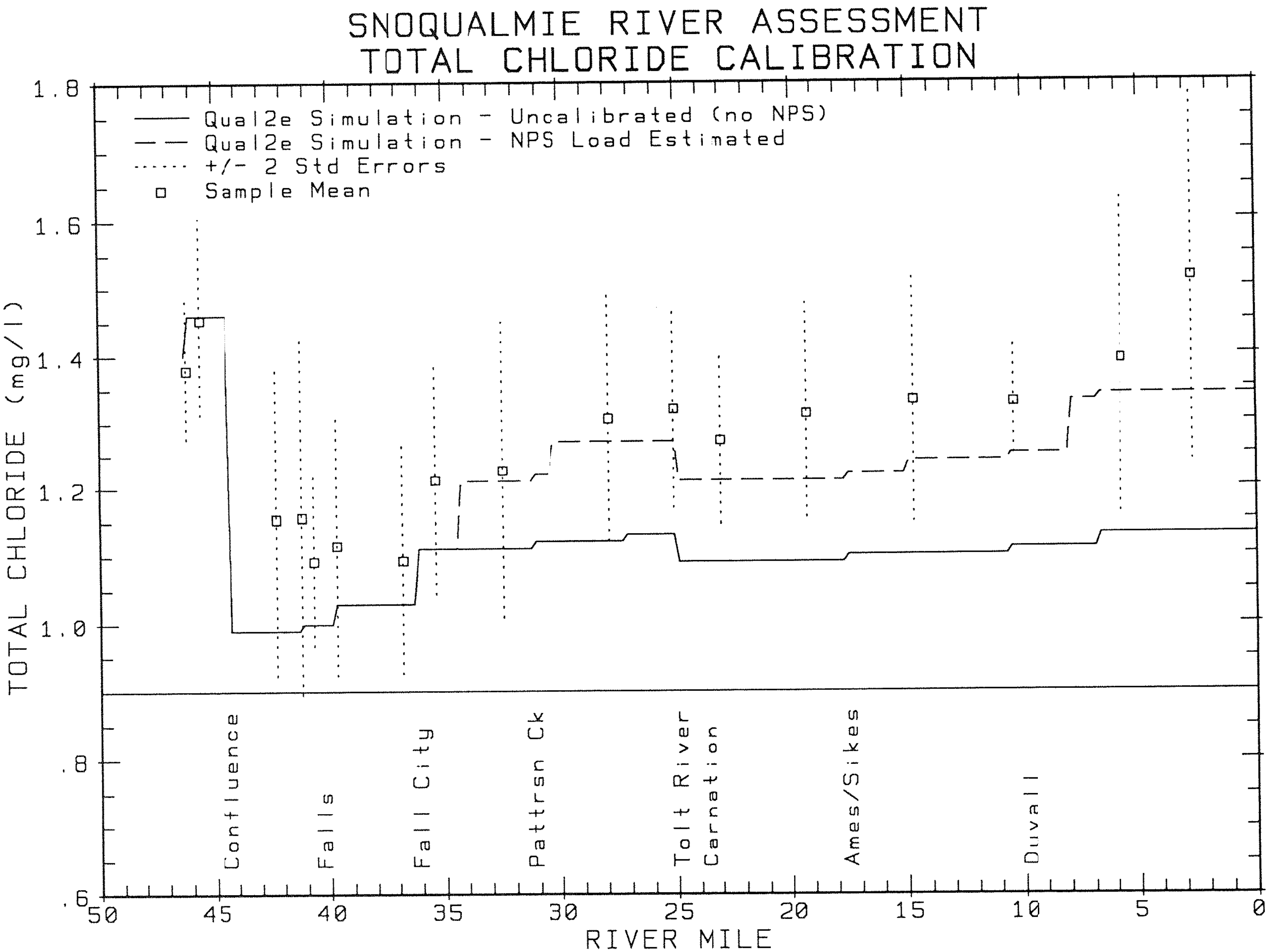
Total phosphorus, TN, NH_3-N, BOD, FC, and chloride concentrations for manure and runoff from manured fields were obtained from the literature (American Society of Agricultural Engineers, 1971 & 1985; URS, 1977); the mean or median values were calculated. The discharge volume for each of the nonpoint sources was solved by matching the apparent increase in chloride load between survey sites to a load based on the mean manure chloride concentration (220 mg/L). The size of the discharge based on the chlorides data provided NH_3-N, fecal coliform, and TP increases that greatly improved those simulations of the field data (Figures 19, 21, and 23). The additional NPS or, CBOD and NBOD loads fron NPS inputs did not appear to significantly affect the D.O. simulation.

The nonpoint source inputs were not changed for the 7Q10 flow conditions, or in the future load scenario (Table 22-24). There is not enough information at this point to adjust or estimate changes in nonpoint discharges over the range of low flow conditions in the river. The implementation schedule of nonpoint source controls, and their success in reducing water quality impacts cannot be estimated until the regulatory agencies and landowners agree on sub-basin or individual management plans.

Dissolved Oxygen and BOD

Dissolved oxygen was modeled with QUAL2E incorporating atmospheric reaeration and the demand of oxygen from carbonaceous BOD (CBOD), biological oxidation of NH_3 to NO_3 as NBOD, and net productivity or respiration calculated from diurnal D.O. measurements. Adjustments to rate coefficients and oxygen demands were made while calibrating the model to diurnal data collected at seven stations where primary productivity work was performed

Figure 19. Snoqualmie River QUAL2E model calibration runs of chloride compared to 1989 field data. Simulations without mainstem nonpoint source (NPS) and with NPS inputs are shown (see text).



(Table 14). The diurnal values were more representative of average D.O. concentrations at mainstem stations than data from the four monitoring surveys.

The rate constant for decay of CBOD in natural waters is typically greater than the laboratory "bottle" decay rate (Bowie, *et al.*, 1985). Wright and McDonnell (1979) found the decay rate constant for CBOD to vary as a function of stream flow:

$$K_1 = 10.3\ Q^{-0.49}$$

where K_1 = CBOD decay rate and Q = stream flow in cfs. At flows greater than 800 cfs the decay rate is approximately the laboratory rate, while at flows less than 10 cfs rates are relatively constant at 2.5-3.5 d^{-1}. Loss of CBOD due to settling was assumed to be negligible.

CBOD concentrations during the 1989 study were generally below the detection limit in headwater and tributary inputs (Appendix, Tables A1-A6). Therefore, the CBOD concentration for these sources was assumed to equal 1 mg/L, which is half of the detection limit. Effluent from WWTPs had measurable 5-day BOD concentrations. CBOD (ultimate) of WWTP effluent was estimated as 5-day BOD divided by 0.68 (Mills *et al.*, 1985).

NBOD was included as a normal QUAL2E incorporation of nitrification processes (Brown and Barnwell, 1987). Oxygen demand from conversions of NH_3 to NO_2, and NO_2 to NO_3, were assigned constants of 3.43 mg/L and 1.14 mg/L O_2, respectively (Bowie, *et al.*, 1985) Nitrification rates are discussed below (see -Ammonia).

The rate of atmospheric reaeration was estimated from empirical equations provided in QUAL2E relating reaeration to velocity and depth or velocity and slope. Selections of appropriate reaeration equations were based on recommendations by Mills *et al.* (1985). For reaches with stream depth less than two feet, the Tsivoglou-Wallace equation (QUAL2E option 8) was used. At depths greater than two feet, either of two equations were used: if velocities were less than 1-2 fps, the O'Connor and Dobbins equation (QUAL2E option 3 was used); if velocities were greater than 1-2 fps the Churchill equation (QUAL2E option 2) was used (Table 25).

The reaeration coefficient for the Snoqualmie Falls reach posed a problem. The normal QUAL2E dam input factor is based on research from low-head dams with heights of less than 100 ft. When applied to Snoqualmie Falls, the formula results in bringing the D.O. to saturation regardless of the upstream concentration. A sensitivity analysis was performed to determine the impact of 0.25, 0.5 and 1.0 mg/L D.O. increases over the Falls (see below). For the simulations the QUAL2E dam input was used because of the sensitivity analysis results, and for lack of a better approach.

Net productivity or respiration, calculated as an areal net loss or gain of oxygen in Table 14 was modeled using the QUAL2E "benthic oxygen uptake" coefficient or sediment oxygen demand (SOD). Positive values of SOD indicated net respiration or uptake from the water column D.O., while negative values were input to represent reaches with net production of oxygen. Reaches without field data were given interpolated values. A large SOD was included for the pool reach above Snoqualmie Falls based on calculation of the net decrease in D.O. observed between RM 42.6 and 40.7 (Appendix B, Figure 4). Net benthic uptake measured in this reach was approximately 2 $g/m_2/day$, which is within the typical range of SOD reported in several river studies (Porcella *et al.*, 1986). A SOD demand was also suggested by a loss of D.O. between surface and bottom samples (PEI,1987) in the pool.

The calibration simulation of D.O. is presented in Figure 20. The simulation exhibits a fair fit to the diurnal field data, but generally runs a flatter profile. Some of this may be related to temperature and saturation correction, but productivity or other mechanisms may also be involved. The NPS or, CBOD and NBOD loads from NPS inputs did not appear to affect the D.O. profile substantially; the profile remained at or above saturation (Figure 20). The applied SOD created a 0.3 mg/L net loss in the pool above the Falls, similar to the field data.

<u>Total Phosphorus</u>

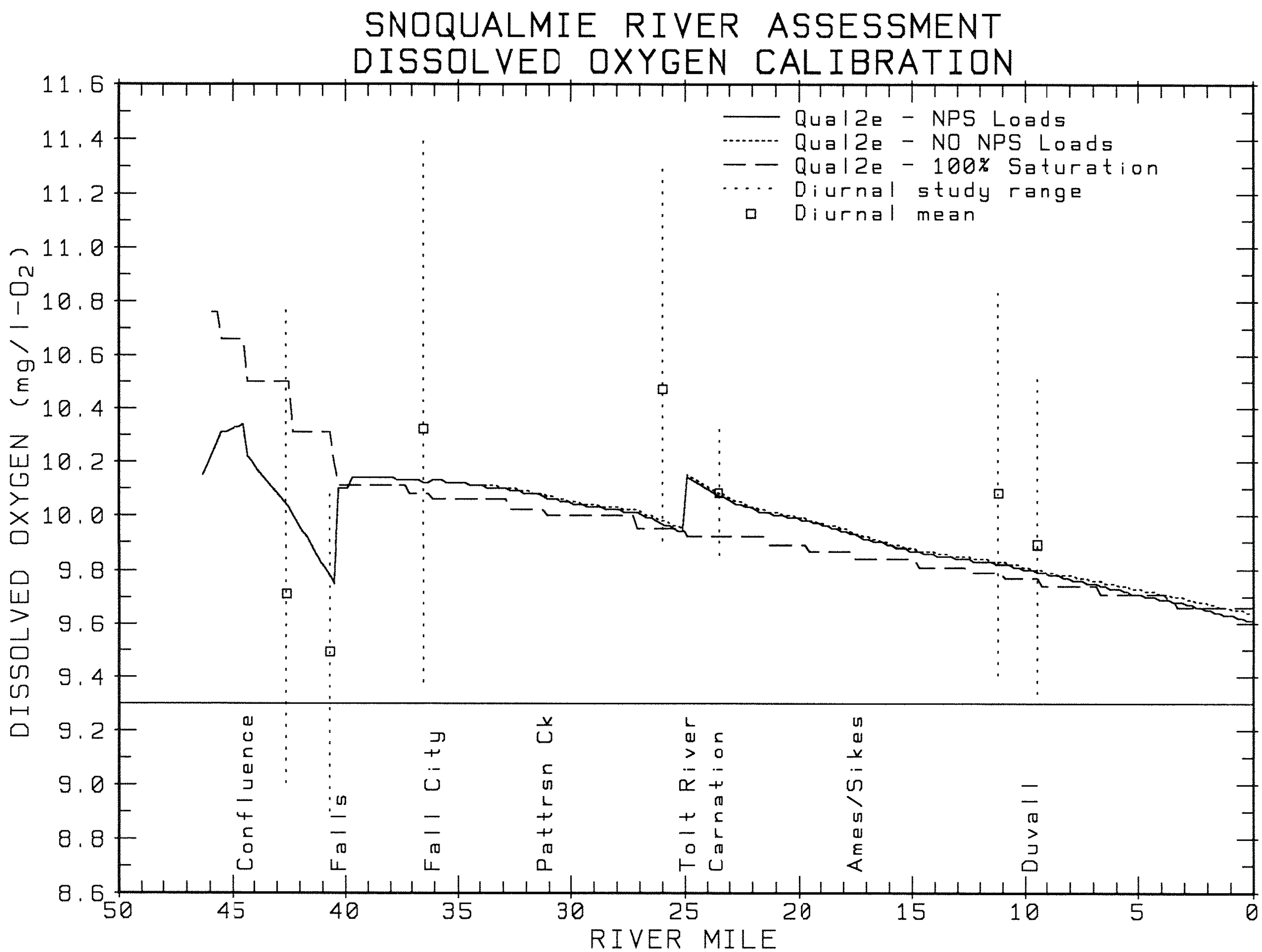
Field data or the model components were lacking to completely model total phosphorus using the QUAL2E phosphorus/algae subroutine. Field data suggested the absence of pelagic algal growth, and the model coefficients were inappropriate for periphyton and aquatic macrophytes. Therefore, TP was modeled as an "arbitrary non-conservative" constituent with applied decay rates.

Phosphorus removal from river systems generally occurs through two pathways: biological uptake by attached plants (primarily periphyton), and adsorption onto fine-grained sediments (Ball and Hooper, 1961; McColl, 1974; Johnson *et al.*, 1976). Rates for both processes have been shown to increase roughly in proportion to water column P when concentrations are relatively low. Biological uptake generally follows Michaelis-Menton kinetics (Thomann and Mueller, 1987). The "half-saturation" concentration of a nutrient is that which causes the uptake rate to be half the maximum possible rate.

At high nutrient concentrations (well above the half-saturation level), uptake rates do not increase substantially if nutrient concentration increases. Conversely, at nutrient concentrations below the half-saturation level, uptake rates are approximately proportional to concentration. Therefore, "first-order" kinetics of uptake can be assumed at concentrations below the half-saturation level (Bowie *et al.*, 1985). The half-saturation concentration of P has been reported to range above 50 μg P/L (Bothwell, 1985). Total P concentrations in the Snoqualmie River were generally less than 30 μg P/L. Therefore, first-order kinetics were considered appropriate for modeling removal of total P from the water column (i.e. the rate of removal was assumed to be proportional to total P concentration).

As seen in the calibration model runs, a first-order loss rate (from biological and chemical/physical processes) of 0.3 d^{-1} resulted in an excellent model fit to the observed river data (Figure 21). Similar total P removal rate constants of 0.2 to 0.4 d^{-1} were reported for the Spokane River (Patmont *et al.*, 1985).

Figure 20. Snoqualmie River QUAL2E model calibration runs of dissolved oxygen compared to 1989 diurnal station field measurements. Simulations without mainstem nonpoint source (NPS) and with NPS inputs are shown (see text).



The NPS loads helped the simulation fit more of the field data, especially once the loss rate was applied. A comparison of TP concentrations at RM 0.0 with and without the NPS loads (with no loss rate) shows a 4 μg/L, or 18% cumulative nonpoint contribution (Figure 21). The TP profile of the South Fork, and mainstem reaches between Fall City (RM 36) and Carnation (RM 25), do not fit the field data as well as at other sites. Rapid conversion to soluble phosphorus and uptake by periphyton may be causing more loss of TP than can be simulated on the South Fork.

Ammonia

The hydrolysis rate of organic nitrogen of 0.2/day was selected as a mid-range literature value (Brown and Barnwell, 1987) after some experimentation. In conjunction with the nitrification numbers and estimated NPS loads, the rate resulted in a good fit to the observed field ammonia (Figure 22). An attempt was also made to fit a first order reaction rate decay to organic nitrogen (ON), but indirect estimates of ON (ON = TN - NH_3 - NO_3 - NO_2) frequently resulted in negative numbers for ON, so this latter approach was not used.

Nitrification reaction rates were initially estimated from literature ranges (Brown and Barnwell, 1987; Bowie *et al.*, 1985; and CH_2M Hill, 1988). A maximum NH_3 to NO_2 conversion rate of 0.45/day was selected for favorable nitrifier habitat reaches with shallow water depths and cobbly substrate after discussions with USGS-Portland personnel (S. McKenzie, personal communication) regarding magnitudes of nitrification rates and ammonia observed in the Santiam and Willamette Rivers. The rate was decreased to 0.2 - 0.25 for reaches with greater depths, less potential for cobbly substrate, and a less favorable benthic surface area to water column depth ratio. The NO_2 to NO_3 conversion rates were set equal to the NH_3 to NO_2 rates for each reach (Table 25).

As with TP, we did not attempt to model the entire nitrogen cycle or the algal cycle. For instance, there was no NH_3 or NO_3 algal uptake included. In the actual river, periphyton would compete with nitrifiers for NH_3 & NO_3, as well as providing additional substrate for colonization. These losses to periphyton and macrophytes were not directly incorporated into the model, but were assumed to be minor and included in the rates calculated for the two reactions modeled.

The profile run without the NPS inputs described earlier clearly indicates the impact of the Duvall WWTP, Tokul Creek and Ames-Sikes Creek NH_3-N loads during the 1989 study period (Figure 22). The addition of the four NPSs to the model input greatly improved the fit of the simulation profile with the field data (Figure 22). However, as with the chloride simulation, there also appeared to be a source of NH_3-N near RM 44.4. Since no adjustments were made, the profile remained a bit lower than field data from RM 44.4 to RM 37.

Figure 21. Snoqualmie River QUAL2E model calibration runs of total phosphorus compared to 1989 field data. Simulations without mainstem nonpoint source (NPS) and with NPS inputs are shown, along with the decay coefficient applied (see text).

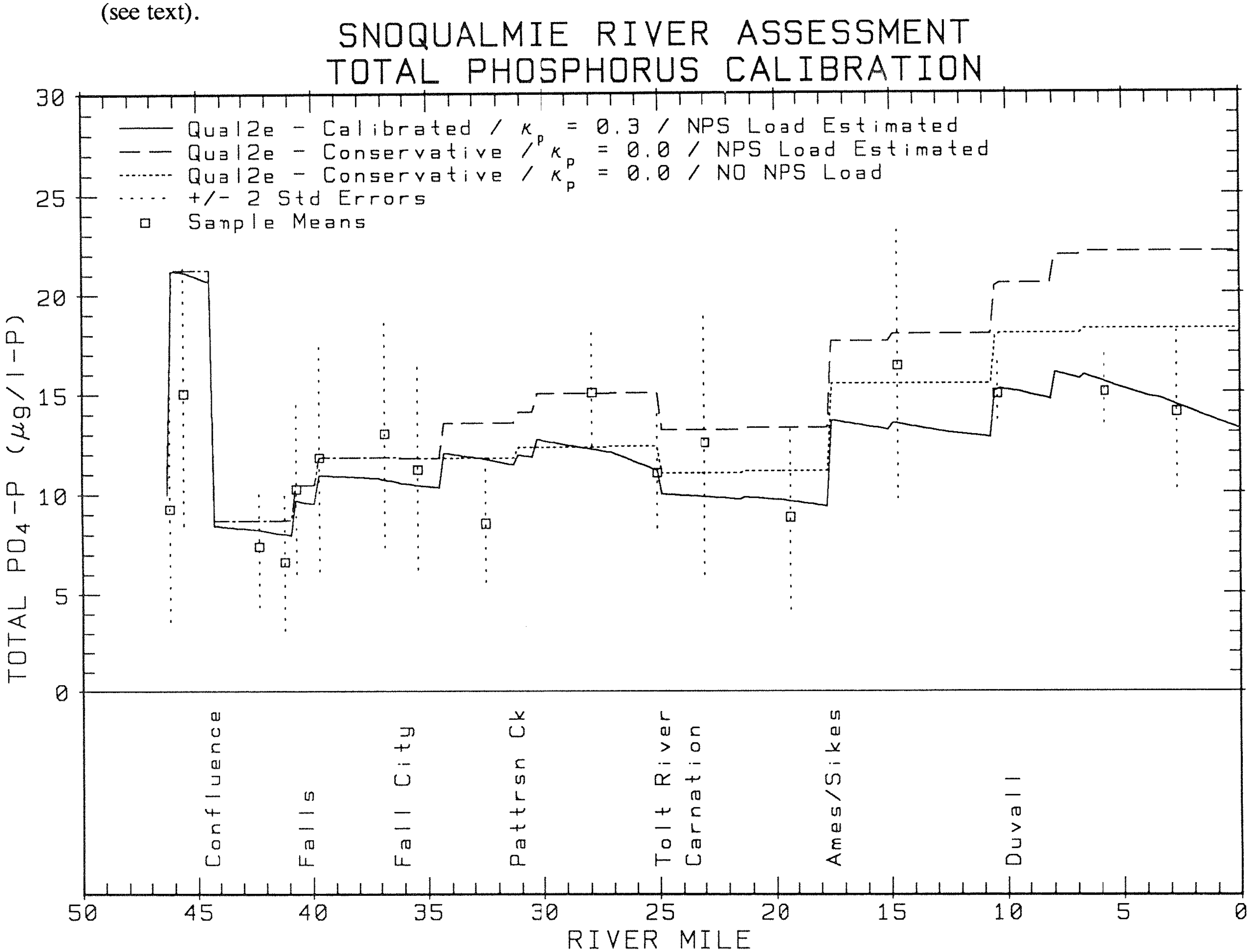


Figure 22. Snoqualmie River QUAL2E model calibration runs of ammonia compared to 1989 field data. Simulations without mainstem nonpoint source (NPS) and with NPS inputs are shown, along with rate coefficients (see text).

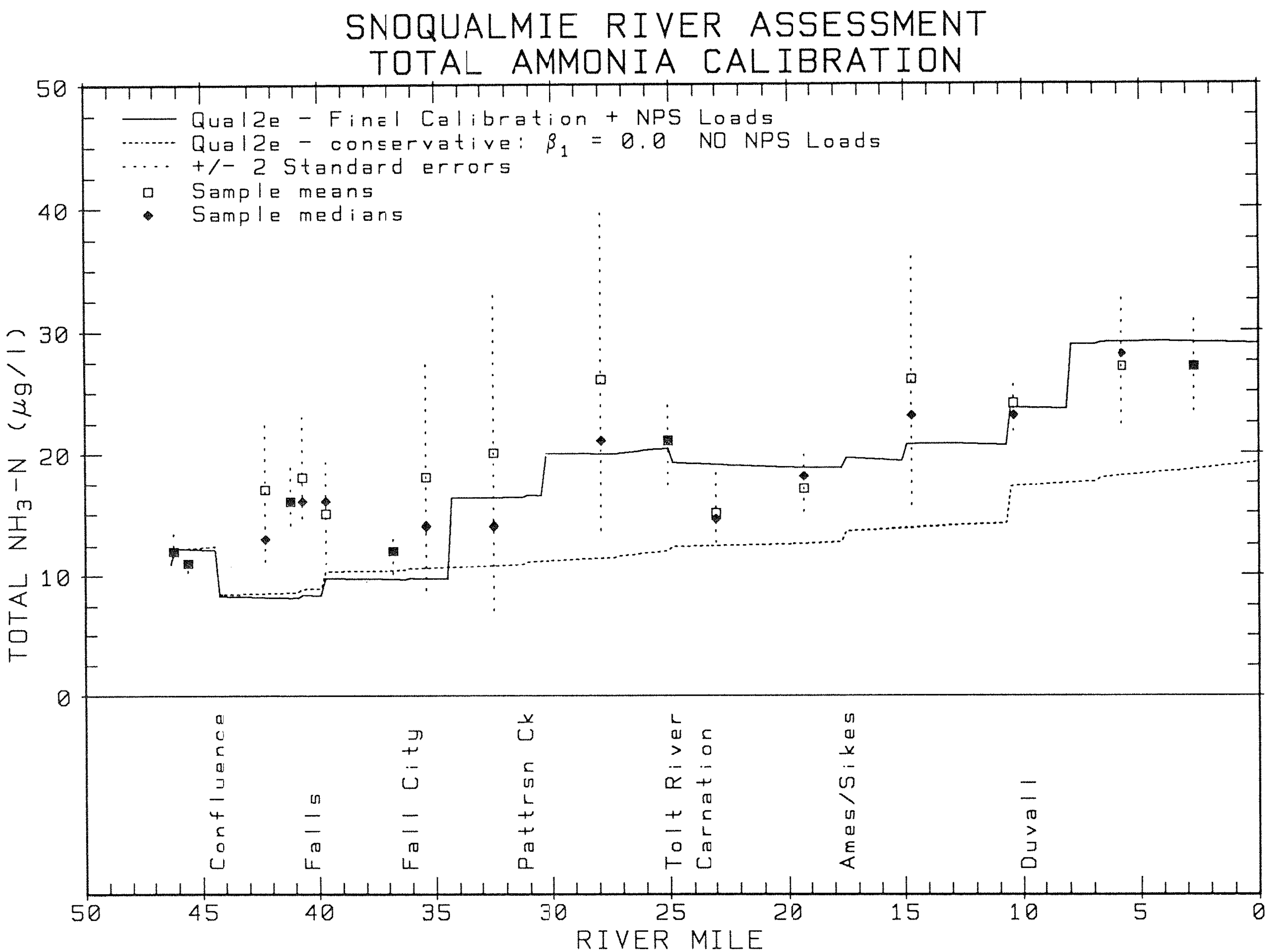


Table 25. Snoqualmie River-QUAL2E System Hydraulics, Reaeration Rates, and Temperature.

REACH	RIVER MILES	STREAMFLOW (cfs)		VELOCITY (fps)		REAERATION COEFF (/day)			TEMPERATURE (°F)		SOD (/day)	CBOD5 (k1,/day)		NBOD (/day)
		CALIB	7Q10	CALIB	7Q10	CALIB	7Q10	OPT*	CALIB	7Q10		CALIB	7Q10	(ß1)
1	46.4 - 45.6	154.3	78.2	2.36	1.68	17.32	13.11	8	53.7	58.3	0.00	0.87	1.20	0.45
2	45.6 - 44.4	154.3	78.2	0.75	0.53	3.27	3.48	3	54.5	59.1	0.00	0.87	1.20	0.45
3	1.0 - 0.0	479.1	267.2	0.99	0.74	2.98	3.90	3	57.3	61.9	0.00	0.50	0.67	0.40
4	44.4 - 42.4	633.4	345.4	1.13	0.84	2.64	3.49	3	55.7	60.4	0.20	0.44	0.59	0.30
5	42.4 - 40.6	635.4	346.8	0.60	0.37	0.67	0.65	3	57.2	61.9	0.20	0.44	0.59	0.20
6	40.6 - 40.4	635.4	346.8	0.38	0.23	0.48	0.46	3	58.1	62.7	0.20	0.44	0.59	0.20
7	40.4 - 37.2	664.4	360.9	3.09	2.28	4.16	3.62	2	58.8	63.4	-0.03	0.43	0.58	0.40
8	37.2 - 36.2	664.4	368.4	0.78	0.48	0.59	0.58	3	59.0	63.6	-0.03	0.43	0.58	0.25
9	36.2 - 32.8	677.7	368.4	1.17	0.86	1.55	2.14	3	59.2	63.8	-0.02	0.42	0.57	0.30
10	32.8 - 31.2	677.7	375.4	0.83	0.51	0.81	0.75	3	59.5	64.1	-0.02	0.42	0.57	0.25
11	31.2 - 27.2	685.0	377.2	0.98	0.73	2.60	3.36	3	59.7	64.4	-0.01	0.42	0.56	0.35
12	27.2 - 25.0	688.5	443.7	0.42	0.26	0.26	0.23	3	60.1	64.7	0.00	0.42	0.56	0.20
13	25.0 - 21.4	845.1	445.2	2.04	1.48	6.87	5.29	8	60.4	65.0	0.00	0.38	0.52	0.45
14	21.4 - 19.6	848.1	445.2	1.84	1.33	2.43	2.83	3	60.6	65.3	0.00	0.38	0.52	0.40
15	19.6 - 17.6	848.1	447.4	0.91	0.55	1.64	1.44	3	60.8	65.5	0.00	0.38	0.52	0.25
16	17.6 - 14.8	852.5	447.4	1.18	0.85	3.91	3.65	3	61.1	65.7	0.00	0.38	0.52	0.40
17	14.8 - 12.6	852.5	447.4	1.09	0.65	1.14	1.09	3	61.3	66.0	0.00	0.38	0.52	0.25
18	12.6 - 11.0	852.5	447.4	1.68	1.21	2.80	2.93	3	61.5	66.2	0.00	0.38	0.52	0.35
19	11.0 - 10.0	853.5	448.0	1.06	0.64	1.13	1.04	3	61.7	66.3	0.00	0.38	0.52	0.25
20	10.0 - 9.4	853.5	448.0	1.68	1.22	2.92	3.07	3	61.7	66.4	0.01	0.38	0.52	0.35
21	9.4 - 6.8	853.8	448.3	0.87	0.52	0.71	0.58	3	61.9	66.5	0.00	0.38	0.52	0.25
22	6.8 - 3.8	864.0	453.3	0.68	0.41	0.42	0.39	3	62.2	66.8	0.00	0.38	0.52	0.25
23	3.8 - 3.4	864.0	453.3	1.69	1.22	2.50	3.70	3	62.4	67.0	0.00	0.38	0.52	0.35
24	3.4 - 0.0	864.0	453.3	0.52	0.31	0.43	0.39	3	62.6	67.2	0.00	0.38	0.52	0.25

Reaction rates (coefficients) shown above are uncorrected for temperature (base = 20°C)
Default QUAL2E temperature corrections were used.
Nitrite oxidation (β_2) was set equal to ammonia oxidation (β_1).

The following rate parameters were NOT varied by reach:
- total phosphorus (TPO4-P) decay (k_p) = 0.3/day
- organic nitrogen settling (σ_4) = 0.1/day
- organic nitrogen hydrolysis (β_3) = 0.2/day
- fecal coliform decay (k_5) = 2.0/day

*Reaeration Options:
- 3 = O'Connor and Dobbins
- 2 = Churchill, Elmore, and Buckingham
- 8 = Tsivoglou and Wallace

Fecal Coliform

The 2.0/day (0.083/hr.) FC decay rate was estimated from direct computation of decay between four points of the observed field data. It is at the higher end, but well within the range of decay rates reported in the literature (Zison, Mills, Deimer, and Chen, 1978). The high clarity (good light penetration), high D.O., and low nutrient concentrations of the Snoqualmie River would favor a high die-off rate (Zison, Mills, Deimer, and Chen, 1978). In the model this rate resulted in a good fit to the field data once the NPS inputs were added (Figure 23). A median FC concentration of 3×10^5 organisms/100 mL was used for these inputs (Table 22).

QUAL2E Simulations: Existing and Proposed Discharges under 7Q10

The simulation results for each of the four modeled parameters under 7Q10 and existing point source design loads (Scenario 1), and 7Q10 and proposed future point source loads (Scenario 2) are shown in Figures 24-27. The tributary, point source, and NPS inputs for these simulations are listed in Tables 23 & 24. The 7Q10 river reach conditions are listed in Tables 25 & 26. A discussion of both scenario results by each parameter follows.

Dissolved Oxygen

The D.O. profiles of the two 7Q10 scenarios are very similar to each other (Figure 24). There are also several similarities of these profiles to the calibration run (Figure 20): SOD in the Snoqualmie Falls pool creates a 0.5 mg/L demand, much of the net loss in the D.O. profiles is from saturation/temperature differences, the average D.O concentrations at all points along the river would meet the Class A standard, and the Falls and Tolt River help to increase D.O. concentrations at critical points.

The 7Q10 simulations indicate much less of the river would be at or above saturation than it was during the 1989 study. However, the average river D.O. saturation at RM 0.0 would be at 98% in Scenario 1, and 96% in Scenario 2. Nitrogenous oxygen demand contributed approximately 28% of the D.O. demand at RM 0.0 in Scenario 1 and 2 compared to 11% in the calibration simulation. Both the 7Q10 simulations indicate D.O. concentrations in the pool above the Falls and at RM 0.0 would be the lowest along the river. The profiles are generally very flat, and the differences are less than 1 mg/L at points between the confluence of the three forks (RM 44.4) and RM 0.0. Concentrations could drop below the 8 mg/L water quality standard depending upon the upstream temperature and D.O. concentration, and sampling time along the diurnal cycle. The diurnal ranges in the 1989 field data (Figure 20) and uncertainty analyses (see below) indicate this possibility, especially if increased productivity from increased nutrient enrichment occurs throughout the mainstem. It appears from the simulations that the additional secondary treatment loads of CBOD and NBOD would not seriously impact the average D.O. concentrations of the river.

Figure 23. Snoqualmie River QUAL2E model calibration runs of fecal coliform compared to 1989 field data. Simulations without mainstem nonpoint source (NPS) and with NPS inputs are shown with decay coefficients (see text).

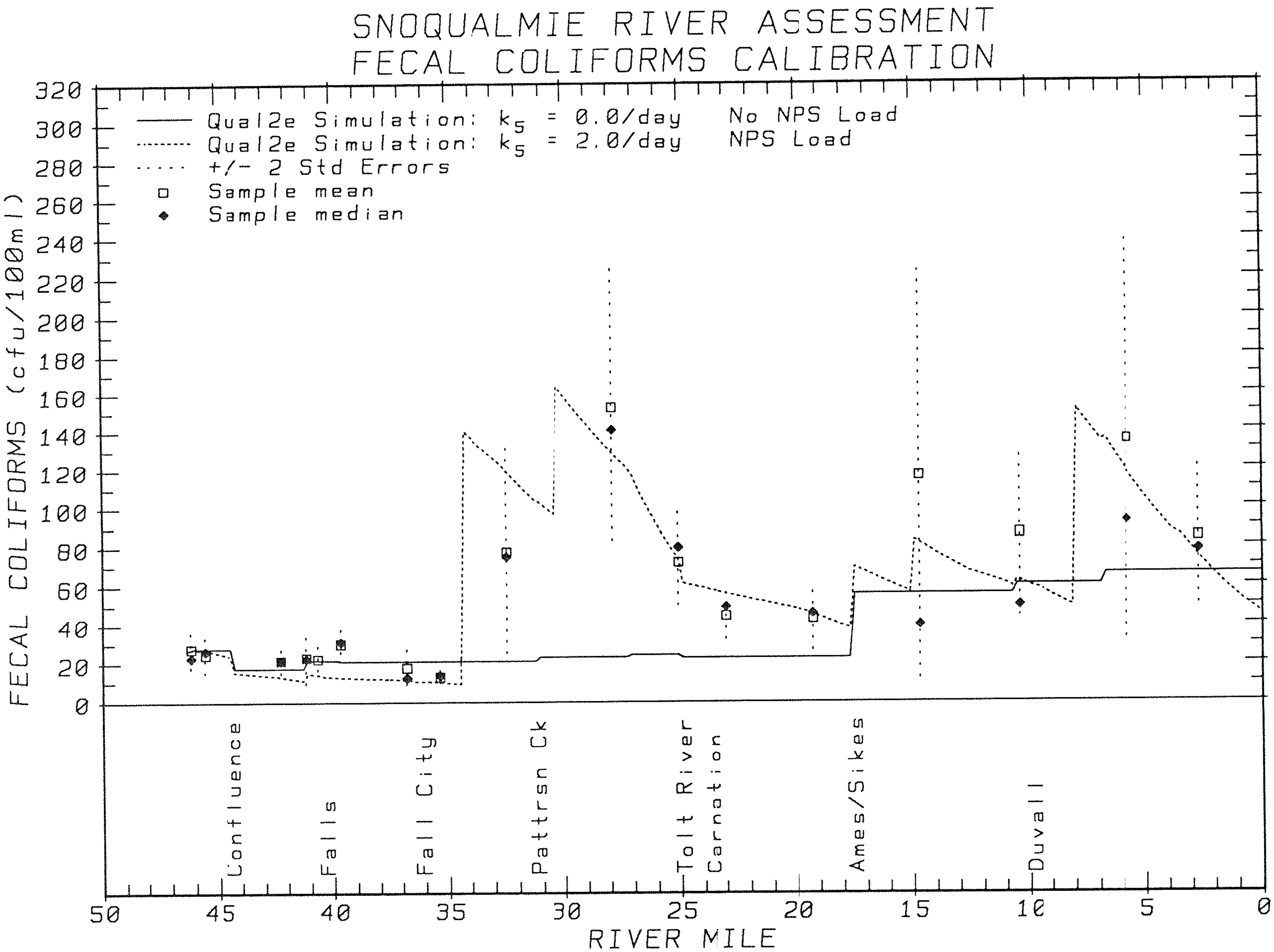
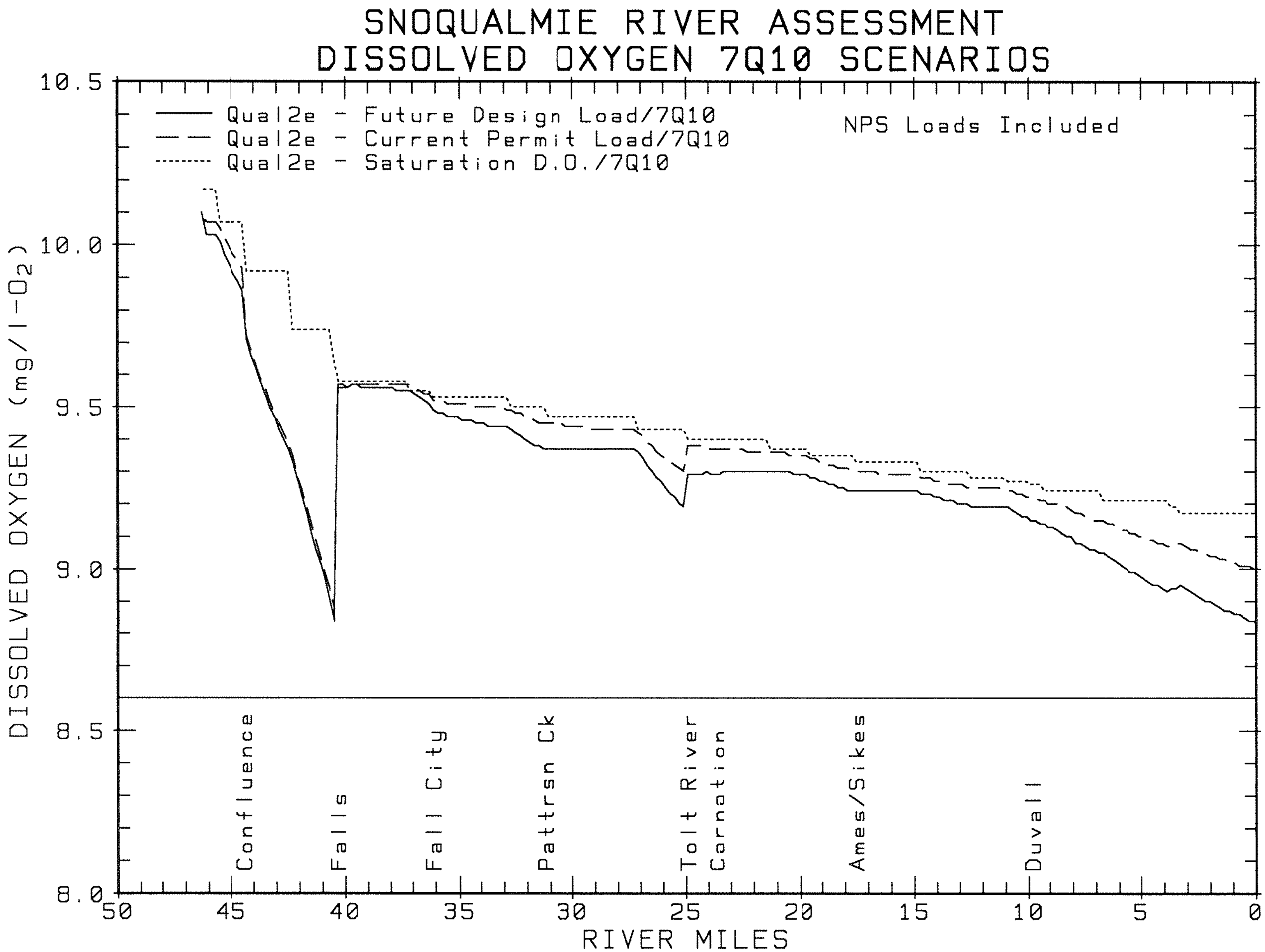


Figure 24. Snoqualmie River QUAL2E model runs of two future wastewater loading scenarios under summer low flow critical conditions showing receiving water dissolved oxygen response (see text).



Total Phosphorus

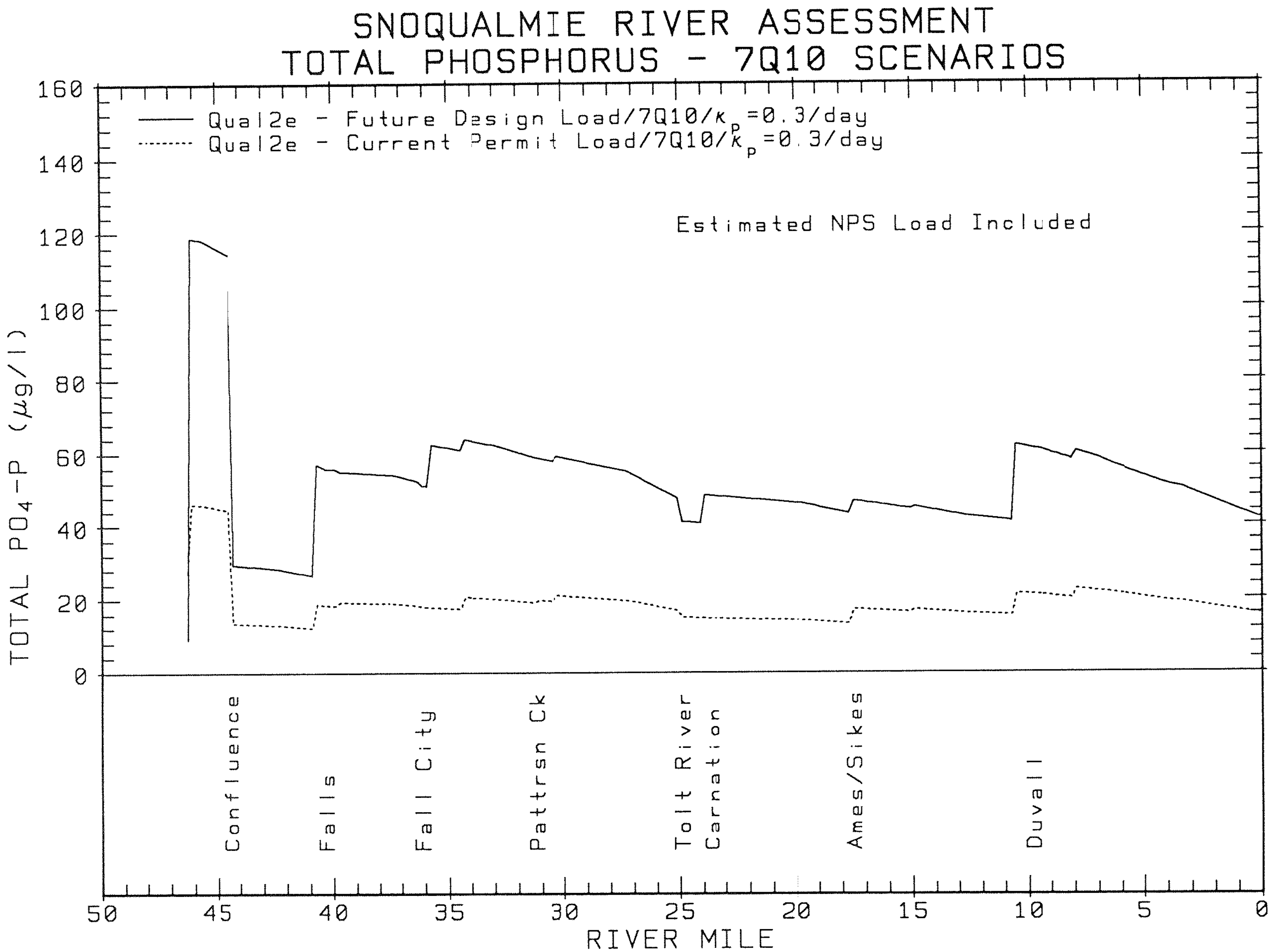
The results for the two 7Q10 scenarios phosphorus simulations are presented in Figure 25. The simulations suggest TP will be an issue as growth occurs in the Snoqualmie River Valley.

The TP profile for Scenario 1 indicates the North Bend WWTP current design load and lower dilution in the receiving water would double TP concentrations on the South Fork during 7Q10 conditions (Figure 21 and 25). Findings of the 1989 study indicated the South Fork has periphyton chlorophyll *a* concentrations at "nuisance levels", so the Scenario 1 increase could aggravate the situation under extended low flow conditions. Average mainstem TP concentrations in Scenario 1 would increase 3 to 8 μg/L over the 1989 calibration conditions. These concentrations would be above the 13 μg/L TP "eutrophication potential threshold" concentration discussed for the 1989 study data, but still far from the 130 μg/L level indicating a "problem likely to exist" in terms of water column algal blooms (see **Ambient Water Quality**, Nutrients, above). Under Scenario 1 conditions, it appears that the combined NPS and tributary loads make about the same contribution to river TP concentrations as the combined WWTPs.

The Scenario 2 profile suggests TP could become a concern in the entire mainstem below the Snoqualmie Falls, as well as in the South Fork (Figure 25). The average South Fork TP concentration would be near the "problem likely" concentration, and many of the mainstem concentrations would be greater than 60 μg/L - half way to the 130 μg/L level. The retention rate of TP in the mainstem could increase because of the lower velocities associated with the 7Q10 conditions. Uptake rates would remain high and may create periphyton or aquatic macrophyte problems, especially from Fall City (RM 36) to the Tolt River (RM 25), and from Duvall (RM 10.5) to the County Line (RM 6.1). The TP load exported to the Snohomish River during 7Q10 would also increase from 39 lbs./day under Scenario 1, to 100 lbs./day under Scenario 2. Preliminary results of the model output also suggest the Snoqualmie River could become nitrogen limited more often. The TN:TP ratio at RM 0.0 would drop from 15:1 in Scenario 1 to 10:1 in Scenario 2. Algal community succession often compensates for a nitrogen limitation by favoring blue-green algae growth (Welch, 1980). Blue-green algae are capable of fixing nitrogen from the atmosphere, but also can become a nuisance because some species are toxic to livestock.

There are few guidelines for the eutrophication potential of nutrients in flowing water. USEPA (1986) suggests TP concentrations in streams and rivers entering a lake or reservoir not to exceed 50 μg/L, and other streams and rivers not to exceed 100 μg/L. The criteria narrative goes on to state that no specific phosphate criteria for flowing (lotic) waters can be made since the dynamics are not well enough understood. Considering the paucity of productivity data for the Snoqualmie - Snohomish River system, and understanding of eutrophication in lotic systems in general, a conservative approach would be warranted at this time. Since the WWTPs would be the major sources of TP in the Snoqualmie River system under Scenario 2, their facilities design plans should include phosphorus management options. Nonpoint source controls would also help. To protect Snoqualmie and Snohomish River water quality, the NWRO should

Figure 25. Snoqualmie River QUAL2E model runs of two future wastewater loading scenarios under summer low flow critical conditions showing receiving water total phosphorus response (see text).



actively seek to keep concentrations in the river below 50 μg/L during the summer low flow growing season until more definitive data are collected.

Ammonia

The NH_3-N profiles for Scenario 1 and 2 are shown in Figure 26. Both point and NPS impacts are evident in both scenarios; tributary impacts appear to be less significant by comparison.

The Scenario 1 profile indicates a maximum average NH_3-N concentration of 0.048 mg/L would occur between RM 9 and RM 5 (Figure 26). It represents a 0.01 mg/L NH_3-N increase over the calibration run results. The concentration is well below levels capable of creating aquatic toxicity problems at pH and temperatures normally observed in the river. The impact of the Duvall WWTP may be somewhat exaggerated because of the elevated NH_3-N effluent concentrations present during the 1989 study. The effect of North Bend WWTP effluent on the South Fork becomes noticeable because of the decreased dilution present during the 7Q10 flow. The NPS inputs appear to dominate the NH3-N profile.

The Scenario 2 profile exhibits some major changes (Figure 26). Point and nonpoint sources appear to contribute equally to the increased concentrations in the river. The North Bend and Snoqualmie WWTP NH_3-N contributions appear to increase enormously. Some of their apparent increased contribution is from increased discharge volume, but increases in the assigned NH_3-N effluent concentration inputs also created major load changes (Tables 23 & 24). The conservative NH_3-N effluent concentrations take into account difficulties with plant maintenance and control as design capacities are approached.

The highest average NH_3-N concentrations along the South Fork and mainstem (0.075 and 0.082 mg/L) displayed in the simulation would not create chronic ammonia toxicity problems unless pH levels were above 9.0 and temperatures were greater than 25°C (USEPA, 1986). The impact of the NH_3-N increase on NBOD has been mentioned earlier (see Dissolved Oxygen, above). Assimilation of the NH_3-N by periphyton could contribute to productivity in the river. The NH_3-N analysis presented in this model is very general. Several reactions important to the ammonia and nitrogen cycle have not been modeled. Therefore, there is a high degree of uncertainty in the model results (see below). Future monitoring in the lower study area should ensure that ammonia toxicity problems are not occurring.

Fecal Coliform

The fecal coliform profiles under Scenario 1 and 2 conditions are presented in Figure 27. They are nearly identical to each other. Also shown in Figure 27 is a plot of Scenario 2 conditions with the NPS removed. The profiles clearly demonstrate how the nonpoint sources, both as mainstem NPS and in tributary loads, dominate the FC concentrations in the river as long as point source effluent quality remains within permit limits. The tributary and point source FC loads alone during a 7Q10 event would probably not cause violations in the mainstem, however,

Figure 26. Snoqualmie River QUAL2E model runs of two future wastewater loading scenarios under summer low flow critical conditions showing receiving water ammonia response (see text).

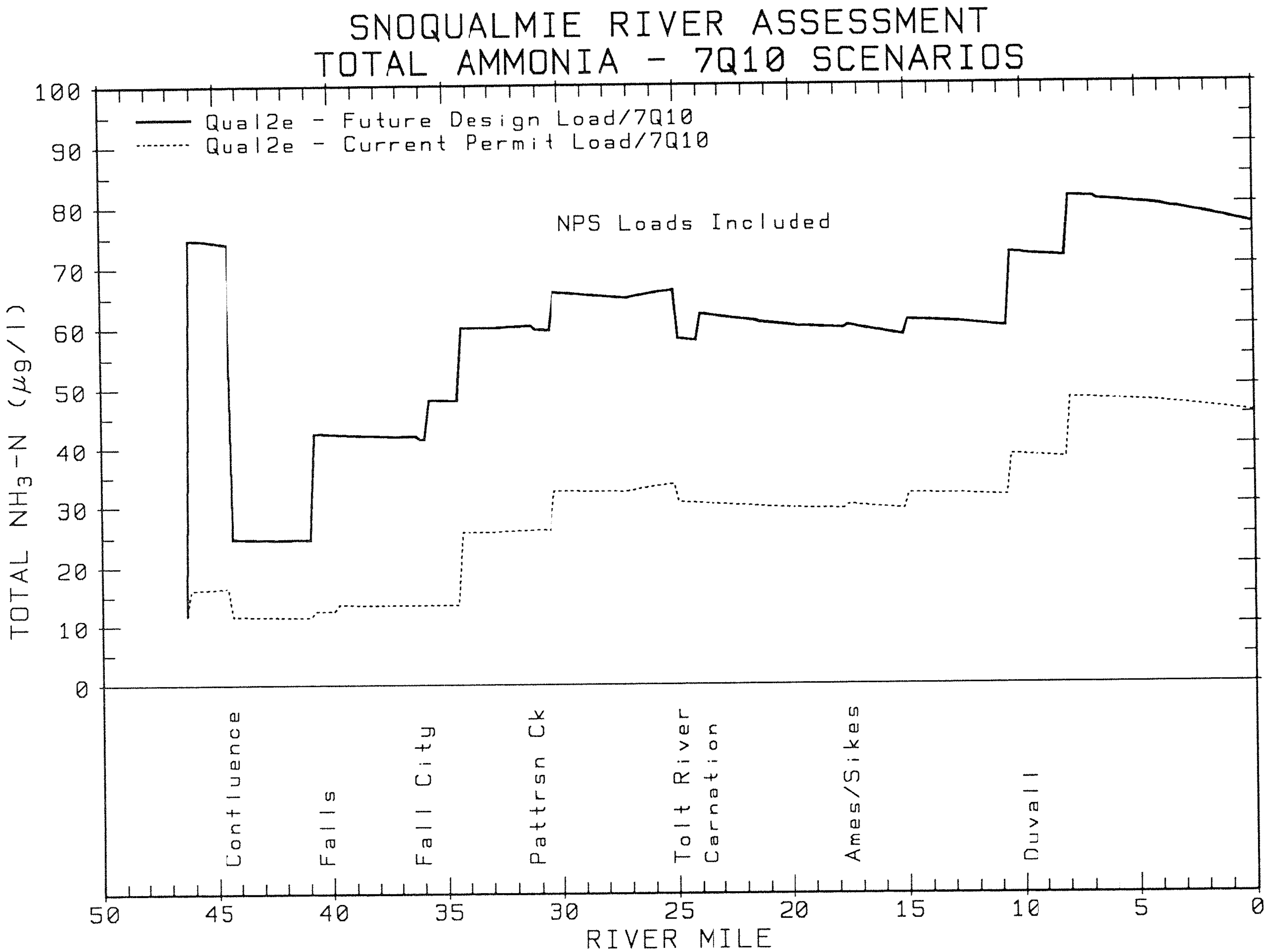
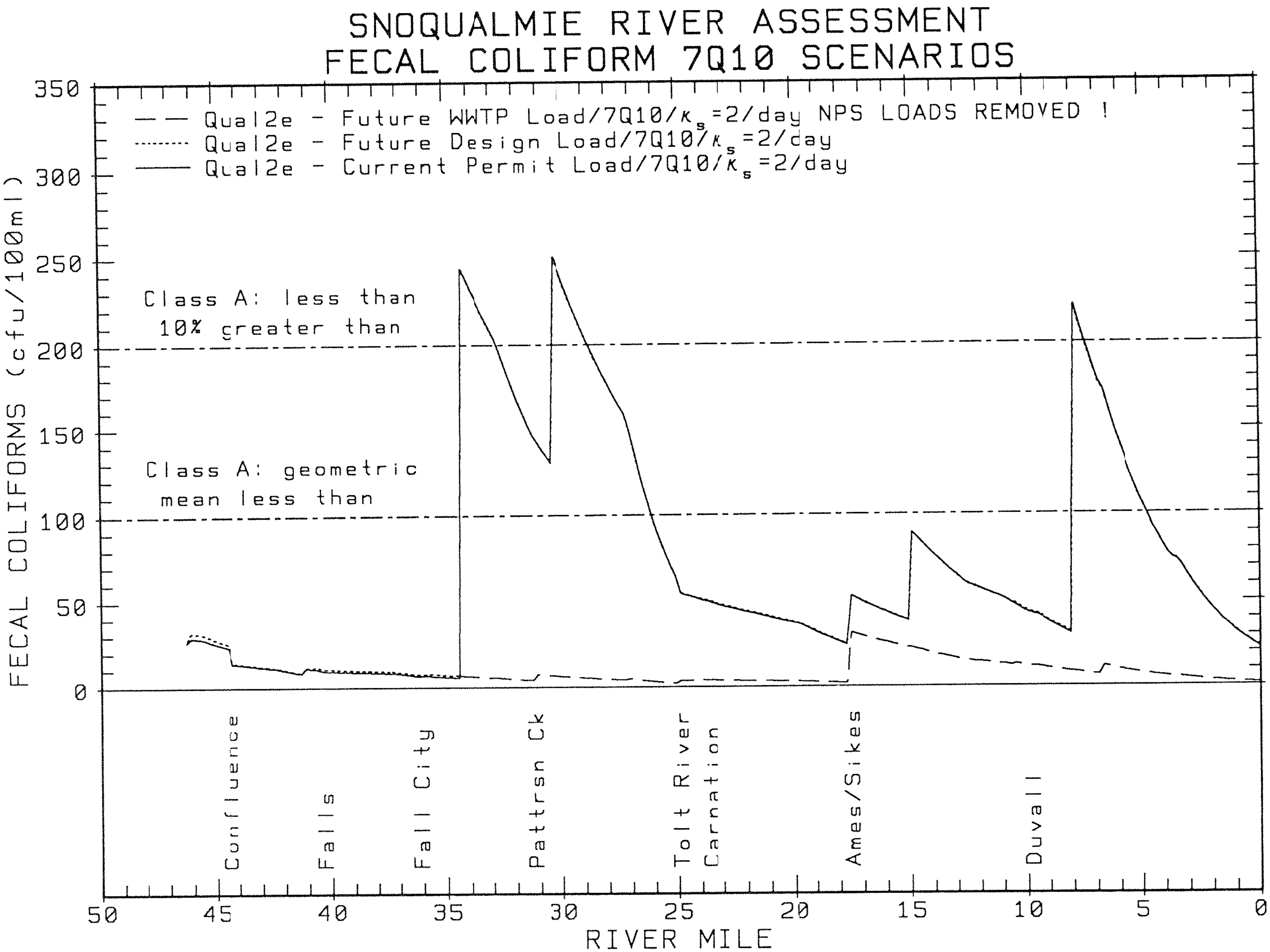


Figure 27. Snoqualmie River QUAL2E model runs of two future wastewater loading scenarios under summer low flow critical conditions showing receiving water fecal coliform response (see text).



if the mainstem NPS inputs were as active during a 7Q10 event as they were during the 1989 study, Class A standards would probably be violated at a greater number of sites than in 1989.

Much of the nonpoint work in the Snoqualmie basin has focused on tributary nonpoint FC impacts (Tulalip Tribes, 1988; URS, 1977). The model simulations and 1989 field data demonstrate that mainstem nonpoint source FC loads may dominate over tributary loads during low flow periods. Ecology and Conservation District staff need to identify and control mainstem nonpoint sources as well as tributary nonpoint sources, especially during lower flow periods when primary contact activities are occurring.

Uncertainty Analyses

Falls Reaeration Sensitivity

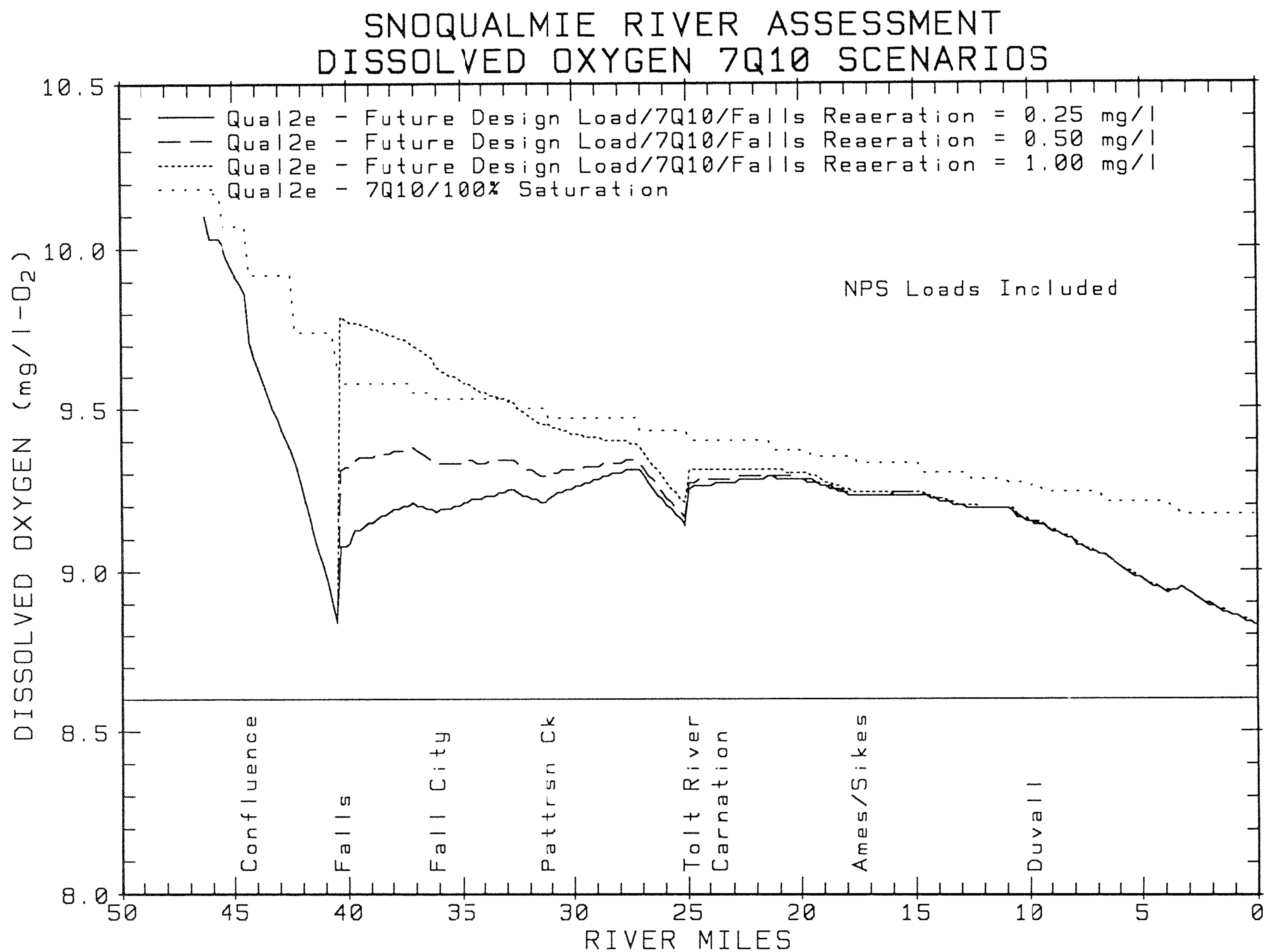
Based on past monitoring experiences with dissolved gas supersaturation at Columbia and Snake River dams, some similar D.O. effects were expected over Snoqualmie Falls. The low-head QUAL2E dam equation was not satisfactory for the situation because it would not create a supersaturated condition. On the Columbia River, significant (130-140%) supersaturation occurred below dam spillways when upstream gas levels were either below or above saturation (USACOE, 1977). Also, oxygen supersaturation was usually of the same magnitude as nitrogen supersaturation (USACOE, 1977; PNWBC, 1974). Furthermore, observations have been made that the lack of downstream turbulence (as in the lower tailrace of some spillways) provided a greater opportunity for gas bubbles to enter solution, whereas the natural turbulence of a stream provided an opportunity for bubbles to be brought near the surface and escape into the atmosphere.

We could not locate predictive equations to estimate the effect of the Falls and naturally turbulent conditions downstream, so the QUAL2E model was used to determine the downstream D.O. impact of 0.25, 0.5 and 1.0 mg/L D.O. increases over the Falls under Scenario 2 conditions. The results shown in Figure 28 suggest downstream effects would not be evident below RM 27. Between the Falls (RM 40.3) and RM 27 channel reaeration factors appeared to gradually overcome the effect of the Falls no matter which of the three D.O. increases were applied.

Sensitivity & Monte Carlo Analyses

The QUAL2E-UNCAS uncertainty analysis model was used to evaluate the effects of the varying coefficients and inputs on D.O., TP, NH_3-N, and FC results in the Scenario 2 simulation. The sensitivity analysis and monte carlo options allow the changes occurring in the simulations to be observed at only a few locations. Seven reaches were chosen during the sensitivity analyses: Reaches 1, 3, 4, 6, 11, 17 and 24 (see Figure 17). Five were selected for the monte carlo plots:

Figure 28. Snoqualmie River QUAL2E model runs evaluating the response of dissolved oxygen to various reaeration coefficients applied at Snoqualmie Falls.



- the South Fork below the North Bend WWTP - Reach 2, RM 45.6
- the pool upstream of Snoqualmie Falls - Reach 5, RM 40.4
- the pool upstream of the Tolt River - Reach 12, RM 25.0
- just above the Duvall WWTP - Reach 18, RM 11.0
- the confluence of the Skykomish River - Reach 24, RM 0.0

Major factors influencing the four parameters were incrementally changed by 25% for the sensitivity analysis option. Changes were biased towards creating degraded water quality conditions, e.g. 25% higher temperature or CBOD; or, 25% lower stream flows or TP settling rates. The 25% choice was arbitrary, and in some cases does not provide an equitable comparison between factors. For example, a 25% increase in 17°C temperature would be much more drastic than a 25% increase in 1 x 10^5 organisms/100 mL FC. Coefficients of variation used in the monte carlo simulations were calculated from the 1989 study data, or taken from the default UNCAS program input (Brown and Barnwell, 1987).

Results of the sensitivity analyses are presented in Appendix A, Tables 18-21. The monte carlo analysis simulations of each of the four parameters are presented in Figures 29-32.

The D.O. simulations appear to be most effected in the upper end of the study area by decreased headwater D.O. concentrations and increased temperature conditions (Appendix A, Table 18). Increased temperature has the largest influence on D.O. in the lower part of the study area. Increased CBOD and NH_3-N loading also begin to have an effect. The monte carlo D.O. simulation indicates the simulation values have standard deviations of $\pm$ 1.5 mg/L at most points along the river due to variability in the coefficients and inputs used (Figure 29). The projected D.O. concentration in the pool above the Falls appears to have slightly less uncertainty associated than the concentration projected for the confluence at RM 0.0. The mean concentrations of the monte carlo runs at RMs 25, 11, and 0 are slightly higher than the original simulation, but the profile remains fairly flat. Class A criteria violations would be most likely to be observed at RM 0.0.

The TP simulations are very sensitive to increased loading from the WWTPs, the NPS, and tributary sources (Appendix A, Table 19). The settling rate becomes important in the lower study area. The monte carlo simulation (Figure 30) shows a slightly larger uncertainty ($\pm$ 18 μg/L) associated with the South Fork and North Bend WWTP inputs than in the mainstem ($\pm$ 10 μg/L). The monte carlo mean concentrations match the original simulation well. The uncertainty in the TP simulation is low enough that a 50 μg/L guideline can be reasonably managed with proper planning.

The NH_3-N simulations are also sensitive to increased loading of ammonia; less so from organic nitrogen loading (Appendix A, Table 20). Decreasing the nitrification rate is important in the lower study area as well. The mean NH_3-N concentrations predicted in the monte carlo simulations closely follow the original simulation. The uncertainty in the NH_3-N mainstem concentrations increase in a downstream direction. From RM 8.0 to 0.0, there would be a higher risk of un-ionized ammonia toxicity than elsewhere (Figure 31). Temperatures greater

Figure 29. Snoqualmie River QUAL2E-UNCAS model results for dissolved oxygen comparing monte carlo analysis at five locations to one of the Figure 24 simulations.

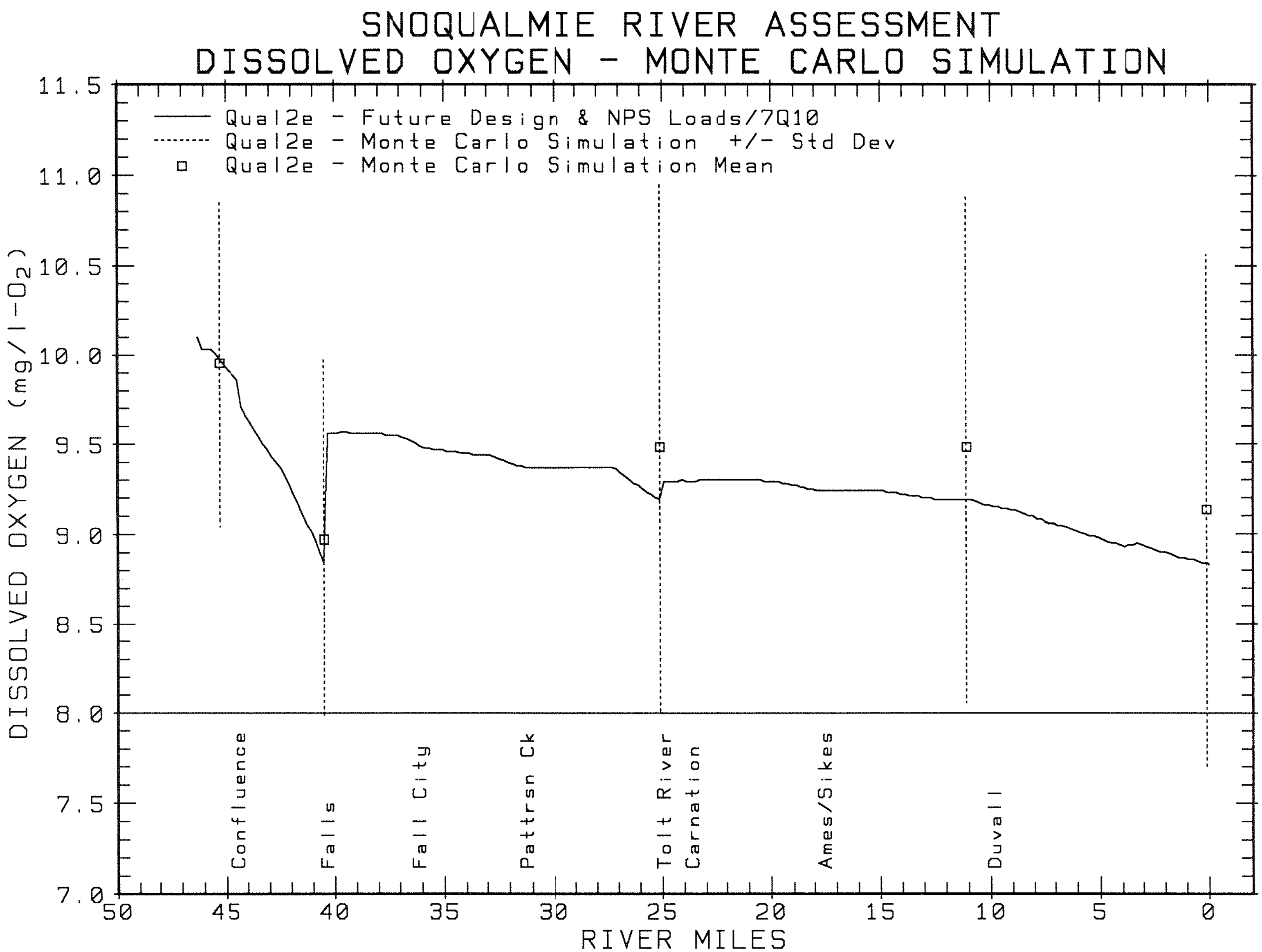


Figure 30. Snoqualmie River QUAL2E-UNCAS model results for total phosphorus comparing monte carlo analysis at five locations to one of the Figure 25 simulations.

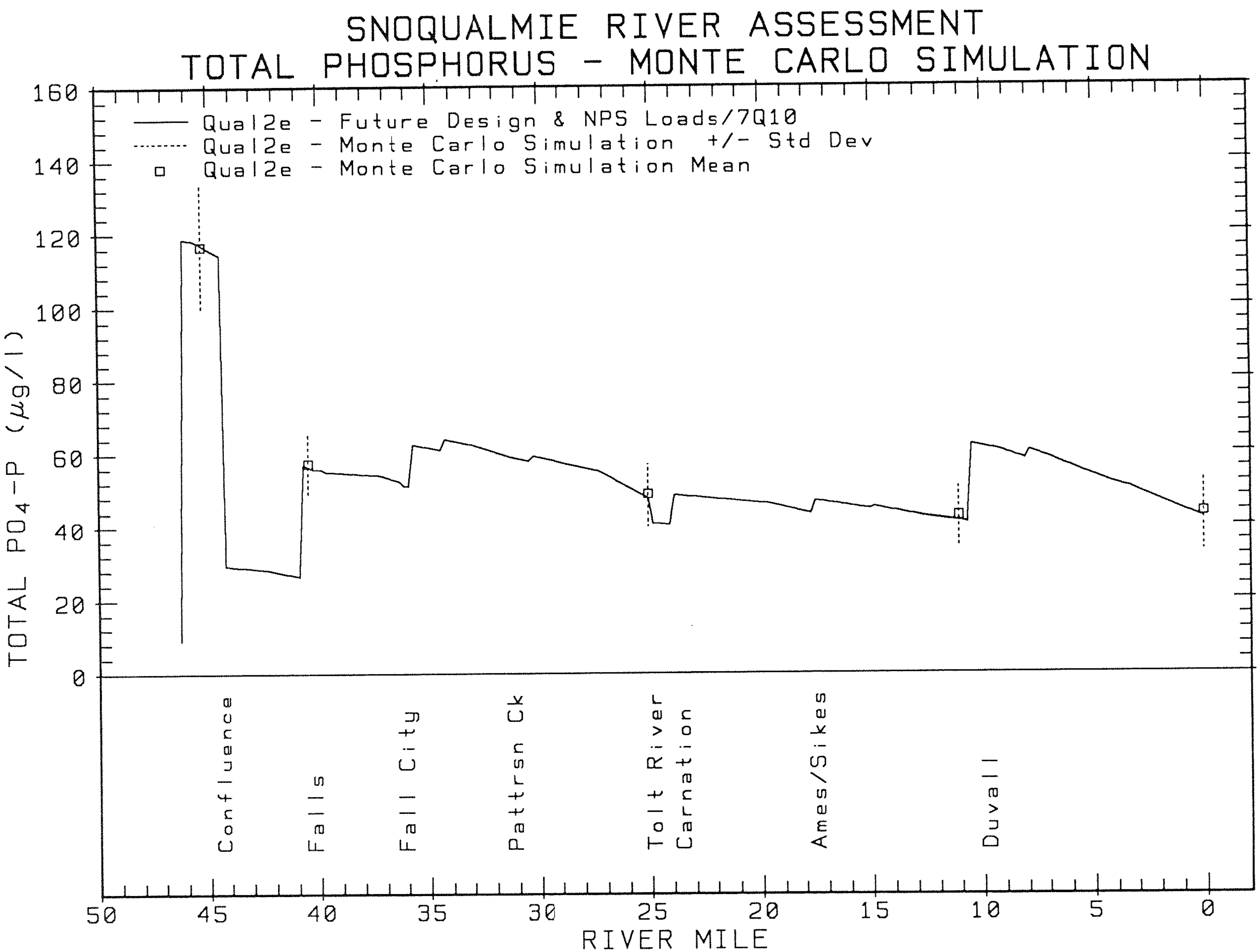
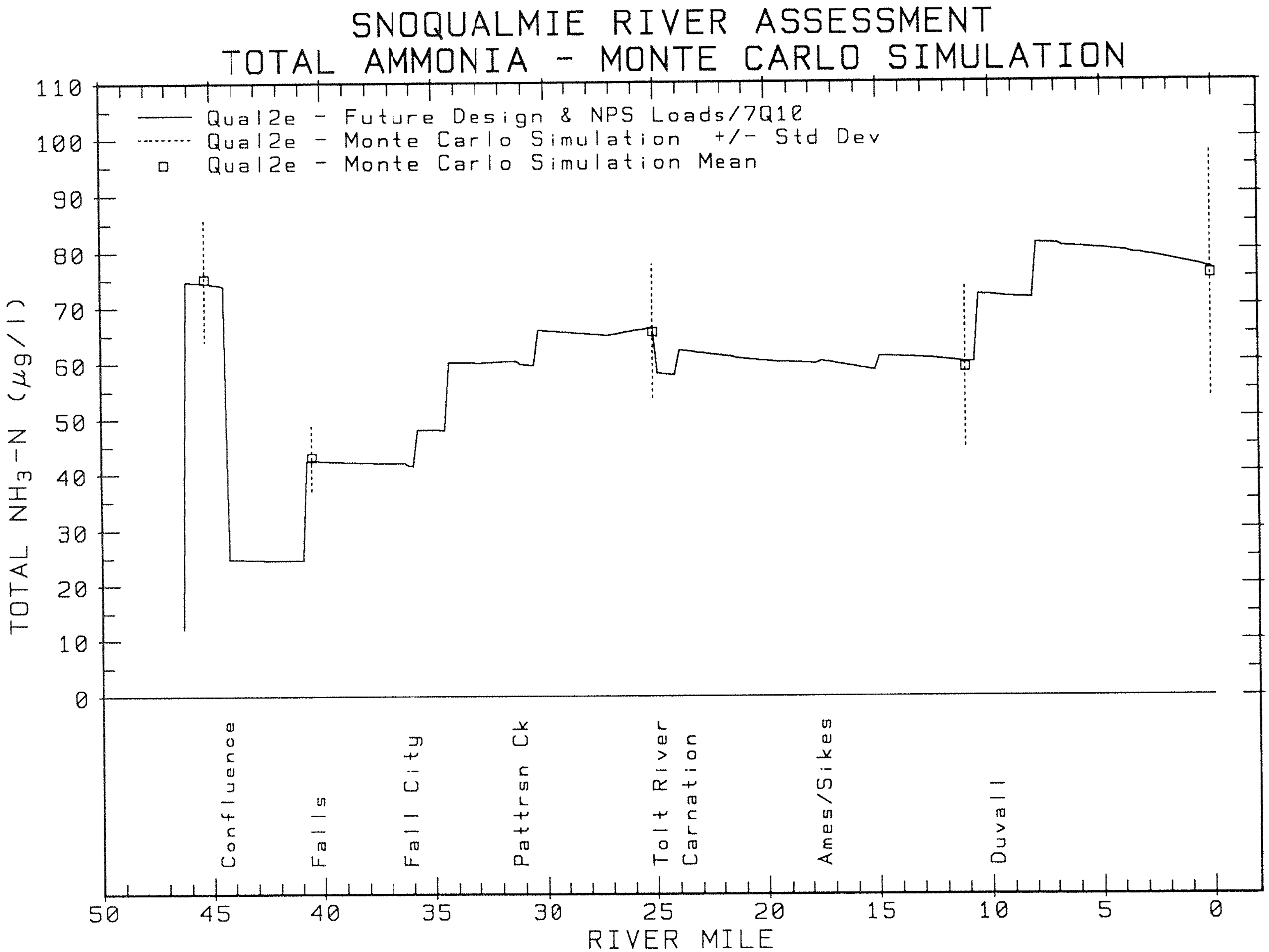


Figure 31. Snoqualmie River QUAL2E-UNCAS model results for ammonia comparing monte carlo analysis at five locations to one of the Figure 26 simulations.



than 20°C and pH levels greater than 7.8 could cause problems at concentrations represented within the standard deviation around the mean. These conditions might be reasonably expected with increased nutrient enrichment, so ammonia loading limits and monitoring may be necessary in the future.

The fecal coliform sensitivity analysis is less helpful than the others since the driving inputs are the NPS loads. The location where FC sensitivity is observed is more important than in most other cases. Also, the 25% increase in FC source concentrations is not as drastic as for TP or NH_3-N, so these values may not represent a fair comparison (Appendix A, Table 21). The monte carlo simulation results fit the original simulation fairly well (Figure 32). A greater uncertainty at stations impacted by the NPS inputs is evident (Figure 32). The uncertainty represented by the standard deviations shown indicates a larger portion of the river could experience Class A fecal coliform standards violations under 7Q10 conditions than was in the original simulations (Scenario 1 & 2).

MIXING ZONE MODEL

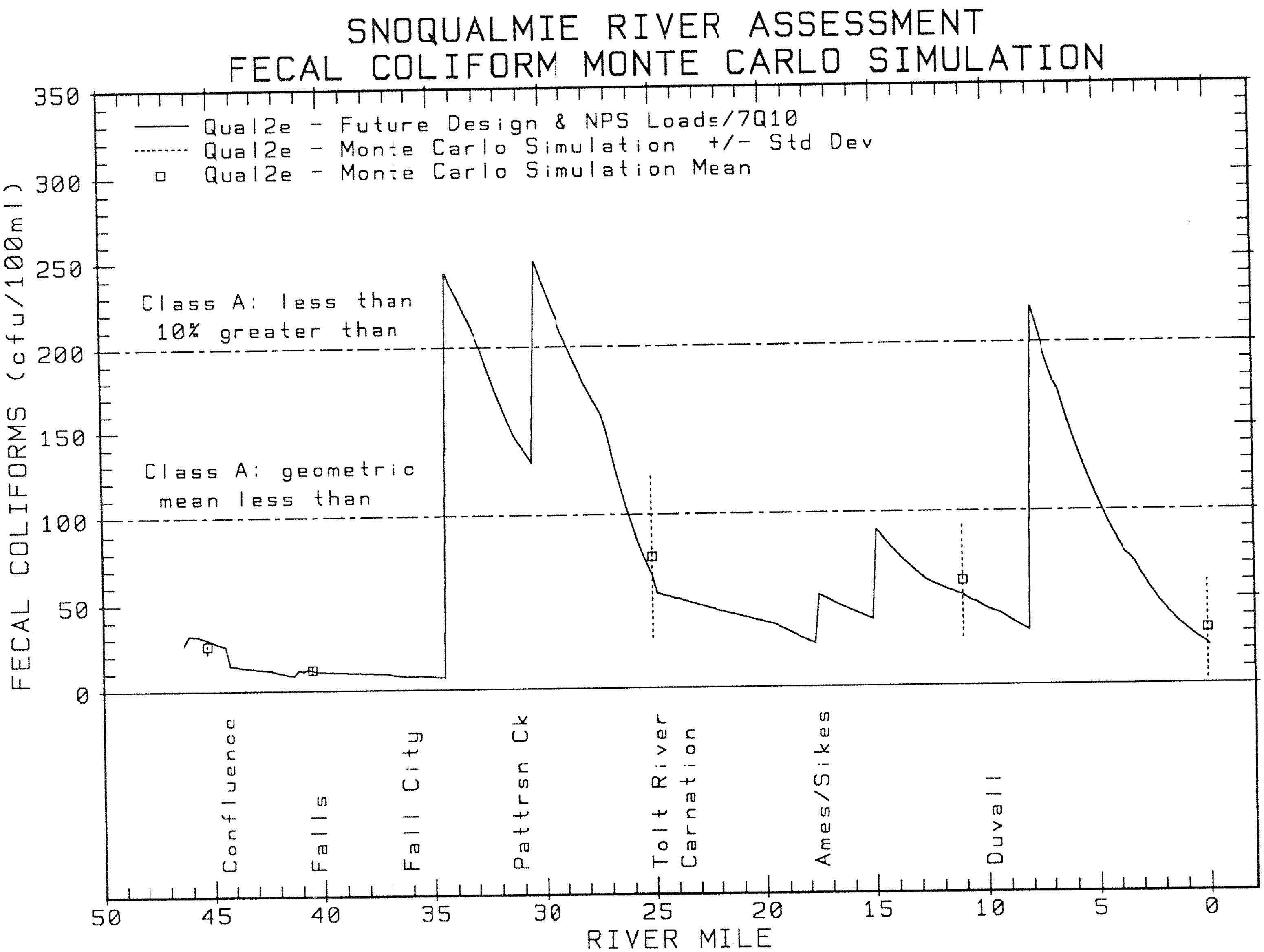
Description

Dilution of WWTP NH_3-N effluent concentration in the river under 7Q10 and future design conditions was evaluated using a simple mixing spreadsheet program (Pelletier, 1989). The program uses generalized mixing formulae from Fischer *et al.*, (1979). The purpose of the evaluation was to determine if chronic and acute un-ionized NH_3-N toxicity criteria could be met within a mid-stream, single-port diffuser, mixing zone. Ammonia was picked for evaluation since most domestic wastewater treatment plants have "end-of-pipe" concentrations exceeding criteria. Residual chlorine and metals concentrations can also be problems in mixing zones, but they were not evaluated in this exercise. A conservative guideline for such cases used for protection of water quality is a dilution ratio greater than 100:1 (Ecology, 1985). Also, toxicants will be addressed on a case by case basis as individual NPDES permits are renewed or written.

Under draft rules, mixing zones will be defined in NPDES permits administered by Ecology, and mixing zone conditions will be defined by regulation (Ecology, 1990b). The following conditions listed were taken from the draft rule and used in this evaluation:

- the mixing zone will not extend downstream a distance greater than 300 ft. plus the depth of water over the diffuser
- it will not use more than 15% of the 7Q10 discharge
- it will not use greater than 25% of the width
- acute toxicity criteria will be met within 10% of the distance from the outfall to any horizontal edge of the mixing zone.

Figure 32. Snoqualmie River QUAL2E-UNCAS model results for fecal coliform comparing monte carlo analysis at five locations to one of the Figure 27 simulations.



An assumption was made that a distance of 30 feet would accommodate the last condition listed. A mid-stream, single port diffuser design was used because of current design guidelines (Ecology, 1985). The mixing zone conditions and design guidelines may change somewhat by the time the rule becomes regulation, but the exercise will give a general idea of problem areas.

The spreadsheet used to evaluate the mixing zone is the same used in the point source section of the low flow water quality assessment above. The specific inputs for each of the WWTPs are listed in Table 26. The 7Q10 channel and discharge conditions were taken from Table 25 for the appropriate reach. As earlier stated, the positions of the Carnation (RM 23.8) and Fall City (RM 35.6) WWTPs outfall were placed in reaches each community would likely use.

Results

Results of the mixing zone evaluation are presented in Table 26. None of the mixing zone concentrations exceeded chronic or acute NH_3-N toxicity criteria 30 feet downstream of the outfall, or at dilutions represented by 15% of the 7Q10 river discharge volume. With these generalized data, a 4 mg/L NH_3-N effluent concentration appears to adequately protect aquatic organisms from toxicity in the mixing zones under 7Q10 conditions. More site specific data should be required as facility improvement designs are reviewed.

The mixing zone analysis, although generalized, indicated some WWTPs could have difficulty meeting certain dimensional requirements for the mixing zones listed above. For example:

- North Bend WWTP would have only a 6.5:1 dilution ratio 30 ft. downstream of the discharge, and a 9.4:1 dilution at 15% of the 7Q10 discharge. These might not be protective against some effluent constituents, i.e. the dilution ratio is less than 100:1.

- The Snoqualmie WWTP dilution ratio at 15% of the 7Q10 would be 33.5:1 only 10 ft. downstream of the outfall while nearly at the maximum width dimension of 49 feet. These too, might not be protective against some effluent constituents.

- As mentioned earlier in the report, Fall City and Carnation will need to avoid prime spawning areas in the river when placing their outfalls.

- Duvall WWTP dilution ratios at 15% of the 7Q10 and 30 ft. downstream of the outfall would be 48:1 and 37.5:1, respectively. These too, might not be protective against some effluent constituents.

Despite these problems, there seems to be better mixing from a mid-channel diffuser compared to some of the existing side-bank outfalls evidenced by the 1989 study dispersion results (see Point Source Surveys, above). A mid-stream diffuser would be a recommended design for the WWTPs unless it would be unreasonable to maintain or keep in the river during floods, or if beneficial uses were impacted.

Table 26. Inputs and results of NH3-N Snoqualmie River WWTP mixing zone evaluations.

INPUTS: Name	TREATMENT PLANT Flow (cfs)	TREATMENT PLANT NH3-N (µg/L)	UPSTREAM RIVER CONDITIONS Flow (cfs)	Depth (ft)	Velo. (ft/s)	Width (ft)	25% width	NH3-N (µg/L)	pH (su)	Temp. (°C)	DILUTION RATIOS* 30' (plume width in feet)	300' (plume width in feet)	15% Vol.
North Bend	1.24	4000	77	0.9	1.68	51.5	13	11	7.6	14.6	6.5 (8.5)	20.5 (27)	9.5
Snoqualmie	1.55	4000	346	7.7	0.23	195	49	24	7.6	17.0	59 (82)	182.5 (261)	33.5
Fall City	0.62	4000	368	5.2	0.51	140	35	42	7.6	17.7	110 (41)	347.5 (130)	89
Carnation	0.51	4000	442	1.46	1.47	206	52	57	7.6	18.3	27 (10)	86.3 (33)	130
Duvall	1.39	4000	447	4.56	0.92	106.5	27	61	7.6	19.1	37.5 (20)	119 (63)	48

RESULTS:	UN-IONIZED AMMONIA CRITERIA** 4-day average (µg/L)	UN-IONIZED AMMONIA CRITERIA** One-hr. average (µg/L)	UN-IONIZED AMMONIA CONC. AT ABOVE DILUTIONS *** (µg/L)	(µg/L)	(µg/L)
North Bend	18.7	112.8	5.7	2.0	
Snoqualmie	19.0	133	1.0	0.6	1.7
Fall City	19.0	140	1.0		1.1
Carnation	19.0	146	2.7		
Duvall	19.3	154	2.4		

* Mixing zone conditions: 30' downstream 1-hr. criteria zone, 300' downstream and 15% discharge volume 4-day zone (see text).
** Un-ionized ammonia criteria assumes WWTP effluent does not change upstream river temperature and pH.
*** Only lowest dilution ratios tested in most cases.

CONCLUSIONS AND SUMMARY

Based on the survey data, many portions of the Snoqualmie River appeared to be meeting most state and federal water quality criteria during the 1989 low flow season. However, violations of Class A temperature and fecal coliform bacteria criteria were observed in some tributaries and mainstem reaches. Some water quality problems require immediate investigation and resolution. Careful consideration, planning and management will be necessary to avoid any additional water quality degradation and losses of the river's diverse beneficial uses.

The field data and QUAL2E modeling simulations indicated both point and nonpoint sources (NPS) require controls to ensure all parts of the river will meet Class A standards. Of immediate concern are the mainstem nonpoint sources of fecal coliform bacteria, NH3-N, and TP represented in the model by the NPS inputs. If impacts are occurring from these sources during a low flow period, greater impacts are likely to occur during storm event and wet weather periods. This possibility needs investigation during the fall or spring season.

The mainstem NPS impacts have not been apparent in the Ecology ambient station data because of station placement, and limited evaluation of the data. Also, data from nonpoint monitoring programs in the basin have concentrated in the tributaries, so these projects may not have observed the mainstem problem either. The results of field work and the QUAL2E model simulations indicated the obvious mainstem NPS impacts are very reach specific. In addition, bacterial and nutrient loads which also could indicate the NPS presence are difficult to calculate due to large daily fluctuations in the river flow.

The survey data and model simulations generally suggest current cumulative WWTP and tributary loads have only localized and minor impacts on Snoqualmie River water quality during the low flow period. However, the WWTPs must come into compliance with current permits. If WWTPs accomplish this and maintain a high treatment efficiency, the current design loads should not create water quality problems during 7Q10 events. One exception may be the total phosphorus load from the North Bend WWTP and its impact on South Fork periphyton growth.

With a future scenario which included expansion of the existing WWTPs, and the addition of two more, the model simulations suggest cumulative TP loads could require a seasonal TMDL and WLA/LAs. A 50 μg/L TP interim limit on average concentrations in lower river during the low flow period is suggested as a facilities planning guide. How soon definite limits will be established depends on pending treatment processes decisions, nonpoint source management success, more intensive monitoring results, and the rate of land use changes in the Snoqualmie Valley from forest and agriculture to residential development.

The simulations of future water quality conditions also suggest that other problems may arise. The current confidence limits placed around the model simulation results suggest NH3-N toxicity and D.O. problems could arise with increasing frequency in the lower river. More definitive nutrient data with a closer examination of the nutrient/periphyton-macrophyte interactions, and the impacts of NBOD on D.O. will be needed to more accurately predict current and future wastewater loading impacts.

Other areas still require investigation. Instream metals and toxic contaminant data also need to be collected to properly interpret current WWTP effluent quality and determine if TMDLs are necessary. Sediment and biota samples analyzed for these contaminants could be useful.

The effects of future Snoqualmie River nutrient, bacterial, and oxygen demand loads on Snohomish River water quality have to be evaluated as well. For example, comparison of model Scenario 1 and 2 simulations indicate the TP load from the Snoqualmie to the Snohomish would nearly triple. The effect of additional phosphorus on Snohomish River water quality could be evident before Scenario 2 conditions were reached, and before problems developed in the Snoqualmie River. In this case, the 50 μg/L TP interim guideline suggested for the Snoqualmie River may not be adequate to protect Snohomish River water quality. If TMDLs and WLA/LAs are pursued, it will be important to establish them with information from the entire effected river system. With this in mind, the NWRO of Ecology has already requested a lower Snohomish River water quality study.

The 1989 low flow water quality assessment of the Snoqualmie River, and model simulations have provided much new information for water resource managers. They provide a resource from which more informed decisions can be made. They can also provide direction for more specific water quality investigations of the river that will be necessary as competition intensifies between various users of the river basin. The following are some of the more important findings of the assessment, and model simulations:

- At discharges of 430 cfs at Snoqualmie Falls and 610 cfs at Carnation, water from North Bend roughly takes 3.5 days to travel 45 miles to High Bridge. The PP&LC dam at the Falls, the pool behind the confluence with the Tolt River, and the diked, channelized low-gradient reach from Duvall to High Bridge appear to retard water movement greatly. At a 7Q10 design flow, the estimated travel time is 4.2 days.

- The PP&LC dam structure and hydroelectric plant operation has a significant impact on daily discharge patterns along the river during low flow. A 270 cfs decrease in discharge over six hours between release and storage cycles was not uncommon.

- The Tolt River has a significant impact on the mainstem channel configuration and lower valley water quantities. It constitutes approximately 20% of the water gaged at the USGS station at Carnation during the summer low flow season. It is also of generally high quality and serves to enhance water quality characteristics downstream.

- Temperatures exceeded the 18°C Class A standard during the first survey at all mainstem sites monitored below RM 20.3. During work in August, temperatures exceeded the criterion as far upstream as RM 32; temperatures greater than 20°C were not uncommon in the lower portion of the river. Direct solar heating of the river in slow channelized reaches without significant riparian cover was the major reason for the elevated temperatures.

- None of the temperatures measured at the North Fork or Middle Fork exceeded the 16°C Class AA standard.

- The Raging River, Ames/Sikes, Tuck, and Cherry Creeks had less riparian cover than the other tributaries, and as a result were generally warmer with a greater potential of exceeding the Class A standard.

- All mainstem station D.O. results met applicable Class A standards, and the North Fork and Middle Fork met Class AA standards.

- Tributaries had relatively low biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentrations. Point source BOD often had elevated concentrations, but loads were usually insignificant relative to the river volume present during the study. Instream concentrations of these parameters were also low. These factors contributed to a generally good low flow D.O. regime throughout the study area.

- There was a general increase in nutrient concentrations on the mainstem from Meadowbrook Bridge (RM 42.3) to High Road Bridge (RM 2.7). The Tolt River (RM 24.9) appeared to temporarily lower instream concentrations of several nutrients.

- Un-ionized NH_3-N was not present in toxic concentrations in samples collected at any of the mainstem or tributary sites.

- None of the chlorophyll *a* samples collected at several sites during each of the four surveys had concentrations above the detection limit. Also, the low response from the light/dark bottle work indicated there was very little water column phytoplankton growth in the river.

- Mainstem TN and TP concentrations during the low flow Snoqualmie study were present at or below the eutrophication "problem threshold" category for algal growth; concentrations never reached the "problem likely to exist" level.

- TN:TP ratios at mainstem Snoqualmie River stations generally indicated a phosphorus limited system if other needs for water column algal growth were met, e.g. light, temperature, and residence time.

- The following average net increases were observed between RM 42.3 and RM 2.7 during the four surveys (mean ± standard deviation):

Total phosphorus:	40 ±	20 lbs./day
Soluble phosphorus:	10 ±	6 lbs./day
Ammonia nitrogen:	70 ±	9 lbs./day
Nitrate & nitrate:	200 ±	100 lbs./day
Total nitrogen:	1000 ±	600 lbs./day

- Of the sources monitored, the three WWTPs were the most significant for TP and SP loading. The tributaries were usually the most significant sources of nitrogen species. Duvall WWTP and the Tolt River were the most significant source loads of NH_3-N, followed by Tokul Creek and Ames/Sikes Creek (RM 17.5).

- Non-point sources of TP, SP, and TN were suspected based on unidentified increased instream loads occuring from RM 35.3 on downstream. Livestock on the banks of the river or in the shallows; poor manure gun placement; failing on-site sewage systems; fertilizer enriched groundwater and at least one culvert suspected of discharging manure may be sources of these loads.

- North Fork and Middle Fork samples met Class AA fecal coliform standards on all sampling occasions. Mainstem Class A fecal coliform standard violations occurred in the lower valley between RM 32.6 and RM 2.7.

- Samples from Ames/Sikes Creek, Cherry Creek, Kimball Creek, Griffin Creek, and Patterson Creek exceeded Class A fecal coliform standards during three or more surveys. Tokul Creek, the Raging River, the Tolt River, and Harris Creek met standards on all surveys. Ames/Sikes Creek delivered the largest average fecal coliform load of the monitored tributaries and point sources.

- Significant non-point sources of fecal coliform loading were suspected between RM 35.3 and RM 27.2, RM 18.3 to RM 10.7, and RM 9.8 to RM 2.7. Livestock in the river, bank-side manure storage piles, failing on-site sewage systems, and careless placement of manure guns may be contributing to non-point fecal loading.

- The enterococcus bacteria results indicated swimmers in the Snoqualmie River were usually subjected to a low risk of illness from water contact.

- All WWTP outfalls were not in conformance with current Ecology mixing zone guidelines because of their bankside locations. Effluent concentrations suggested aquatic toxicity criteria would probably have been exceeded in localized areas near the outfalls for chlorine residual, NH_3-N, and some metals. Preliminary calculations suggest North Bend and Snoqualmie WWTPs may have some difficulty meeting mixing zone criteria if mid-stream, single port diffusers were installed.

- All three WWTPs were approaching design flow capacities which contributed to some of the observed effluent quality problems.

- North Bend WWTP effluent quality met all permit limits during the first two monitoring surveys. During one or more of the last two surveys, TSS, BOD, and fecal coliform concentrations were elevated above permitted weekly and monthly average levels. Effluent un-ionized NH_3-N toxicity and temperature problems were not present. Poorly diluted effluent chlorine residuals (TRC) would have caused local violation of USEPA criteria. Copper, silver, zinc, lead, and mercury concentrations in one or more undiluted effluent samples exceeded USEPA acute and/or chronic toxicity criteria to protect aquatic life. Alpha-chlordane effluent concentrations exceeded the USEPA 24-hour average aquatic toxicity criterion. Effluent would have difficulty meeting α-chlordane aquatic life chronic toxicity and a 10^{-6} human health risk criteria (0.46 ng/L) at the edge of an ideal mixing zone under 7Q10 conditions. The effluent displayed low toxicity in the effluent bioassays.

- Discharge volume and effluent contaminants from the Weyerhaeuser mill log pond were insignificant over the course of the study; all permit parameters were well within limits. The effluent quality of the log pond was more similar to the tributaries than the WWTPs.

- At the Snoqualmie WWTP, TSS concentrations were elevated above permitted monthly and/or weekly average levels on three visits. Several problems were experienced with the BOD analyses from this facility, so the degree of BOD permit compliance needs further investigation. Based on effluent concentrations, un-ionized NH_3-N toxicity was not a problem at the outfall. Effluent TRC and some temperatures would have exceeded criteria in a localized area near the outfall. Undiluted copper, cadmium, silver, lead, and zinc concentrations in one or more effluent samples exceeded USEPA acute and/or chronic aquatic toxicity criteria. Very few organic compounds were detected in the effluent samples.

- Duvall WWTP effluent quality was generally poor during monitoring visits, and operational problems were evident by poor permit limit compliance. Suspended solids, fecal coliform, and BOD concentrations were elevated above permitted weekly and/or monthly average levels on some survey occasions. Based on effluent analyses, un-ionized NH_3-N and chlorine residual toxicity may have been problems at the outfall on two or more surveys. The maximum effluent temperature observed at the chlorine contact chamber was 21.2°C at a time when the river already exceeded the 18°C Class A standard. Violation of the 0.3°C should have been contained within a limited area near the outfall. Undiluted copper, silver, lead, mercury and zinc concentrations in one or more effluent samples exceeded USEPA acute and/or chronic aquatic toxicity criteria. Total phthalate esters (estimated 23 μg/L) exceeded the 3 μg/L aquatic chronic toxicity criterion. Acute and chronic toxicity were observed in bioassay tests of the effluent. Metal and ammonia concentrations present in the effluent were possible agents of toxicity.

- Highest primary productivity and respiration rates in the river were observed at RM 36.5. Lowest productivity and respiration were measured at RM 23.5. Net productivity was near zero or in deficit at the majority of seven sites tested. Highest net productivity was found at RM 36.5. Productivity estimates for the Snoqualmie River fell in the lower range of values reported by other investigators for large rivers.

- Three of four periphyton samples collected in the South Fork had biomass above the 100 mg chl. *a*/m^2 "nuisance levels". Biomass of chl. *a* from nineteen mainstem Snoqualmie River samples were in the lower range of values reported by other investigators of Pacific Northwest streams, and were well below nuisance levels.

- Mean benthic macroinvertebrate diversity as measured by the Shannon- Weaver Index was highest at RM 33.5 (2.8) and lowest at RM 9.9 (2.2). The mean diversity of all samples collected was 2.6 indicating fair to good water quality. Waste loading from the North Bend WWTP did not appear to adversely affect benthic macroinvertebrate communities in the South Fork. High variability in benthic macroinvertebrate abundance at all sites and lower abundance at RM 9.9 in September may have been a result of an August storm event.

- Trace quantities of cadmium, copper, chromium, lead, zinc, and mercury and two pesticides, aldrin and p,p'DDE, were detected in one or both of two fish tissue samples collected in the mainstem above the Tolt River. None of the concentrations exceeded human health criteria or guidelines for the protection of wildlife. The 15 μg/kg aldrin concentration in the whitefish fillet sample exhibited the highest potential human health risk of the chemicals detected: a 3 X 10^{-5} carcinogenic risk.

- The QUAL2E model simulations of D.O. profiles for the two 7Q10 scenarios are very similar to each other, and to the calibration run. D.O. concentrations in the pool above the Falls (RM 40.7), and at RM 0.0 would continue to be the lowest along the river, but the differences averaged less than 1 mg/L at points between the confluence of the three forks (RM 44.4) and RM 0.0. The simulations suggested NBOD contributed approximately 28% of the D.O. demand at RM 0.0 in the 7Q10 scenarios compared to 11% in the calibration simulation. However, the additional secondary treatment loads of CBOD and NBOD would not seriously impact the average D.O. concentrations of the river.

- The diurnal field data and monte carlo uncertainty analyses indicate D.O. concentrations could drop below the 8 mg/L Class A water quality standard over the course of a day during both 7Q10 scenario conditions. Increased productivity from increased nutrient enrichment throughout the mainstem could accelerate the frequency of future violations.

- The TP profile for Scenario 1 indicates the North Bend WWTP could exacerbate the "nuisance" periphyton/chlorophyll *a* biomass levels in the South Fork under extended low flow conditions. Average mainstem TP concentrations in Scenario 1 would increase 3 to 8 μg/L over the 1989 average concentrations, but would be below a 50 μg/L recommended guideline to avoid eutrophication conditions. The mainstem NPS and tributary loads had similar impacts on river TP concentrations as the combined WWTPs.

- The Scenario 2 profile suggests TP could become a concern in the entire mainstem below Snoqualmie Falls, as well as in the South Fork. Mainstem and South Fork concentrations would be greater than 60 μg/L in places. The retention rate of TP in the mainstem could increase, but uptake rates would also remain high and may create periphyton or aquatic macrophyte problems, especially from Fall City (RM 36) to the Tolt River (RM 25), from Duvall (RM 10.5) to the County Line (RM 6.1). The TP load exported to the Snohomish River during 7Q10 would also increase from 39 lbs./day under Scenario 1, to 100 lbs./day under Scenario 2.

- The NH3-N profiles for existing and future loads under 7Q10 conditions are impacted by point and mainstem NPS sources; tributary impacts appear to be less significant by comparison. The Scenario 1 profile indicates a maximum average NH3-N concentration represented a 0.01 mg/L NH3-N increase over the calibration run results. The concentration would still be well below levels capable of creating aquatic toxicity problems even if pH and temperatures were greatly elevated.

- The Scenario 2 NH3-N profile showed point and nonpoint sources contributing equally to the increased concentrations in the river. Average concentrations in the South Fork and mainstem would not usually create chronic ammonia toxicity problems. However, uncertainty analysis results indicated future NH3-N concentrations may not leave much of a "safety margin" in the lower river. Toxicity could occur where pH levels above 7.8, and temperatures greater than 20°C were present. The NH3-N could also slightly increase NBOD impacts on D.O., and assimilation of the NH3-N by periphyton could contribute to increased productivity in the river.

- The fecal coliform profiles for calibration, Scenario 1 and 2 conditions were nearly identical to each other. They clearly demonstrated how the nonpoint sources, both as mainstem NPS and tributary loads, dominate the FC concentrations in the river as long as point source effluent quality remains within permit limits. The tributary and point source FC loads alone during a 7Q10 event would probably not cause violations in the mainstem. However, if the mainstem NPS inputs were as active during a 7Q10 event as they were during the 1989 study, Class A standards would probably be violated at a greater number of sites than in 1989.

- Mixing zone modeling indicated ammonia toxicity would probably not occur within the proposed mixing zone dimensions if mid-stream diffusers were installed, and effluent total NH3-N concentrations were 4 mg/L or less. Other effluent constituents with very strict criteria may not meet mixing zones conditions because of low dilution ratios during 7Q10 events and elevated background concentrations.

RECOMMENDATIONS

- Improve permit compliance of the current WWTP discharges.

- Ecology and Conservation District staff need to establish nonpoint management plans to identify and control the NPS sources on the mainstem of the Snoqualmie and in selected sub-basins: Patterson Creek, Griffin Creek, Ames-Sikes Creek, and Cherry Creek.

- Evaluate the efficacy of the 50 μg/L TP guideline. If it is acceptable, establish a monitoring plan for total phosphorus in the river, and collect data. Then use the guideline to evaluate existing and new discharge permit applications.

- Monitor ammonia and diurnal D.O. in the lower study area to ensure toxicity or criteria violations do not occur.

- Change the location of the Ecology ambient monitoring station from Carnation, (RM 23) downstream to High Bridge (RM 2.7).

- Since they appear to be limited, the fish spawning and rearing habitats along the mainstem river should be protected against degradation.

- Determine instream and sediment metals and priority pollutants concentrations to adequately develop NPDES discharge permit limits, and evaluate possible TMDLs.

- Evaluate the Weyerhaeuser mill log pond NPDES discharge permit compliance during wet weather conditions.

- Evaluate the impact of the Washington Department of Wildlife hatchery on Tokul Creek water quality, and the Carnation Research Farms spray fields on Ames/Sikes Creek basin water quality.

- Examine basin-wide storm event or wet weather water quality problems, and develop land use to water quality relationships in basin or sub-basins.

- Investigate the impact of the Snoqualmie River on the Snohomish River, and evaluate the need for TMDLs for the entire system (Snoqualmie-Skykomish-Snohomish).

- Future enterococcus and e. coli monitoring of the Snoqualmie River to evaluate public health risks should concentrate on popular swimming areas: Raging River confluence; NE 124th Bridge; and Duvall at the proposed park bench (RM 9.9).

- Perform a verification run of the QUAL2E model to establish its continued usefulness as a planning tool, especially for nutrient assessment.

- Evaluate groundwater to river interactions during low flow periods, and better define the water budget for various reaches of the river.

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APPENDIX A

Appendix A-1. Snoqualmie River survey data collected July 24 - 25, 1989 (Survey #1 of 4) as part of the Ecology Snoqualmie River low flow study.

Station Number*	River Mile	Date	Time	Elev. ft.	D.O.2 mg/L	D.O.1 mg/L	Temp °C	pH s.u.	Cond. umhos	DOSat1 %	DOSat2 %	Flow cfs	Staff cfs	Hard. mg/L	Alk. mg/L	Cl- mg/L	TSS mg/L	Solids mg/L	TNVS mg/L	TNVSS mg/L	NH_3-N µg/L	TP µg/L	SP-P µg/L	NO_{2+3}-N µg/L	TN-N µg/L
M444020L		07/24	0807	430		10.6	12.1	7.1	71	99.9			215			1.19	1				12	3	240		
M444020R		07/24	0820	430	10.4	10.6	12.2	7.0	71	100.0	98.4		215	30	29	1.21	1 U	77	56	1 U	18	6	3	240	244
NO.BEND			24-hr.				18.7	7.2	281			0.35		50	73	23	6	165	135	5	360	1496	826	350	
M444012C		07/24	0854	420	10.4	10.8	11.9	6.9	74	101.1	97.8		217	32	31	1.25	1	65	51	1 U	11	5	4	254	283
M453000C	45.3	07/24	0935	411	10.3	10.7	14.5	7.0	31	106.6	102.5		455			0.69	2				10 U	2 U		47	
M449003C		07/24	0950	411	10.3	10.5	14.3	7.0	44	104.2	102.0		236			0.74	1				19	2 U		149	
M423R	42.3	07/24	1022	400	10.3	10.6	14.4	7.0	46	104.9	102.3		895	14	17	0.85	1	40	13	1 U	10 U	2 U	1	118	134
M423C	42.3	07/24	1045	400		10.5	14.4	6.9	46	104.6			895												
M423L	42.3	07/24	1100	400		10.4	14.4	6.8	46	103.5			895			0.84	2				15	2		122	
WEYCO			24-hr.				24.0	7.5	151			0.02		54	59	7	9	100	62	3	170	60		10	
M412R	41.2	07/24	1127	395	10.3	10.3	14.8	6.9	47	103.2	102.8		895	15	18	0.86	2	44	10	1	21	2 U	1	116	108
M412C	41.2	07/24	1135	395		10.2	14.8	6.9	47	102.4			895												
M412L	41.2	07/24	1146	395		10.3	14.8	6.8	47	102.6			895												
T411005		07/24	1208	400	10.1	10.3	15.7	6.8	93	105.2	103.1	1.8				2.14	6				25	18	6	404	429
SNOQWWTP			24-hr.				24.3	7.6	335			0.22		50	100	33	78	310	150	20	1900	4900	2800	590	
M407R	40.7	07/24	1227	390	10.3	10.6	15.3	7.1	45	106.8	103.7		895	16	18	0.89	2	48	39	2	12	5	3	122	264
M407C	40.7	07/24	1243	390		10.4	15.1	6.8	46	104.8			895												
M407L	40.7	07/24	1300	390		10.3	15.1	6.8	46	104.1			895			0.87	2				18	2 U		117	
M397R	39.7	07/24	1342	104	10.2	10.8	15.8	7.0	46	109.7	103.4		895			0.86	3				16	3		115	
T39600		07/24	1405	104	10.6	10.9	15.4	7.8	134	109.4	106.3	35.4				1.45	2				48	34	17	501	473
M363	36.3	07/24	1430	78	11.0	10.7	17.1	7.1	50	110.6	114.2		935			0.92	2	37	19	1 U	10	4	3	120	117
T36200		07/24	1450	78	10.6	10.4	22.6	8.8	82	120.7	122.9	10		27	32	4.36	3				24	3	2	129	173
M3535	35.4	07/24	1510	75	10.9	11.1	17.4	7.3	50	115.8	114.1		950	18	20	0.96	3	47	38	1	18	2	2	117	116
E45		07/24																					2		
T411005D		07/24																					6		
T39600D		07/24																							
T36200D		07/24																							
M407RF	40.7	07/24																			27	2 U		113	
M363D	36.3	07/24																							93
M444018D		07/24																			13	2 U		233	
M412D	41.2	07/24																			16	4		115	
M3535	35.4	07/25	0823	75		10.2	16.0	7.0	50	103.8			950												
M326	32.6	07/25	0840	62	9.3	9.9	16.4	7.0	51	101.6	94.7		950		20	1.00	3				16	5	2	121	80
T312004		07/25	0915	69	9.5	9.9	12.7	7.3	149	93.5	89.9	6.8			67	2.81	1				25	46	26	782	784
M251R	25.1	07/25	1025	58	9.4	10.1	16.7	7.0	52	103.9	96.9		970	24	21	1.01	1 U	86	60	1	29	11	2	154	79
T249		07/25	1055	58		11.3	13.9	7.3	54	109.9			190	23	21	0.94	1 U				11	2 U	1	152	50
T272007		07/25	1120	60	10.3	10.9	14.4	7.3	89	106.9	100.6	3.5			40	1.50	1 U				17	11	8	389	348
M2301L	23.0	07/25	1155	46		10.6	16.9	7.2	53	109.2			1160			1.02	1				15	7	2	136	173
M2301R	23.0	07/25	1210	46	10.6	16.9	7.1		54	109.6			1160	22	21	1.08	1	110	56	1	12	2 U	1	136	104
T213017		07/25	1840	60	10.1	10.4	14.4	7.4	92	102.0	99.0	2.7			39	1.76	1				15	76	42	797	642
M203	20.3	07/25	1255	34	9.8	10.4	18.0	7.2	54	110.1	103.6		1165		22	1.09	2				13	2 U	1	128	101
T175001		07/25	1755	30	9.0	9.2	18.7	7.5	145	98.9	96.5	3.8			66	2.94	7				49	85	63	697	899
M147L	14.7	07/25	1330	25	9.6	10.1	18.4	7.2	54	107.2	101.9		1170												
M147R	14.7	07/25	1340	25		10.0	18.4	7.0	54	107.0			1170			1.12	1				32	2 U	2	134	56
DUVALL			24-hr.				20.7	7.3	450			0.25		41	108	40	50	350	180	12	1300	2300		660	
T103001		07/25	1430	22	7.8	8.0	17.5	7.1	121	84.1	81.6	0.6				1.99	32				88	460	16	72	339
MO98R	9.8	07/24	1430	21	9.5	10.0	19.3	7.2	55	108.2	102.5		1175	21	22	1.18	4	83	63	3	24	15	3	131	110
M027R	2.7	07/25	1600	17	9.5	9.9	19.3	7.1	55	107.8	103.1		1195	23	23	1.24	7	110	71	6	19	6	3	133	225
T067002		07/25	1645	20	9.3	9.8	17.4	7.1	96	102.0	96.5	6.8			41	2.38	7				62	27	5	502	606
M251D	25.1	07/25														1.10					24	2 U	2	125	60
T175001D		07/25																							
E01		07/25																			15	15	4	74	50
M147RF	14.7	07/25																			11	20		108	
M251RD	25.1	07/25																							

Appendix A-1. (Continued)

Station Number*	River Mile	Date	Time	COD mg/L	TOC mg/L	BOD_5 mg/L	BOD_5-NI mg/L	BOD_{20} mg/L	F.COLI org/100	%Kleb. %	ENTERO org/100	Chl *a*. mg/m^3	Pheo *a* mg/m^3
M444020L		07/24	0807						9				
M444020R		07/24	0820		2.94		4 E		14		17		
NO. BEND			24-hr.	18		5			100				
M444012C		07/24	0854		2.31		4 E		6		9		
M453000C	45.3	07/24	0935		1.68				11				
M449003C		07/24	0950		1.74				6				
M423R	42.3	07/24	1022	4.0 U	2.38		4 E		3	0		0.10 U	0.10 U
M423C	42.3	07/24	1045										
M423L	42.3	07/24	1100	5.0					6	0	9		
WEYCO			24-hr.	21					7				
M412R	41.2	07/24	1127	4.1	1.99		4 E		17	0			
M412C	41.2	07/24	1135										
M412L	41.2	07/24	1146										
T411005		07/24	1208	10.0	4.38	4 E			460	0			
SNOQWWTP			24-hr.	138		42			3				
M407R	40.7	07/24	1227	4.0 U	1.73			4 E	11	0		0.10 U	0.10 U
M407C	40.7	07/24	1243										
M407L	40.7	07/24	1300	4.0 U					20				
M397R	39.7	07/24	1342										
T39600		07/24	1405		4.40	4 E			11		6		
M363	36.3	07/24	1430		2.15		4 E		3 U		3	0.10 U	0.10 U
T36200		07/24	1450			4 E			6		11		
M3535	35.4	07/24	1510		2.01			4 E	3 U		9	0.10 U	0.10 U
B45		07/24											
T411005D		07/24											
T39600D		07/24							17		6		
T36200D		07/24							31		6		
M407RF	40.7	07/24											
M363D	36.3	07/24											
M444018D		07/24											
M412D	41.2	07/24		4.0 U									
M3535	35.4	07/25	0823										
M326	32.6	07/25	0840		1.47	4 E			29				
T312004		07/25	0915		2.58	4 E			200				
M251R	25.1	07/25	1025	7.5	2.77			4 E	26			0.10 U	0.10 U
T249		07/25	1055		1.94	4 E			3		3 U		
T272007		07/25	1120		3.70	4 E			140				
M2301L	23.0	07/25	1155						9		3		
M2301R	23.0	07/25	1210		1.84				14		17	0.10 U	0.10 U
T213017		07/25	1840		3.45	4 E			49				
M203	20.3	07/25	1255		1.92				9			0.10 U	0.10 U
T175001		07/25	1755	13.0	7.87		4 E		320				
M147L	14.7	07/25	1330										
M147R	14.7	07/25	1340		1.79	4 E			17		3 U	0.10 U	0.10 U
DUVALL			24-hr.	78		14			6000				
T103001		07/25	1430		7.82	4 E			84				
MO98R	9.8	07/24	1430	4.3	1.94			4 E	17		3 U	0.10 U	0.10 U
M027R	2.7	07/25	1600	4.2	1.99			4 E	29			0.10 U	0.10 U
T067002		07/25	1645		4.38	4 E			390				
M251D	25.1	07/25							17				
T175001D		07/25							410				
B01		07/25		4.0 U	0.66								
M147RF	14.7	07/25											
M251RD	25.1	07/25											

Appendix A-1. (Continued).

Station coding: R = right bank, L = left bank, C = center, F = filtered, D = duplicate field sample,
M = mainstem, T = tributary, B = blank.

Sample qualifiers:

U = below detection limit indicated
J or E = estimated value
Flow = Field measured discharge
Staff = rating curve estimated flow (USGS, 1990) and interpolated for some stations.

BOD_5-NI = Five-day biochemical oxygen demand, nitrification inhibited.
D.O.1, D.O.Sat1 = measurement of D.O. by membrane probe
D.O.2, D.O.Sat2 = measurement of D.O. by Winkler-Azide titration

Appendix A-2. Snoqualmie River survey data collected August 15 - 16, 1989 (Survey #2 of 4) as part of the Ecology Snoqualmie River low flow study.

Station Number	River Mile	Date	Time	D.O.2 mg/L	D.O.1 mg/L	Temp °C	pH s.u.	Cond. umhos	DOSat1 %	DOSat2 %	FLOW cfs	STAFF cfs	Hard. mg/L	Alk. mg/L	Cl- mg/L	TSS mg/L	Solids mg/L	TNVS mg/L	TNVSS mg/L	NH_3-N ug/L	TP ug/L	SP-P ug/L	NO_2+$_3$-N ug/L	TN-N ug/L
M444020L		08/15	0850		10.1	12.1	6.6	71	95.1			161			1.42	4	70	35	3	10 U	7	4	215	
M444020R		08/15	0840	10.4	10.1	12.0	6.7	71	95.1	97.7		161	34	32	1.34	2				13	8	2	218	154
NO.BEND			24-hr.			17.5	7.0	311			0.37		57	39	25	3	240	160	1	920	5400	4200	8500	
M444012C		08/15	0950	10.4	10.3	12.2	6.8	74	97.1	98.4	163	163	36	32	1.47	3	73	30	3	10	19	16	226	181
M453000C	45.3	08/15	1025	10.2	10.1	14.7	6.7	53	101.1	101.7		301			0.84	3				10 U	6		46	
M449003C		08/15	1038	10.1	9.9	13.4	6.7	51	96.1	97.6		168			0.86	1				10 U	4		156	
M423R	42.3	08/15	1128	10.0	9.8	13.8	6.7	52	95.7	97.6		613	23	21	1.72	2	41	26	2	11	10	2	127	78
M423C	42.3	08/15	1122		9.8	13.8	6.8	52	95.8			613												
M423L	42.3	08/15	1117	9.9	9.9	13.9	6.8	52	97.2	97.3		613			1.39	2				32	15	2	120	
WEYCO	41.6		24-hr.			20.6	7.1	144			0.004		56	57	7	4	120	60	1	20 J	50	10 U	50	
M412R	41.2	08/15	1200	9.6	9.5	14.2	6.6	53	93.5	95.2		613	25	22	1.42	4	75	30	4	15	11	1	121	56
M412C	41.2	08/15	1155		9.5	14.1	6.7	53	93.6			613												
M412L	41.2	08/15	1150		9.7	14.2	6.8	52	95.6			613												
T411005		08/15	1205	10.8	10.6	14.4	7.0	82	105.1	107.4	2.7				1.79	2				12	13	2	304	217
SNOQWWTP	40.8		24-hr.			19.9	7.2	350			0.25		55	83	31	78	350	190	14	480 J	5800	3400 J	3400	
M407R	40.7	08/15	1300	9.6	9.5	14.5	6.9	54	94.1	95.3		617	23	24	1.20	3	55	24	2	16	14	5	123	63
M407C	40.7	08/15	1305		9.5	14.4	6.8	53	93.8			617												
M407L	40.7	08/15	1310		9.4	14.5	6.8	53	93.7			617			1.22	2				12	14	2	122	
M397R	39.7	08/15	1402	10.0	10.0	14.9	7.0	53	99.0	99.8		617			1.10	2				11	12	3	119	
T39600		08/15	1416	10.8	10.8	14.2	7.4	130	105.7	105.3	31				1.62	2				50	39	15	361	421
M373C	37.3	08/15	1530	10.7	10.6	15.7	7.2	57	107.4	108.2		648			1.16	3	79	28	2	11	13	2	120	68
M373L	37.3	08/15	1535		10.5	15.6	7.2	57	105.8			648												
M373L	37.3	08/15	1540		10.7	15.8	7.1	54	108.0			648												
T36200		08/15	1610	10.8	10.7	18.1	8.7	82	113.3	114.3		12			5.56	2				10	9	2	78	229
M3535	35.4	08/15	1630	10.8	11	16.4	7.2	58	108			660			1.33	4	58	25	2	37	14	2	119	65
M3535RD	35.4	08/15	1635	10.7								660			1.22	4	54	28	3	14	15	1	119	237
T39600D		08/15	1418																					
M412F	41.2	08/15	2030																					
B44		08/15	2035																	15	5	6	127	
M3535	35.4	08/16	0910		9.6	14.9	6.8	57	94.9			660												
M326	32.6	08/16	0950	9.7	10.5	14.8	6.8	57	103.9	96.0		660		22	1.21	1				45	71	1	133	174
T312004		08/16	1028	9.6	9.3	13.0	7.1	142	88.0	91.3	8.1				3.16	1 U				34	82	40	736	960
M279	27.9	08/16	1220	9.9	9.7	15.0	7.0	58	96.0	98.4		668		23	1.25	1 U				21	13	2	147	111
T27200		08/16	1250	11.8	11.8	15.2	7.9	88	118.2	118.2	2.9				1.84	7				41	30	4	232	324
M251R	25.1	08/16	1340	9.8		16.4	8.0			100.3		671	31	24	1.42	2	49	36	2	21	11		139	105
M251L	25.1	08/16	1335			17.1	7.7					671			1.44	1				22	18	2	124	117
T249		08/16	1430	10.8		13.9	7.7			104.9		165	24	18	0.86	1 U				29	11	1 U	107	75
M2301L	23.0	08/16	1535		10.1	16.1	7.1	59	102.2			825			1.38	1 U				17	26	1 U	120	94
M23O1C	23.0	08/16	1539		9.9	16.0	7.1	59	100.6			825												
M2301R	23.0	08/16	1542	9.8	10.0	16.0	7.1	59	101.4	99.4		825	30	23	1.42	2	71	36	1	10 U	29	1 U	117	81
T213017		08/16	1723	11.2	10.4	13.3	7.3	88	99.5	107.4	3.5			36	2.38	1				11	43	8	458	638
M203	20.3	08/16	1627	10.	10.	16.	7.1	61	103.4	104.5		830		24	1.27	1 U				17	97	1	138	119
T175001		08/16	1645	9.0	8.9	14.7	7.1	147	87.4	89.0	4.2			64	3.53	4				125	221	120	627	1272
M109	10.9	08/16	1840	9.6	9.8	16.5	6.7	63	100.0	98.3		835	31	24	1.29	3	98	47	3	32	16	2	129	152
T103001		08/16	1858	8.2	8.1	15.9	6.8	122	82.4	82.6	1	1			3.42	5				29	89	28	24	311
DUVALL			24-hr.			19.0	7.6	560			0.23		35	183	36	42	360	215	16	18500 J	4580	3260 J	338	152
M098R	9.8	08/16	1920	9.8	9.7	16.5	7.0	63	98.8	100.4		838	29	24	1.29	2	68	43	2	27	19	2	132	148
M098L	9.8	08/16	1915		9.9	16.5	6.9	63	100.9			838			1.29	1				23	18	1	128	191
T067004		08/16	2100		9.7	15.2	6.9	92	97.1		3				2.92	1				35	51	8	418	659
M058L	5.8	08/16	2015	10.5	9.4	16.8	6.9	64	96.5	108.2		845		25	1.33	2				28	17	2	146	146
M027R	2.7	08/16	2120	9.9	9.2	17.2	7.0	67	96.0	102.8		860	28	25	2.08	6	58	42	5	32	13	2	131	151
B01		08/16	2300																			1 U		

Appendix A-2. (continued).

Station Number	River Mile	Date	Time	COD mg/L	TOC mg/L	BOD_5 mg/L	BOD_5-NI mg/L	BOD_{20} mg/L	F.coli org/100	Entero org/100	% Kleb. %	Chl *a*. mg/m^3	Pheo *a* mg/m^3
M444020L		08/15	0850						47				
M444O2OR		08/15	0840		3.66	2.0 J			51				
NO.BEND		08/15	24-hr.	24		4 J			5				
M444012C		08/15	0950		2.94		3.4 J		35				
M453000C		08/15	1025		1.83				10				
M449003C		08/15	1038		2.71				16				
M423R	42.3	08/15	1128	4.0U	2.32	2.2 J			33	7	0	0.1 L	0.1 L
M423C	42.3	08/15	1122										
M423L	42.3	08/15	1117						28				
WEYCO	41.6	08/15	24-hr.	22		4 U			5				
M412R	41.2	08/15	1200	4.0U	2.05	2.2 J			40		7		
M412C	41.2	08/15	1155										
M412L	41.2	08/15	1150										
T411005		08/15	1205	6.5	2.71	2.2 J			1100		0		
SNOQWWT	40.8			158		23 J			22				
M407R	40.7	08/15	1300	4.0U	2.92		2.8 J		27	7	0	0.1 U	0.1 U
M407C	40.7	08/15	1305										
M407L	40.7	08/15	1310						27				
M397R	39.7	08/15	1402						40	1 U			
T39600		08/15	1416		5.06	2.2 J			10	2			
M373C	37.3	08/15	1530		2.19	2.2 J			37	3		0.1 U	0.1 U
M373L	37.3	08/15	1535										
M373R	37.3	08/15	1540										
T36200		08/15	1610		3.26	2.2 J			77	19			
M3535	35.4	08/15	1630		1.86				18			0.1 U	0.1 U
M3535RD	35.4	08/15	1635		2.56				13			0.1 U	0.1 U
T39600D		08/15	1418						11	3			
M412F		08/15	2030										
B44		08/15	2035										
M3535	35.4	08/16	0910										
M326	32.6	08/16	0950		2.50	2.2 J			130				
T312004		08/16	1028		7.05		2.2 J		240				
M279	27.9	08/16	1220		2.45				140			0.1 U	0.1 U
T27200		08/16	1250	13.8	4.04		2.2 J		240				
M251R	25.1	08/16	1340		2.69			2 J	88	5		0.1 U	0.1 U
M251L	25.1	08/16	1335						130				
T249		08/16	1430		2.56	2.2 J			15	6			
M2301L	23.0	08/16	1535						84				
M23O1C	23.0	08/16	1539										
M2301R	23.0	08/16	1542		2.33				55			0.1 U	0.1 U
T213017		08/16	1723		4.15	2.2 J			95				
M203	20.3	08/16	1627	5.5	2.18				67				
T175001		08/16	1645	17.7	6.77		2.2 J		2000				
M109	10.9	08/16	1840	7.0	2.23		2.2 J		130		4	0.1 U	0.1 U
T103001		08/16	1858	13.2	6.66	2.2 J			80				
DUVALL				152		38 J			9300				
M098R	9.8	08/16	1920	4.0U	1.76			1.7J	80		3	0.1 U	0.1 U
M098L	9.8	08/16	1915		1.65								
067004		08/16	2100		5.36	2.2 J			360				
M058L	5.8	08/16	2015		3.11				290			0.1 U	0.1 U
M027R	2.7	08/16	2120	4.0U	3.11			2 J	130			0.1 U	0.1 U
B01		08/16	2300										

Appendix A-2. (continued).

* = Station coding: R:right bank, L:left bank, C:center, F:filtered, B:blank, M:mainstem, T:tributary, D:duplicate.

Sample qualifiers:

U	=	below detection limit indicated
J or E	=	estimated value
DO1	=	Dissolved oxygen by membrane probe
DO2	=	Dissolved oxygen by Winkler titration

Appendix A-3. Snoqualmie River data collected on September 5 - 6, 1989 (Survey #3 of 4) as part of the Snoqualmie River low flow study.

Station Number*	River Mile	Date	Time	D.O.2 mg/L	Temp °C	pH s.u.	Cond. umhos	DOSat2 %	Flow cfs	Staff cfs	Hard. mg/L	Alk. mg/L	Cl- mg/L	TSS mg/L	Solids mg/L	TNVS mg/L	TNVSS mg/L	NH_3-N ug/L	TP ug/L	SP-P ug/L	NO_2+_3-N ug/L	TN-N ug/L
M444020L		09/05	0820		11.9	6.9	75			161			1.34	2	99	44	1	10 U	6	4	264	
M444020R		09/05	0813	9.8	11.9	6.9	75	92.1		161	37	32	1.35	2				11	6	3	259	202
NO.BEND			24-hr.		17.1	7.2	288		0.37		57	72	26	60	100	90	10	210	5900	5000	1200	
M444012C		09/05	0945	10.2	12.1	6.9	79	96.3	163	163	35	34	1.47	1	53	33	2	11	19	14	259	201
M453000C	45.3	09/05	1015	10.3	13.9	6.8	32	101.2		274			0.75	1				10 U	5		57	
M449003C		09/05	1030	10.1	13.7	6.8	43	98.8		182			0.71	1				10 U	2		149	
M423R	42.3	09/05	1100	10.1	13.2	7.0	49	97.7		615	22	20	0.91	2	34	26	1	10 U	5	4	119	90
M423C	42.3	09/05	1105		13.5	6.9	49			615												
M423L	42.3	09/05	1110	9.9	13.5	6.8	50	96.4		615			0.90	2				25	7	3	124	
WEYCO	41.7		24-hr.		19.5	7.3	141		0.009		58	62	7					40	50	50	20	
M412R	41.2	09/05	1150	9.9	13.8	6.8	50	97.0		615	21	20	1.00	1	34	26	1	13	6	3	123	100
M412C	41.2	09/05	1155		13.8	6.9	50			615												
M412L	41.2	09/05	1200		13.8	6.9	50			615												
T411005		09/05	1219	10.2	14.4	7.1	95	101.3	1.3				2.33	3				24	14	5	344	357
SNOQWWTP	40.8	09/05	24-hr.		18.6	7.7	333		0.41		52	88	25	100	280	88	11	330	5900	3300	2800	
M407R	40.7	09/05	1300	10.1	14.1	6.9	50	99.6		618	21	20	0.98	2	87	20	1	12	13	10	140	343
M407C	40.7	09/05	1305		14.0	6.9	50			618												
M407L	40.7	09/05	1310	10.0	14.1	6.8	50	98.6		618			0.93	1				23	6	3	137	
M407D	40.7	09/05	1300							618												
M397R	39.7	09/05	1420	10.8	14.4	7.5	50	106.1		618			0.95	3				11	8	4	128	
T39600		09/05	1430	11.0	13.7	7.6	145	105.9	28				1.63	2				42	40	28	397	561
M373C	37.3	09/05	1525	11.3	15.4	7.3	54	112.9		646		22	0.98	1	39	24	2	12	10	6	129	143
M373D	37.3	09/05	1530	11.3	15.4	7.4	53	112.9		646	23	22	0.99	2				12	21	6	158	373
T36200		09/05	1711	10.2	20.6	9.0	89	113.8		12			5.44	3				13	9	5	100	249
M3535	35.4	09/05	1604	11.4	16.2	7.3	55	115.8		658	23	23	1.09	4	63	36	2	10	9	5	118	90
M323	32.3	09/05	1627	10.7	16.4	7.2	56	109.6		658			1.15	3				13	8	5	118	103
T312004		09/05	1751	9.3	14.6	7.4	128	91.7	6.5				3.05	3				28	52	40	708	1079
B44		09/05	1800											1 U				10 U 5		2	20	50
M323	32.3	09/06	0840		14.0	7.0	56			658												
M279	27.9	09/06	0953	9.9	14.1	7.1	58	96.5		690	23	24	1.17	1 U				18 14		6	148	165
T27200		09/06	1024	11.9	12.7	7.6	101	112.4	3.70			43	1.79	1				23		21	9	281330
M251R	25.1	09/06	1105	10.1	15.7	7.2	58	101.9		696	26	24	1.21	1 U		62	30	2 13		11	3	131126
M251L	25.1	09/06	1110		16.0	7.1	60			696			1.20	1 U				14 11		3	127	172
T249		09/06	1147	11.4	12.7	7.4	56	107.7		158		22	0.86	1 U				10 U 2		3	127	86
M2301L	23.0	09/06	1305		16.1	7.2	61			854			1.14	1 U				20 8		14	125	324
M23O1C	23.0	09/06	1310		15.8	7.3	59			854												
M2301R	23.0	09/06	1255	10.6	15.8	7.4	57	107.1		854	25	24	1.19	1 U		100	52	3 10 U		8	5	145196
T213017		09/06	1214	10.8	11.4	7.4	99	99.1	2.9			39	1.90	1 U				17 24		14	618	713
M1825	18.3	09/06	1330	10.4	16.1	7.1	59	105.7		857		24	1.19	1 U				20 11		5	144	150
M1825D	18.3	09/06	1335							857												
T175001		09/06	1350	9.4	14.1	7.4	168	91.5	4.50			69	3.62	66				246		2900	81	7631849
M147R	14.7	09/06	1435	10.0	16.5	7.2	63	102.5		862	26	25	1.23	2		78	32	3 20		19	13	166430
M147L	14.7	09/06	1440			7.3	61			862			1.20	1				18		11	4	145
M107	10.7	09/06	1545		16.4	7.3	56			862	28	25	1.22	2		150	76	4 25		11	5	147188
M107D	10.7	09/06	1550	9.8	16.4	7.2	56	100.2		862	25	25	1.24	1				16		11	4	146116
DUVALL	10.6		24-hr.		19.2	7.6	492		0.26		37	144	36	140		230	150	31 9700		11000	7800	190
M105R	10.5	09/06	1625							863												
T103001		09/06	1640	8.4	15.4	7.2	123	84.1	0.90				2.44	7				41	68	20	37	382
M10	10.0	09/06	1649							863												
M098R	9.8	09/06	1657	9.8	16.5	7.2	56	100.4		864	26	25	1.21	3		82	26	5 26	14	8	145	163
M098L	9.8	09/06	1653		16.5					864			1.22	1				22	16	7	144	
T06700		09/06	1745	10.3	13.8	7.2	97	99.6	5.60				2.63	1				26	29	10	456	574
M058	5.8	09/06	1815	9.9	16.3	7.1	59	101.0		870		25	1.22	2				22	14	7	162	208
M027R	2.7	09/06	1940	9.7	16.7	7.3	60	99.8		870	28	25	1.23	3		150	1	3 31	19	6	140	216
MO27L	2.7	09/06	1950	9.8	16.7	7.3	60	100.8		870			1.27	1	U			25	17	6	153	375
B01		09/06	2300										0.10					11	4	1	15	64

Appendix A-3. (continued).

Station Number*	River Mile	Date	Time	COD mg/L	TOC mg/L	BOD_5 mg/L	BOD_5-NI mg/L	BOD_{20} mg/L	F.Coli org/100	Entero org/100	% Kleb. %	Chl *a*. mg/m^3	Pheo *a* mg/m^3
M444020L		09/05	0820						18				
M444020R		09/05	0813		3.36	2			13				
NO.BEND		09/05	24-hr.	81		35 J			25				
M444012C		09/05	0945		2.26		2 U		19	8			
M453000C	45.3	09/05	1015		1.84				8				
M449003C		09/05	1030		2.68				15				
M423R	42.3	09/05	1100	8	2.03				14	3	0	0.1 U	0.1 U
M423C	42.3	09/05	1105										
M423L	42.3	09/05	1110	8					13				
WEYCO	41.7		24-hr.	23		4 U			7				
M412R	41.2	09/05	1150	5	2.47				7		0		
M412C	41.2	09/05	1155										
M412L	41.2	09/05	1200										
T411005		09/05	1219	12	4.51	2 U			730		0		
SNOQWWTP	40.8		24-hr.	189		56	24		10		0		
M407R	40.7	09/05	1300	7	2.06		2 U		10	2		0.1 E	0.1 E
M407C	40.7	09/05	1305										
M407L	40.7	09/05	1310	7					15	3			
M407D		09/05	1300						14	6			
M397R	39.7	09/05	1420						18				
T39600		09/05	1430	9	5.39				7				
M373C	37.3	09/05	1525		2.11				9	5		0.1 U	0.1 U
M373D	37.3	09/05	1530		1.85	2 U			12				
T36200		09/05	1711	11	3.57				35	7			
M3535	35.4	09/05	1604		2.47				13	1		0.1 U	0.1 U
M323	32.3	09/05	1627		2.54				120				
T312004		09/05	1751	13	5.50				290				
B44		09/05	1800		0.31				1 U				
M323	32.3	09/06	0840										
M279	27.9	09/06	0953		3.23				96			0.1 U	0.1 U
T27200		09/06	1024		5.63				140				
M251R	25.1	09/06	1105	6	2.27		2 U		92	6		0.1 U	0.1 U
M251L	25.1	09/06	1110						60				
T249		09/06	1147		2.54				11	1 U			
M2301L	23.0	09/06	1305						52				
M23O1C	23.0	09/06	1310										
M2301R	23.0	09/06	1255	6	3.38				41				
T213017		09/06	1214		5.37				36				
M1825	18.3	09/06	1330		2.11				45				
M1825D	18.3	09/06	1335						33	1 U			
T175001		09/06	1350	26	8.47				12000				
M147R	14.7	09/06	1435	6	2.34				39	1		0.1 U	0.1 U
M147L	14.7	09/06	1440		2.63				33				
M107	10.7	09/06	1545	6	3.07				33	2		0.1 U	0.1 U
M107D	10.7	09/06	1550		3.50				51				
DUVALL	10.6	09/06	24-hr.	152			25		50000				
M105R	10.5	09/06	1625						31				
T103001		09/06	1640	11	6.31				20				
M10	10.0	09/06	1649						31				
M098R	9.8	09/06	1657	6	3.16		2 U		47	1		0.1 U	0.1 U
M098L	9.8	09/06	1653						31				
T06700		09/06	1745	10	5.00				180				
M058	5.8	09/06	1815	8	2.45				63			0.1 U	0.1 U
M027R	2.7	09/06	1940	9	2.20		2 U		55			0.1 U	0.1 U
MO27L	2.7	09/06	1950		2.77				48				
B01		09/06	2300		0.44				1 U	1 U			

Appendix A-3. (continued).

* = Station coding: R:right bank, L:left bank, C:center, F:filtered, B:blank, M:mainstem, T:tributary, D: duplicate

Sample qualifiers:

U =below detection limit indicated
J or E=estimated value
DO1 =Dissolved oxygen by membrane probe
DO2 =Dissolved oxygen by Winkler titration

Appendix A-4. Snoqualmie River data collected on September 26 - 27, 1989 (Survey #4 of 4) as part of the Ecology low flow study.

Station Number*	River Mile	Date	Time	D.O.2 mg/L	D.O.1 mg/L	Temp °C	pH s.u.	Cond. umhos	DOSat1 %	DOSat2 %	Flow cfs	Staff cfs	Hard. mg/L	Alk. mg/L	Cl- mg/L	TSS mg/L	Solids mg/L	TNVS mg/L	TNVSS mg/L	NH_3-N µg/L	TP µg/L	SP-P µg/L	NO_2+_3-N µg/L	TN-N µg/L
M444020L		09/26	0810	9.8		11.3	7.0	84		90.9		113			1.59	4	57	53	2	10 U	14	4	270	
M444020R		09/26	0815	9.8		11.3	7.0	85		90.9		113	40	35	1.58	2				15	31	4	264	358
NO.BEND						16.2	7.4	265			0.36		58	68	24	160	400	180	4	660	6000	2500	290	
M444012C		09/26	0925	10.1		11.5	7.2	89		94.0	114	114	39	36	1.62	2	40	52	1	10	17	9	245	350
M444012D		09/26										114												
M453000C		09/26	0945	10.3		13.1	7.4	39		99.4			183		1.09	4				10 U	6		66	
M449003C		09/26	1003	10.1		12.8	7.3	57		96.8		102			1.07	2				10	8		178	
M423R	42.3	09/26	1025	9.8		13.2	7.5	62		94.3		430	26	24	1.34	2	40	36	1	10	8	4	144	195
M423C	42.3	09/26	1029			13.2	7.4	62				430												
M423L	42.3	09/26	1032	9.8		13.2	7.2	62		94.3		430			1.27	2				21	10	4	143	
WEYCO	41.7					17.9	7.3	146			0.004		58	61	8	1 U	130	78	1	80	80	10	10	
M412R	41.2	09/26	1110	9.4		13.7	7.3	63		91.9		430	27	25	1.34	2	50	44	1	17	10	4	128	204
M412C	41.2	09/26	1117			13.5	7.1	62				430												
M412L	41.2	09/26	1125			13.5	7.1	62				430												
T411005		09/26	1138	9.6		13.1	7.1	97		92.6	1.2				2.19	2				10	19	4	295	453
SNOQWWTP	40.8					17.4	7.5	325			0.36		51	89	30	44	350	180	1	550	7100	3700	2500	
M407R	40.7	09/26	1220	9.5		13.8	7.2	64		93.0		433	31	24	1.32	3	41	31	1	31	22	8	148	207
M407C	40.7	09/26	1215			13.9	7.1	61				433												
M407L	40.7	09/26	1209	9.4		14.0	7.1	61		92.5		433			1.32	2				14	14	4	135	
M397R	39.7	09/26	1353	10.1		13.9	7.4	64		98.1		433			1.33	1				22	17	6	139	
M397RD	39.7	09/26	1354	10.0		13.9	7.2	62		97.2		433			1.33	1				17	19	7	153	
T39600		09/26	1405	11.1		12.3	7.6	152		104.1	25				1.77	3				25	54	22	357	501
M373C	37.3	09/26	1455	11.0		14.3	7.5	70		107.7		458		27	1.41	2	41	37	1	14	17	7	136	191
T36200		09/26	1519	11.2		15.5	9.4	95		112.6		12			6.01	1				12	14	5	36	128
M3535	35.4	09/26	1643	10.9		14.5	7.4	72		107.2		470	29	28	1.45	3	71	41	2	12	16	6	131	214
M323	32.3	09/26	1700	10.8		14.2	7.3	71		105.5		470			1.54	3				12	13	5	147	229
M323F		09/26										470								14	8		142	
T312004		09/26	1550	10.2		12.4	7.5	159		95.3	8	6.8			0.34	3				35	71	41	746	854
BO1F		09/27	2110																			5		
B40F		09/26																				2		
B35		09/26													0.10					10 U	4	3	10	50
M323	32.3	09/27	0755			13.6	6.8	70				470												
M279	27.9	09/27	0844	9.9		14.2	7.5	65		96.7		479	32	28	1.49	1 U				40	18	7	153	346
T27200		09/27	0900	9.6		12.9	7.3	102		91.1	3.4	3.7		41	2.14	4				43	24	9	443	836
M251R	25.1	09/27	0935	10.1		14.2	7.3	75		98.6		482	32	30	1.61	1 U	81	55	1	20	14	4	164	530
M251L	25.1	09/27	0940	10.2		14.2	7.3	74		99.6		482			1.55	1 U				21	10	4	156	362
T249		09/27	1034	10.8		13.3	7.6	56		103.4		127		21	1.02	1 U				12	3	3	114	189
M2301L	23.0	09/27	1158	10.7		14.7	7.4	71		105.1		609			1.46	1 U				14	10	4	128	326
M23O1C	23.0	09/27	1205			14.4	7.4	71				609												
M2301R	23.0	09/27	1210	10.5		14.8	7.4	70		103.8		609	32	28	1.47	1 U	66	46	1	25	10	4	145	252
T213017		09/27	1119	10.7		11.8	7.5	101		99.0		2.9		40	1.91	1 U				21	30	16	569	883
M1825	18.3	09/27	1220	10.4		14.8	7.4	74		102.8		612		29	1.49	1 U				18	12	4	146	283
M1825D	18.3	09/27	1222	10.3		14.8	7.4	71		101.3		612		29	1.51	1 U				18	10	3	141	346
T175001		09/27	1244	9.1		13.3	7.4	169		87.0	3.8			68	3.88	48				330	269	117	602	1456
M147R	14.7	09/27	1316	10.2		15.2	7.4	74		101.7		616	31	29	1.55	1 U	120	72	1	26	26	9	139	380
M147L	14.7	09/27	1323			15.4	7.3	73				616			1.55	1 U				46	20	7	128	
SNOQ5**	14.7											616								53	24		123	
M107	10.7	09/27	1430	10.5		15.2	7.3	70		104.2		616	31	29	1.53	1 U	70	49	1	21	12	5	136	328
DUVALL	10.6					18.4	7.6	474			0.23		40	137	33	101	445	215	2	13500	16000	8800	105	
T104		09/27	1451			14.5					0.4					6						24		
T103001		09/27	1456	8.6		14.1	7.1	126		83.7	0.6				2.50	4				47	130	20	26	366
M098R	9.8	09/27	1510	10.4		15.2	7.4	72		103.7		618	30	29	1.54	1 U	77	43	1	23	16	7	129	319
M098L	9.8	09/27	1517	10.2		15.2	7.5	73		101.2		618			1.58	4				23	16	6	130	
SNOQ6**	9.8											618								31	12		120	
T06700		09/27	1601	9.6		13.5	7.3	101		92.2	8.9				2.76	14				42	39	11	517	1044
M058	5.8	09/27	1619	10.7		15.3	7.5	74		106.9		627		30	1.62	1 U				32	14	6	130	702
M058D	5.8	09/27	1620									627												
M027R	2.7	09/27	1728	10.1		15.5	7.3	76		101.3		635	31	30	1.64	1 U	61	28	1	27	17	5	115	997
M027RF	2.7	09/27	2115									635								24	7		100	
M027L	2.7	09/27	1735	10.2		15.5	7.4	72		102.3		635			1.62	1 U				32	19	6	115	304
B020		09/27	2100												0.10					10	1	2	10	79

Appendix A-4. (continued).

Station Number*	River Mile	Date	Time	COD mg/L	TOC mg/L	BOD_5 mg/L	BOD_5-NI mg/L	BOD_{20} mg/L	F.Coli org/100	Entero org/100	% Kleb. %	Chl *a*. mg/m^3	Pheo *a* mg/m^3
M444020L		09/26	0810						40				
M444020R		09/26	0815		3.60		2 U		27				
NO.BEND				249		64			1400				
M444012C		09/26	0925		5.72			4	35	20			
M444012D		09/26							26	21			
M453000C		09/26	0945		2.30				10				
M449003C		09/26	1003		3.02				47				
M423R	42.3	09/26	1025	5.4	4.87				32	15	4	0.1 U	0.1 U
M423C	42.3	09/26	1029										
M423L	42.3	09/26	1032	7.9					41				
WEYCO	41.7			20		6 J			4				
M412R	41.2	09/26	1110	4.9	5.42		2 U		27		17		
M412C	41.2	09/26	1117										
M412L	41.2	09/26	1125										
T411005		09/26	1138	11.0	8.26		2 U		3500 E				
SNOQWWTP	40.8			169		21			20				
M407R	40.7	09/26	1220	6.5	4.64			4	29	35	18	0.1 U	0.1 U
M407C	40.7	09/26	1215										
M407L	40.7	09/26	1209	5.8					44	41			
M397R	39.7	09/26	1353						28	24			
M397RD	39.7	09/26	1354						33	25			
T39600		09/26	1405	8.5	8.90		2 U		6	19			
M373C	37.3	09/26	1455		4.43		2 U		26	4		0.1 U	0.1 U
T36200		09/26	1519		5.52		2 U		8	37			
M3535	35.4	09/26	1643		4.09				16	4		0.1 U	0.1 U
M323	32.3	09/26	1700		4.61		2 U		29				
M323F		09/26											
T312004		09/26	1550	8.7	5.66		2 U		96				
BO1F		09/27	2110										
B40F		09/26											
B35		09/26			2.26				1 U				
M323	32.3	09/27	0755										
M279	27.9	09/27	0844		5.34		2 U		220			0.1 U	0.1 U
T27200		09/27	0900		9.45		2 U		430				
M251R	25.1	09/27	0935	7.2	5.47			2 U	88	17 E		0.1 U	0.1 U
M251L	25.1	09/27	0940						70				
T249		09/27	1034		4.73			2 U	29	1 U			
M2301L	23.0	09/27	1158						49				
M2301C	23.0	09/27	1205										
M2301R	23.0	09/27	1210		5.18		2 U		48			0.1 U	0.1 U
T213017		09/27	1119		6.57		2 U		20				
M1825	18.3	09/27	1220		5.77				45				
M1825D	18.3	09/27	1222		5.05				55				
T175001		09/27	1244	26.6	12.00		2 U		18000				
M147R	14.7	09/27	1316	6.8	6.55		2 U		220	24 E		0.1 U	0.1 U
M147L	14.7	09/27	1323		5.41				270				
SNOQ5**	14.7								200				
M107	10.7	09/27	1430	4.0 U	5.25		2 U		220	19 E		0.1 U	0.1 U
DUVALL	10.6			212		54			1700				
T104		09/27	1451						57				
T103001		09/27	1456	13.8	9.06		2 U		110				
M098R	9.8	09/27	1510	7.3	2.61			2 U	160	31 E		0.1 U	0.1 U
M098L	9.8	09/27	1517		5.04				200				
SNOQ6**	9.8								170				
T06700		09/27	1601	12.0	7.56		2 U		1200				
M058	5.8	09/27	1619	6.6	5.03				83			0.1 U	0.1 U
M058D	5.8	09/27	1620						100	1 U			
M027R	2.7	09/27	1728	8.2	5.51			2 U	100	8 E		0.1 U	0.1 U
M027RF	2.7	09/27	2115										
MO27L	2.7	09/27	1735		5.52				140				
B020		09/27	2100		3.64				1 U				

Appendix A-4. (continued).

* = Station coding: R:right bank, L:left bank, C:center, F:filtered, B:blank, M:mainstem, T:tributary, D:duplicate
** = Sample taken by Tulalip Tribes staff at location indicated-see Tulalip Tribes, 1988.

Sample qualifiers:

U	=	below detection limit indicated
J or E	=	estimated value
DO1	=	Dissolved oxygen by membrane probe
DO2	=	Dissolved oxygen by Winkler titration

Appendix A-5. Water quality field observations taken during cross-sectional surveys, August 1989 as part of the Ecology Snoqualmie River low flow study.

River Mile	Upper Depth(ft)	Lower Depth(ft)	Temp °C	Cond. umhos/cm	pH S.U.	D.O. mg/L	D.O.Sat %
2.87	0.00	0.50	20.56	57	6.92	9.36	104.2
2.87	0.50	1.50	20.52	57	6.89	9.36	104.1
2.87	1.50	2.50	20.49	57	6.88	9.36	104.0
2.87	2.50	3.50	20.47	58	6.87	9.37	104.1
2.87	3.50	4.50	20.46	58	6.87	9.37	104.1
2.87	0.00	0.50	20.39	56	6.92	9.41	104.4
2.87	0.50	1.50	20.36	57	6.89	9.43	104.5
2.87	1.50	2.50	20.34	57	6.88	9.41	104.3
2.87	2.50	3.50	20.34	58	6.87	9.44	104.6
2.87	3.50	4.50	20.33	58	6.87	9.44	104.6
2.87	0.00	0.50	20.30	57	6.85	9.44	104.5
2.87	0.50	1.50	20.27	57	6.86	9.44	104.4
2.87	1.50	2.50	20.27	58	6.86	9.44	104.4
5.30	0.00	0.50	21.17	57	6.92	9.40	105.9
5.30	0.50	1.50	20.08	58	6.91	9.40	103.6
5.30	1.50	2.50	20.03	58	6.90	9.46	104.2
5.30	2.50	3.50	20.00	58	6.90	9.46	104.1
5.30	0.00	0.50	19.96	58	6.93	9.44	103.8
5.30	0.50	1.50	19.91	58	6.91	9.48	104.1
5.30	1.50	2.50	19.90	58	6.89	9.49	104.2
5.30	2.50	3.50	19.87	58	6.89	9.50	104.3
5.30	3.50	4.50	19.86	58	6.89	9.51	104.4
5.30	0.00	0.50	19.89	57	6.94	9.43	103.6
5.30	0.50	1.50	19.87	57	6.92	9.47	104.0
5.30	1.50	2.50	19.87	57	6.91	9.47	104.0
6.64	0.00	0.50	19.30	59	6.90	9.42	102.2
6.64	0.50	1.50	19.26	60	6.89	9.41	102.0
6.64	1.50	2.50	19.22	60	6.89	9.48	102.7
6.64	0.00	0.50	19.12	56	6.89	9.44	102.1
6.64	0.50	1.50	19.07	57	6.88	9.47	102.3
6.64	1.50	2.50	19.04	58	6.86	9.51	102.7
6.64	0.00	0.50	19.21	57	6.89	9.53	103.2
6.64	0.50	1.50	19.11	58	6.88	9.53	103.0
6.64	1.50	2.50	19.10	58	6.88	9.54	103.1
9.40	0.00	0.50	18.17	58	6.78	9.39	99.6
9.40	0.50	1.50	18.17	58	6.82	9.27	98.3
9.40	1.50	2.50	18.17	58	6.83	9.13	96.8
9.40	0.00	0.50	18.16	58	6.86	9.12	96.7
9.40	0.50	1.50	18.16	58	6.85	9.07	96.2

Appendix A-5. Continued.

River Mile	Upper Depth(ft)	Lower Depth(ft)	Temp °C	Cond. umhos/cm	pH S.U.	D.O. mg/L	D.O.Sat %
9.40	1.50	2.25	18.17	58	6.84	9.08	96.3
9.40	2.25	2.60	18.17	58	6.82	9.11	96.6
9.40	0.00	0.50	18.13	58	6.83	9.10	96.5
9.40	0.50	1.50	18.13	58	6.75	9.10	96.5
9.40	1.50	2.50	18.13	58	6.70	9.10	96.5
9.40	0.00	0.50	18.13	58	6.78	9.09	96.3
9.40	0.50	1.50	18.13	58	6.74	9.09	96.3
9.40	1.50	2.50	18.13	58	6.71	9.13	96.8
9.40	2.50	3.50	18.13	58	6.68	9.13	96.8
10.50	0.00	0.50	18.34	59	6.88	9.31	99.1
10.50	0.00	0.50	18.32	58	6.87	9.26	98.5
10.50	0.00	0.50	18.32	58	6.86	9.26	98.5
10.50	0.50	1.50	18.31	58	6.85	9.23	98.2
10.50	0.00	0.50	18.33	58	6.85	9.22	98.1
10.50	0.50	1.50	18.33	58	6.91	9.25	98.4
10.50	1.50	2.50	18.33	58	6.94	9.25	98.4
10.50	0.00	0.50	18.34	58	6.90	9.24	98.4
10.50	0.50	1.50	18.33	58	6.90	9.28	98.8
10.50	1.50	2.50	18.33	58	6.94	9.28	98.8
10.50	0.00	0.50	18.37	58	6.91	9.27	98.7
10.50	0.50	1.50	18.37	57	6.91	9.30	99.1
11.70	0.00	0.50	19.01	56	6.99	9.44	101.9
11.70	0.00	0.50	19.00	56	7.03	9.41	101.5
11.70	0.00	0.50	18.99	56	7.03	9.45	101.9
11.70	0.00	0.50	18.98	56	7.03	9.45	101.9
11.70	0.00	0.50	18.99	57	7.01	9.47	102.1
13.55	0.00	0.50	17.73	59	6.58	9.45	99.4
13.55	0.50	1.50	17.72	59	6.58	9.43	99.1
13.55	0.00	0.50	17.72	59	6.61	9.34	98.2
13.55	0.50	1.50	17.71	59	6.58	9.31	97.8
13.55	0.00	0.50	17.71	59	6.64	9.28	97.5
13.55	0.50	1.50	17.69	58	6.70	9.31	97.8
13.55	1.50	2.50	17.71	58	6.71	9.37	98.5
13.55	0.00	0.50	17.71	58	6.61	9.33	98.0
13.55	0.50	1.50	17.71	58	6.60	9.34	98.2
13.55	1.50	2.50	17.71	58	6.59	9.37	98.5
13.55	2.50	3.50	17.72	59	6.59	9.37	98.5
15.40	0.00	0.50	18.69	58	6.64	9.58	102.7
15.40	0.00	0.50	18.67	58	6.62	9.53	102.1
15.40	0.00	0.50	18.67	56	6.62	9.53	102.1
16.70	0.00	0.50	18.94	58	6.75	9.81	105.7

Appendix A-5. Continued.

River Mile	Upper Depth(ft)	Lower Depth(ft)	Temp °C	Cond. umhos/cm	pH S.U.	D.O. mg/L	D.O.Sat %
16.70	0.50	1.50	18.92	58	6.74	9.79	105.5
16.70	1.50	2.50	18.92	58	6.72	9.82	105.8
16.70	2.50	3.50	18.91	58	6.73	9.82	105.8
16.70	3.50	4.50	18.91	58	6.73	9.83	105.9
16.70	0.00	0.50	18.89	58	6.74	9.80	105.5
16.70	0.50	1.50	18.89	58	6.72	9.81	105.6
16.70	1.50	2.50	18.88	58	6.72	9.81	105.6
16.70	0.00	0.50	18.88	58	6.76	9.81	105.6
18.05	0.00	0.50	18.75	56	6.77	9.82	105.4
18.05	0.00	0.50	18.69	56	6.80	9.73	104.3
18.05	0.00	0.50	18.71	56	6.80	9.78	104.9
19.40	0.00	0.50	18.11	57	6.72	9.70	102.8
19.40	0.50	1.50	18.11	57	6.74	9.70	102.8
19.40	0.00	0.50	18.13	57	6.77	9.72	103.1
19.40	0.50	1.50	18.11	57	6.76	9.69	102.7
19.40	1.50	2.50	18.12	57	6.76	9.70	102.8
25.30	0.00	0.50	17.29	56	6.69	9.42	98.2
25.30	0.50	1.50	17.26	57	6.68	9.34	97.4
25.30	1.50	2.50	17.25	57	6.68	9.35	97.4
25.30	0.00	0.50	17.26	56	6.72	9.34	97.4
25.30	0.50	1.50	17.26	56	6.69	9.35	97.5
25.30	1.50	2.50	17.23	57	6.69	9.35	97.4
25.30	0.00	0.50	17.38	56	6.71	9.28	97.0
25.30	0.50	1.50	17.34	56	6.70	9.30	97.1
25.30	1.50	2.50	17.32	56	6.69	9.32	97.3
25.30	2.50	3.50	17.30	57	6.67	9.32	97.2
27.10	0.00	0.50	16.80	57	6.75	9.62	99.3
27.10	0.50	1.50	16.77	57	6.74	9.59	98.9
27.10	0.00	0.50	16.76	56	6.73	9.51	98.1
27.10	0.50	1.50	16.71	56	6.71	9.56	98.5
27.10	1.50	2.50	16.71	56	6.72	9.56	98.5
27.10	2.50	3.50	16.69	56	6.72	9.57	98.6
27.10	3.50	4.50	16.70	57	6.72	9.57	98.6
27.10	4.50	5.50	16.70	57	6.71	9.60	98.9
27.10	0.00	0.50	16.71	55	6.73	9.52	98.1
27.10	0.50	1.50	16.71	55	6.72	9.56	98.5
27.10	1.50	2.50	16.69	56	6.72	9.57	98.6
28.30	0.00	0.50	17.25	55	6.77	9.70	101.1
28.30	0.00	0.50	17.22	55	6.75	9.65	100.5
28.30	0.00	0.50	17.25	55	6.75	9.64	100.5
31.75	0.00	0.50	18.96	54	6.99	10.18	109.9

Appendix A-5. Continued.

River Mile	Upper Depth(ft)	Lower Depth(ft)	Temp °C	Cond. umhos/cm	pH S.U.	D.O. mg/L	D.O.Sat %
31.75	0.50	1.50	18.92	54	7.03	10.15	109.5
31.75	1.50	2.50	18.89	55	7.03	10.60	114.3
31.75	2.50	3.50	18.88	55	7.02	10.20	109.9
31.75	0.00	0.50	18.89	54	7.06	10.23	110.3
31.75	0.00	0.50	18.89	54	7.03	10.19	109.8
32.80	0.00	0.50	17.78	55	6.89	10.18	107.3
32.80	0.00	0.50	17.74	55	6.97	10.05	105.8
32.80	0.00	0.50	17.73	55	6.97	10.06	105.9
35.30	0.00	0.50	16.64	53	7.25	10.65	109.7
35.30	0.50	1.50	16.61	54	7.26	10.62	109.3
35.30	1.50	2.50	16.58	54	7.25	10.57	108.7
35.30	2.50	3.50	16.58	55	7.25	10.55	108.5
35.30	3.50	4.50	16.54	55	7.22	10.60	108.9
35.30	0.00	0.50	16.60	54	7.25	10.56	108.6
35.30	0.50	1.50	16.58	55	7.25	10.62	109.2
35.30	1.50	2.50	16.55	55	7.25	10.62	109.1
37.80	0.00	0.50	15.10	53	7.20	10.63	106.0
37.80	0.50	1.50	15.08	54	7.20	10.58	105.4
37.80	0.00	0.50	15.04	53	7.20	10.49	104.4
37.80	0.50	1.50	15.05	54	7.20	10.49	104.4
37.80	1.50	2.50	15.02	55	7.19	10.54	104.9
38.30	0.00	0.50	15.54	53	7.23	10.58	106.5
38.30	0.00	0.50	15.38	54	7.22	10.47	105.0

Appendix A-6. Lab data from synoptic surveys near Snoqualmie WWTP.

Station	River Mile	Date	Time	Flow (cfs)	T-N (mg/L)	NO_{23}-N (mg/L)	NH_3-N (mg/L)	T-P (mg/L)	SR-P (mg/L)	Cl (mg/L)	COD (mg/L)	TOC (mg/L)	BOD_5 (mg/L)	BOD_{20} (mg/L)	Chl *a* (ug/L)	TSS (mg/L)	Turbidity (NTU)
1	42.6	8/30	0740	620	0.272	0.160	0.032	0.012	0.003	1.0	5	2.0					
1	42.6	8/30	1500	620	0.087	0.121	0.014	0.010	0.003	1.0	6	2.0	2 U	2 U	BDL	1 U	0.7
5	41.2	8/30	0835	620	0.081	0.119	0.017	0.013	0.002	1.0	7	2.6					
5	41.2	8/30	1530	620	0.112	0.122	0.012	0.008	0.002	1.1	5	2.0	2 U		BDL	3	0.8
6	40.7	8/30	0850	620	0.084	0.120	0.013	0.011	0.003	1.0	6	2.5					
6	40.7	8/30	1545	620	0.116	0.121	0.010U	0.010	0.002	1.0	4	2.5	2 U	2 U	BDL	2	0.8
STP Effluent	R-40.8	8/30	0855	0.15	11.495	3.400	0.520	6.400	4.000	26.1	143	38.3					
STP Effluent	R-40.8	8/30	1605	0.15	6.160	3.750	0.380	5.600	3.600	29.2	144	33.3	12.6		315	81	
Kimball Ck	L-41.1	8/30	1150	1.09	0.506	0.342	0.023	0.039	0.004	2.2	10	4.7					
Kimball Ck	L-41.1	8/30	1400	1.09	0.389	0.342	0.022	0.023	0.004	2.4	10	5.4	2 U			2	
Drain	L-41.8	8/30	0800	1 J	0.546	0.389	0.017	0.011	0.002	1.0	4 U	3.8	2 U				
Log Pond	R-41.6	8/30	1130	0.02J	0.211	0.029	0.028	0.016	0.004	7.2	26	8.8					
Log Pond	R-41.6	8/30	1345	0.02J	0.507	0.021	0.012	0.049	0.004	7.4	26	8.8	2 U				
Seep	R-41.6	8/30	0820		2.662	0.086	1.320	0.224	0.001	1.8	24	11.8					

DATA QUALIFIERS:
- J = Estimated value; value less than method quantification limit.
- U = Compound analyzed for but not detected; value reported is the detection limit.
- BDL = Below detection limit.

Appendix A-6. (Continued) Field data from synoptic surveys near Snoqualmie WWTP.

Station	Date	Time	RM	Flow (cfs)	Temp (deg C)	D.O. (mg/L)	pH	Raw Cond (um/cm)
1	8/29	1201	42.6	660	14.8	10.1	6.97	36
2	8/29	1254	42.3	660	14.6	10.3	7.29	37
3	8/29	1325	41.9	660	14.9	10.3	7.33	37
4	8/29	1412	41.6	660	15.2	10.2	7.29	38
5	8/29	1455	41.2	660	15.1	10.3	7.32	38
6	8/29	1555	40.7	660	15.0	10.2		37
1	8/30	0740	42.6	620	14.0	9.5	6.78	32
2	8/30	0750	42.3	620	14.0	9.5	6.92	36
3	8/30	0755	41.9	620	14.2	9.4	7.05	37
4	8/30	0815	41.6	620	14.3	9.2	7.15	38
5	8/30	0835	41.2	620	14.4	9.2	7.07	38
6	8/30	0850	40.7	620	14.8	9.2	7.11	38
1	8/30	1500	42.6	620	14.3	10.3	7.67	38
2	8/30	1505	42.3	620	14.3	10.2	7.47	38
3	8/30	1514	41.9	620	14.3	10.3	7.4	38
4	8/30	1525	41.6	620	14.3	10.0	7.33	38
5	8/30	1530	41.2	620	14.3		7.21	38
6	8/30	1545	40.7	620	14.3	9.8	7.21	38
Drain	8/30	0800	L-41.8	1 J	10.4	11.3	7.03	55
Seep	8/30	0820	R-41.6	0	13.2	1.4	6.6	104
Pond	8/30	1130	R-41.6	0.02J	20.6	6.0	7.26	133
Pond	8/30	1345	R-41.6	0.02J	20.3	6.0	7.53	138
Kimball Ck	8/30	1150	L-41.1	1.09	14.2	9.3	7.3	74
Kimball Ck	8/30	1400	L41.1	1.09	14.3	10.0	7.43	73
STP	8/30	0855	R-40.8	0.15	20.3	7.7	7.61	275
STP	8/30	1605	R-40.8	0.15	20.1	7.8	7.55	305

Data Qualifiers: J = estimated value; value less than quantification limit.

Appendix A-7. Duvall WWTP - Snoqualmie River low flow study, July 25 - September 6, 1989.

			7/24-25					8/15-16									
Lab Log- :	308095	308096		308094	338400	338407	338408		338401	338403	338409	338411	338413		338404	338406	338414
Numbers:					338425				338402		338410	338412			338405		338415
Sample:	Effluent	Effluent	Effluent	ECO- Ef	Blank	Influent	Influent	Influent	ECO-Inf	STP-Inf	Effluent	Effluent	Ef- Dup	Effluent	ECO- Ef	STP-Ef	RAS
Date:	7/25	7/25	7/26	7/25-26	8/15	8/15	8/15	8/16	8/15-16	8/15-16	8/15	8/15	8/15	8/16	8/15-16	8/15-16	8/16
Time:	1150	1600	1400	1200-1200	1140	1125	1600	1130	1200-1200	1200-1200	1105	1540	1540	1115	1200-1200	1200-1200	1205
Type:	Grab	Grab	Grab	Composite		Grab	Grab	Grab	Composite	Composite	Grab	Grab	Grab	Grab	Composite	Composite	Grab
Field Analyses																	
Average flow (MGD)				0.147											0.152		
pH (S.U.)	7.2	7.2	7.3	7.4		8.5	9.1	8.6	8.7	8.5	7.4	7.4		7.5	7.9	7.9	
Temperature (°C)	19.7	21.2	21.1	6.7		19.5	19.5	19.7	7.2	8.9	18.4	19.4		18.5	6.2	7.0	
Conductivity (umhos/cm)	440	445	472	444		500	685	480	560	539	558	560		562	545	565	
Chlorine Residual (mg/L)																	
Total	1.3	0.7	<0.1								0.2	0.5		<0.1			
Free	0.4	<0.1	<0.1								<0.1	<0.1		<0.1			
Laboratory Analyses																	
Turbidity (NTU)				13					64	46	19	19	19		18	18	
Conductivity (umhos/cm)				428					615	597	557	558	555		569	566	
Alkalinity (mg/L $CaCO_3$)				108					201	201	187	185	185		182	178	
Hardness (mg/L $CaCO_3$)				41					41	43	30	33	38		39	34	
Chloride (mg/L)				40.4					35.7	28.7	35.2	34.7	35.0		35.8	37.0	
Cyanide (ug/L)								4						5			
TS (mg/L)				350					580	470					360	360	
TNVS (mg/L)				180					250	210					210	220	
TSS (mg/L)				50					180	150	38	36	37		54	47	
TNVSS (mg/L)				12					40	22					14	18	
BOD_5 (mg/L)				14J					LAC	240J					LAC	38J	
Inhib. BOD_5 (mg/L)								200J						43J			
COD (mg/L)				78					495	425	144	151	158		153	156	
TOC (mg/g dry wt)																450	
NH_3-N (mg/L)				1.3					21J	24J	18J	18J	18J		19J	20.4J	
NO_3+NO_2-N (mg/L)				0.66					0.14J	0.16J	0.12J	0.12J	<0.05J		<0.05J	1.4J	
Total-P (mg/L)				2.3					10J	11J	2.8J	3.2J	4.4J		5.9J	6.6J	
Ortho-P (mg/L)				2.6J					5.8J	5.5J	2.9J	2.8J	2.9J		4.4J	3.3J	
% Solids																	0.98
Fecal Coliform (#/100mL)	12000	29									27000JL	8400JL	9300JL				
Antimony (ug/L)				2.0 U	3.0 U				3.0 U						3.0 U		12 U
Arsenic (ug/L)				1.0 U	1.0 UR				1.9 R						1.7 R		18.9
Beryllium (ug/L)				2.0 U	2.0 U				2.0 U						2.0 U		1.0 U
Cadmium (ug/L)				5.0 U	5.0 U				5.0 U						5.0 U		23
Chromium (ug/L)				5.0 U	5.0 U				5.0						5.0 U		63
Copper (ug/L)				15	4.0 U				52.1						23		1320
Lead (ug/L)				3.6 B	12.9				10 B						4.3 B		180
Mercury (ug/L)				0.42	0.06 U				0.33						0.22		17.5
Nickel (ug/L)				20 U	20 U				20 U						20 U		89
Selenium (ug/L)				2.0 U	2.0 U				2.0 U						2.0 U		9.7 J
Silver (ug/L)				0.50 U	0.50 U				0.50 U						1.7		20.2
Thallium (ug/L)				1.0 U	1.0 U				2.0 U						2.0 U		4.0 U
Zinc (ug/L)				66.7 B	7.0 B				104 B						52.2 B		2550

Appendix A-7. (continued).

	9/5-6					9/26-27					
Lab Log- : Numbers :		368252	368253		368248	398182	398188	398183		398191	398194
Sample:	Influent	Effluent	Effluent	Effluent	ECO- Ef	Effluent	Ef-Dup	Effluent	Effluent	ECO- Ef	ECO-Ef-Dup
Date:	9/6	9/5	9/5	9/6	9/5-6	9/26	9/26	9/26	9/27	9/26-27	9/26-27
Time:	1325	1130	1555	1300	1145-1145	1110	1110	1510	1130	1115-1115	1115-1115
Type:	Grab	Grab	Grab	Grab	Composite	Grab	Grab	Grab	Grab	Composite	Composite
Field Analyses											
Average flow (MGD)					0.165					0.147	
pH (S.U.)	8.4	7.5	7.3	7.6	7.8	7.3		7.3	7.7	7.9	
Temperature (°C)	19.5	18.8	19.9	18.9	5.4	18.1		18.7	18.4	5.6	
Conductivity (umhos/cm)	445	478	494	485	510	448		484	496	467	
Chlorine Residual (mg/L)											
Total		0.6	0.3	0.7		0.6		1.2	0.3		
Free		0.2	0.1	<0.1		<0.1		<0.1	<0.1		
Laboratory Analyses											
Turbidity (NTU)					28					26	29
Conductivity (umhos/cm)					508					513	515
Alkalinity (mg/L CaCO3)					144					137	137
Hardness (mg/L $CaCO_3$)					37					39	40
Chloride (mg/L)					35.8					37.5	28.7
Cyanide (μg/L)											
TS (mg/L)					230					450	440
TNVS (mg/L)					150					230	200
TSS (mg/L)					140					110	92
TNVSS (mg/L)					31					4	1U
BOD_5 (mg/L)					NR					>22J	>85J
Inhib. BOD_5 (mg/L)					25						
COD (mg/L)					152					207	216
TOC (mg/g dry wt)											
NH_3-N (mg/L)					9.7					14	13
NO_3+NO_2-N (mg/L)					0.19					0.16	0.05
Total-P (mg/L)					11					16	16
Ortho-P (mg/L)					7.8					9.8	7.8
% Solids											
Fecal Coliform (#/100mL)		24000JL	75000JL			2000	1300	1800			
Antimony (μg/L)					3.0 U					3.0 U	3.0 U
Arsenic (μg/L)					1.0 UR					1.0 UR	1.0 UR
Beryllium (μg/L)					2.0 U					2.0 U	2.0 U
Cadmium (μg/L)					5.0 U					5.0 U	5.0 U
Chromium (μg/L)					5.0 U					5.0 U	5.0 U
Copper (μg/L)					26					28	28
Lead (μg/L)					3.9 B					3.9 B	3.6 B
Mercury (μg/L)					0.10					0.25	0.29
Nickel (μg/L)					20 U					20 U	20 U
Selenium (μg/L)					2.0 U					2.0 U	2.0 U
Silver (μg/L)					0.50 U					4.5	3.8
Thallium (μg/L)					1.0 U					1.0 U	1.0 U
Zinc (μg/L)					82.2					105	114

JL estimated - total plate count greater than 200.

LAC laboratory accident.

NR requested but not analyzed.

U indicates compound was analyzed for but not detected at the given detection limit.

J indicates an estimated value.

B This flag is used when the analyte is found in the blank as well as the sample. Indicates possible/probable blank contamination.

R low spike recovery - result may be biased low.

UR indicates compound was analyzed for but not detected at the given detection limit, and the spike recovery was low so the actual detection limit may be higher.

Appendix A-8. Snoqualmie WWTP-Snoqualmie low flow study July 25-September 6, 1989.

	7/25-26				8/15-16				9/5-6								
Lab Log- : Numbers :	308092	308093		308091	338421	338422		338417	368230 368231	368238		368239	Weyco	Town	Falls		
Sample:	Effluent	Effluent	Effluent	ECO- Ef	Effluent	Effluent	Effluent	ECO- Ef	Blank	Influent	Influent	Influent	Influent	Influent	Influent	Influent	Influent
Date:	7/25	7/25	7/26	7/25-26	8/15	8/15	8/16	8/15-16	9/5	9/5	9/5	9/5	9/5	9/5	9/5	9/6	9/6
Time:	1045	1515	1130	1100-1100	0905	1430	0940	0915- **	0910	0920	0930	1350	1430	1430	1430	0925	0930
Type:	Grab	Grab	Grab	Composite	Grab	Grab	Grab	Composite		Grab	Grab	Grab	Grab	Grab	Grab	Grab	Grab
Field Analyses																	
Average flow (MGD)				0.147				0.152									
pH (S.U.)	7.4	7.6	7.8	7.5	7.1	7.1	7.3	7.5		9.7	7.9	7.5	7.2	7.5	7.5	11.3	8.8
Temperature (°C)	27.7	21.1	24.2	7.5	19.7	20.5	19.4	9.2		21.4	17.1	18.0	16.9	17.3	17.8	24.7	21.5
Conductivity (umhos/cm)	335	335	330	340	347	355	348	345		304	390	541	148	558	475	1300	355
Chlorine Residual (mg/L)																	
Total	1.0	1.2			1.1	1.2	1.2										
Free	0.2	0.1			<0.1	<0.1	<0.1										
Laboratory Analyses																	
Turbidity (NTU)				20				19									
Conductivity (umhos/cm)				327				353									
Alkalinity (mg/L $CaCO_3$)				100				83									
Hardness (mg/L $CaCO_3$)				50				55									
Chloride (mg/L)				32.9				30.5									
Cyanide (µg/L)																	
TS (mg/L)				310				350									
TNVS (mg/L)				150				190									
TSS (mg/L)				78				78									
TNVSS (mg/L)				20				14									
BOD_5 (mg/L)				42 J				23 J									
Inhib. BOD_5 (mg/L)																	
COD (mg/L)				138				158									
TOC (mg/gm dry-wt)																	
NH_3-N (mg/L)				1.9				0.48 J									
NO_3+NO_2-N (mg/L)				0.59				3.4 J									
Total-P (mg/L)				4.9				5.8 J									
Ortho-P (mg/L)				2.8 J				3.4 J									
% Solids																	
Fecal Coliform (#/100mL)	3 U	3 U			26	17											
Antimony (µg/L)				2.0 U				3.0 U	3.0 U								
Arsenic (µg/L)				1.0 U				1.0 UR	1.0 UR								
Beryllium (µg/L)				2.0 U				2.0 U	2.0 U								
Cadmium (µg/L)				5.0 U				6.9	5.0 U								
Chromium (µg/L)				5.0 U				6.0	5.0 U								
Copper (µg/L)				20				30	4.0 U								
Lead (µg/L)				3.8 B				3.8	1.0 U								
Mercury (µg/L)				0.06 U				0.06 U	0.06 U								
Nickel (µg/L)				20 U				20 U	20 U								
Selenium (µg/L)				2.0 U				2.0 U	2.0 U								
Silver (µg/L)				0.50 U				2.2	0.50 U								
Thallium (µg/L)				1.0 U				2.0 U	1.0 U								
Zinc (µg/L)				72.9 B				39.3 B	4.9 B								

** The compositor failed during the sampling period. The first 17 aliquots were collected as equal volumes every 30 minutes. An 18th aliquot that was equal in volume to the sum of the previous 17 was added at 0925 on 8/16.
U indicates compound was analyzed for but not detected at the given detection limit.
J indicates an estimated value.
B This flag is used when the analyte is found in the blank as well as the sample. Indicates possible/probable blank contamination.
UJ indicates compound was analyzed for but not detected at the given detection limit, and the internal standard on which detection limit quantification was based was outside acceptance limits.
NR requested but not analyzed
UR indicates compound was analyzed for but not detected at the given detection limit, and the spike recovery was low so the actual detection limit may be higher.
BOF bottle over filled.

Appendix A-8. (Continued)

	9/5-6								9/26-27									
Lab Log- : Numbers :	368232 368233	368234	368240 368241	368242 368243	368244		368235 368236	368237	368245 368246							398180	398181		398190
Sample:	ECO-Inf	STP-Inf	Effluent	Effluent	Ef- Dup	Effluent	ECO- Ef	STP-Ef	Sludge	Weyco Influent	Weyco Influent	Town Influent	Town Influent	Falls Influent	Falls Influent	Effluent	Effluent	Effluent	ECO- Ef
Date:	9/5-6	9/5-6	9/5	9/5	9/5	9/6	9/5-6	9/5-6	9/6	9/26	9/26	9/26	9/26	9/26	9/26	9/26	9/26	9/27	9/26-27
Time:	0930-0930	0800-0800	1005	1415	1415	1005	1000-1000	0800-0800	1545-1700	1428	1434	1425	1432	1420	1430	0915	1410	1030	0915-0915
Type:	Composite	Composite	Grab	Grab	Grab	Grab	Composite	Composite	Grab	Grab	Grab	Grab	Grab	Grab	Grab	Grab	Grab	Grab	Composite
Field Analyses																			
Average flow (MGD)							0.23												0.23
pH (S.U.)	7.7	9.9	7.6	7.7		7.8	7.8	7.6		7.3	7.4	7.9	7.9	7.3	7.8	7.4	7.4	7.5	7.8
Temperature (°C)	6.9	17.9	17.9	20.1		17.7	6.7	14.6		16.1	16.1	17.6	17.4	25.0	23.5	17.2	17.9	17.1	4.5
Conductivity (umhos/cm)	428	582	318	324		341	311	318		130	166	625	630	463	450	318	336	325	320
Chlorine Residual (mg/L)																			
Total			0.8	0.5		1.0										0.6	0.6	0.6	
Free			0.1	<0.1		<0.1										<0.1	<0.1	<0.1	
Laboratory Analyses																			
Turbidity (NTU)	49	230	17	17	18		17	24											18
Conductivity (umhos/cm)	441	614	342	342	342		343	348											349
Alkalinity (mg/L $CaCO_3$)	158	264	88	88	87		87	88											89
Hardness (mg/L $CaCO_3$)	65	48	52	51	50		57	52											51
Chloride (mg/L)	23.4	25.8	20.9	25.8	24.4		28.2	23.3											30.2
Cyanide (μg/L)	<4						<4												
TS (mg/L)	280	750					270	290											350
TNVS (mg/L)	85	79					110	66											180
TSS (mg/L)	140	360	54	96	120		80	150											44
TNVSS (mg/L)	14	38					9	12											1 U
BOD_5 (mg/L)	NR	>60					NR	56 J											21
Inhib. BOD_5 (mg/L)	>20						24												
COD (mg/L)	406	1240	185	199	211		99	251											169
TOC (mg/gm dry-wt)									140										
NH_3-N (mg/L)	15	9.6	0.24	0.26	0.23		0.51	0.41											0.55
NO_3+NO_2-N (mg/L)	0.59	0.40	2.6	2.8	2.7		2.9	2.9											2.5
Total-P (mg/L)	8.4	6.5	6.0	5.2	5.1		6.0	7.0											7.1
Ortho-P (mg/L)	3.6	3.0	3.4	3.2	3.2		3.2	3.4											3.7
% Solids									6.5										
Fecal Coliform (#/100mL)			3	23 BOF	10 U				(mg/Kg dry wt)							29	11		
Antimony (μg/L)	3.0 U						3.0 U		0.06 UJ										3.0 U
Arsenic (μg/L)	1.0 UR						1.0 UR		40										1.0 UR
Beryllium (μg/L)	2.0 U						2.0 U		0.17 J										2.0 U
Cadmium (μg/L)	5.0 U						5.0 U		4.8										5.0 U
Chromium (μg/L)	12						5.0 U		42.0										5.0 U
Copper (μg/L)	136						20		637										20
Lead (μg/L)	10.1 B						2.9 B		120										2.8 B
Mercury (μg/L)	0.08						0.06 U		98										0.06 U
Nickel (μg/L)	20 U						20 U		21 J										20 U
Selenium (μg/L)	2.0 U						2.0 U		0.024 J										2.0 U
Silver (μg/L)	0.50 U						0.50 U		54.3										0.50 U
Thallium (μg/L)	1.0 U						1.0 U		0.020 U										1.0 U
Zinc (μg/L)	134 B						30.4 B		1150										29.6 B

Appendix A-9. Weyerhaeuser Log Pond Discharge results - Snoqualmie River low flow study, 1989.

Date:	7/25	7/25	7/26	7/25-26	8/15	8/15	8/16	8/15-16	9/5	9/5	9/6	9/5-6	9/26	9/26	9/27	9/26-27
Time:	1005	1500	1105	*	1005	1420	1000	*	0845	1510	0850	*	0900	1355	0940	*
Type:	Grab	Grab	Grab	Composite	Grab	Grab	Grab	Composite	Grab	Grab	Grab	Composite	Grab	Grab	Grab	Composite
Field Analyses																
Average flow (MGD)				0.014				0.003				0.006				0.003
pH (S.U.)	7.5	7.7	7.5	7.5	7.0	6.9	7.2	7.1	7.1	7.3	7.3	7.3	7.2	7.1	7.5	7.4
Temperature (°C)	22.9	25.0	24.0	12.0	20.4	21.5	19.9	10.3	18.9	21.3	18.4	7.3	17.7	18.5	17.4	8.4
Conductivity (umhos/cm)	161	148	153	143	147	143	145	142	135	143	148	138	138	146	146	147
Chlorine Residual (mg/L)																
Total					<0.1											
Free																
Flow (mgd)				0.014				0.003				0.006				0.003
Turbidity (NTU)				1.5				1.7				1.4				1.5
Conductivity (umhos/cm)				138				145				147				153
Alkalinity (mg/L $CaCO_3$)				59				57				62				61
Hardness (mg/L $CaCO_3$)				54				56				58				58
Chloride (mg/L)				7.1				7.0				7.3				8.3
Cyanide (μg/L)																
TS (mg/L)				100				120				1 U				130
TNVS (mg/L)				62				60				1 U				78
TSS (mg/L)				9				4				2				1 U
TNVSS (mg/L)				3				1 U				29				1 U
BOD_5 (mg/L)				<4 J				<4 J				<4 J				<6 J
Inhib. BOD_5 (mg/L)																
COD (mg/L)				21				22				23				20
TOC (mg/L)																
NH_3-N (mg/L)				0.17				0.02 J				0.04				0.08
NO_3+NO_2-N (mg/L)				<0.02				<0.01 J				0.02				0.01
Total-P (mg/L)				0.06				0.05 J				0.05				0.08
SP-P (mg/L)				0.26 J				<0.01 J				0.05				0.01
% Solids																
Fecal Coliform (#/100mL)	11	3			3	8			14	3 U			3	6		
Antimony (μg/L)				2.0 U				3.0 U				3.0 U				3.0 U
Arsenic (μg/L)				1.6				2.9 R				1.8 R				1.9 R

Appendix A-9. (Continued).

Date:	7/25	7/25	7/26	7/25-2	8/15	8/15	8/16	8/15-1	9/5	9/5	9/6	9/5-6	9/26	9/26	9/27	9/26-27
Time:	1005	1500	1105	*	1005	1420	1000	*	0845	1510	0850	*	0900	1355	0940	*
Type:	Grab	Grab	Grab	Composite	Grab	Grab	Grab	Composite	Grab	Grab	Grab	Composite	Grab	Grab	Grab	Composite
Beryllium (µg/L)				2.0 U				2.0 U				2.0 U				2.0 U
Cadmium (µg/L)				5.0 U				5.0 U				5.0 U				5.0 U
Chromium (µg/L)				5.0 U				5.0 U				5.0 U				5.0 U
Copper (µg/L)				4.0 U				4.0 U				4.0 U				4.0 U
Lead (µg/L)				1.2 B				1.0 U				1.0 U				1.0 U
Mercury (µg/L)				0.06 U				0.06 U				0.02 UH				0.06 U
Nickel (µg/L)				20 U				20 U				20 U				20 U
Selenium (µg/L)				2.0 U				2.0 U				2.0 U				2.0 U
Silver (µg/L)				0.50 U				0.50 U				0.50 U				0.50 U
Thallium (µg/L)				1.0 U				2.0 U				1.0 U				1.0 U
Zinc (µg/L)				23.3 B				8.0 B				1310				3.8 B

* composite was made by mixing equal volumes of the three grab samples.
Sample types: G = grab, C = composite

Sample qualifiers:
- B = detected in blank as well.
- U = below detection limit indicated
- J = estimated value; below level of quantification
- H = analysis performed after an acceptable holding time had passed.

Appendix A-10. North Bend WWTP results-Snoqualmie River low flow study, July 25-September 6, 1989.

Lab Log Numbers:	308080	308085	308086		308081	308082	308087	308088	308089		308083	308084
Sample:	Blank	Influent	Influent	Influent	ECO-Inf	STP-Inf	Effluent	Effluent	Ef- Dup	Effluent	ECO- Ef	STP-Ef
Date:	7/25	7/25	7/25	7/26	7/25-26	7/25-26	7/25	7/25	7/25	7/26	7/25-26	7/25-26
Time:	0835	0945	1420	0910	0915-0915	0915-0915	0930	1430	1430	0850	0915-0915	0915-0915
Type:		Grab	Grab	Grab	Composite	Composite	Grab	Grab	Grab	Grab	Composite	Composite
Field Analyses												
Average flow (MGD)											0.23	
pH (S.U.)		7.5	7.7	7.3	7.5	7.0	7.3	7.2		7.1	7.3	7.4
Temperature (°C)		17.7	17.9	17.9	5.7	13.7	18.1	19.3		18.7	6.7	13.1
Conductivity (umhos/cm)		430	471	395	390	370	280	275		275	300	275
Chlorine Residual (mg/L)												
Total							0.2	0.6		0.6		
Free							0.2	0.2		<0.1		
Laboratory Analyses												
Turbidity (NTU)					62	52	2.0	1.9	2.0		1.7	1.8
Conductivity (umhos/cm)					375	310	265	263	265		270	269
Alkalinity (mg/L $CaCO_3$)					130	128	74	72	72		73	77
Hardness (mg/L $CaCO_3$)					55	44	49	50	49		50	54
Chloride (mg/L)					21.2	21.5	22.2	23.8	23.1		23.2	21.4
Cyanide (µg/L)					5 U						5 U	
TS (mg/L)					440	500					160	170
TNVS (mg/L)					140	160					130	140
TSS (mg/L)					150	170	9	6	3		6	6
TNVSS (mg/L)					16	24					4	6
BOD_5 (mg/L)					190 J		140 J				5 J	5 J
Inhib. BOD_5 (mg/L)					160 J						4 UJ	
COD (mg/L)					414	509	21	18	19		18	16
TOC (mg/gm dry-wt)												
NH_3-N (mg/L)					15.8	13.2	0.52	0.17	0.24		0.69	0.19
NO_3+NO_2-N (mg/L)					0.17	0.02 U	0.46	0.38	0.47		0.22	0.21
Total-P (mg/L)					2.4	3.7	0.78	1.8	1.6		1.6	1.7
Ortho-P (mg/L)					2.9 J	2.2 J	0.45 J	0.96 J	0.78 J		0.97 J	0.97 J
% Solids												
Fecal Coliform (#/100mL)							220	3	3 U			
Antimony (µg/L)	2.0 U				2.0 U						2.0 U	
Arsenic (µg/L)	1.0 U				3.8						4.2	
Beryllium (µg/L)	2.0 U				2.0 U						2.0 U	
Cadmium (µg/L)	5.0 U				5.0 U						5.0 U	
Chromium (µg/L)	5.0 U				5.0						5.0 U	
Copper (µg/L)	4.0 U				40.2						4.0 U	
Lead (µg/L)	1.0 U				5.4 B						5.7 B	
Mercury (µg/L)	0.06 U				0.17						0.06	
Nickel (µg/L)	20 U				20 U						20 U	
Selenium (µg/L)	2.0 U				2.0 U						2.0 U	
Silver (µg/L)	0.50 U				1.0						0.50	
Thallium (µg/L)	1.0 U				1.0 U						1.0 U	
Zinc (µg/L)	40.6 B				120 B						95.1 B	

Appendix A-10. (Continued)

Lab Log-: Numbers:	338419	338420		338416	338426 338427	368250	368251		368247	398186	398187	398189		398193
Sample:	Effluent	Effluent	Effluent	Effluent	RAS	Effluent	Effluent	Effluent	Effluent	Effluent	Effluent	EF-Dup	Effluent	Effluent
Date:	8/15	8/15	8/16	8/15-16	8/16	9/5	9/5	9/6	9/5-6	9/26	9/26	9/26	9/27	9/26-27
Time:	0815	1350	0830	0830-0830	0845	00815	1315	0810	0830-0830	0830	1320	1320	0915	0830-0830
Type:	Grab	Grab	Grab	Composite	Grab	Grab	Grab	Grab	Composite	Grab	Grab	Grab	Grab	Composite
Field Analyses														
Average flow (MGD)				0.24					0.24					0.23
pH (S.U.)	6.8	6.7	7.0	7.3		7.1	7.0	7.3	7.3	7.4	6.8		7.4	7.7
Temperature (°C)	17.5	17.8	17.2	5.0		16.9	17.9	16.5	3.9	16.0	16.7		15.8	4.0
Conductivity (umhos/cm)	301	315	318	309		301	289	286	277	260	270		260	269
Chlorine Residual (mg/L)														
Total	0.6	0.5	0.5			0.3	0.3	0.5		0.5	0.3		0.5	
Free	<0.01	<0.01	<0.01			<0.1	0.1	<0.1		<0.1	<0.1		<0.1	
Laboratory Analyses														
Turbidity (NTU)				1.4					16					38
Conductivity (umhos/cm)				317					308					281
Alkalinity (mg/L $CaCO_3$)				39					72					68
Hardness (mg/L $CaCO_3$)				57					57					58
Chloride (mg/L)				25.4					25.8					23.9
Cyanide (µg/L)														
TS (mg/L)				240					100					400
TNVS (mg/L)				160					90					180
TSS (mg/L)				3					60					160
TNVSS (mg/L)				1 U					10					4
BOD_5 (mg/L)				4 J					35 J*					64
Inhib. BOD_5 (mg/L)														
COD (mg/L)				24					81					249
TOC (mg/gm dry-wt)					320**									
NH_3-N (mg/L)				0.92 J					0.21					0.66
NO_3+NO_2-N (mg/L)				8.5 J					1.2					0.29
Total-P (mg/L)				5.4 J					5.9					6.0
Ortho-P (mg/L)				4.2 J					5.0					2.5
% Solids					0.34									
Fecal Coliform (#/100mL)	8	3				23	26			14	12000	15000		
Antimony (µg/L)				3.0 U	6.0 U				3.0 U					3.0 U
Arsenic (µg/L)				5.7 R	24.8				3.2 R					1.0 UR
Beryllium (µg/L)				2.0 U	0.50 U				2.0 U					2.0 U
Cadmium (µg/L)				5.0 U	16				5.0 U					5.0 U
Chromium (µg/L)				5.0 U	34				5.0 U					5.0 U
Copper (µg/L)				14	1270				33					79.3
Lead (µg/L)				1.0 U	150				3.3 B					9.2 B
Mercury (µg/L)				0.06 U	8.7				0.13					0.38
Nickel (µg/L)				20 U	62				20 U					20 U
Selenium (µg/L)				2.0 U	6.0 J				2.0 U					2.0 U
Silver (µg/L)				0.50 U	21.3				0.50 U					6.7
Thallium (µg/L)				2.0 U	2.0 U				1.0 U					1.0 U
Zinc (µg/L)				69.8 B	1900				94.7					196

*	possible toxic effect - BOD_5 = 13J mg/L at dilution factor of 2.0: BOD_5 = 35J mg/L at dilution factor 10.0
**	average of sample result (400 mg/gm dry wt) and duplicate analysis (240 mg/gm dry wt).
U	indicates compound was analyzed for but not detected at the given detection limit.
J	indicates an estimated value.
B	This flag is used when the analyte is found in the blank as well as the sample. Indicates possible/probable blank contamination.
UJ	indicates compound was analyzed for but not detected at the given detection limit, and the internal standard on which detection limit quantification was based was outside acceptance limits.
R	low spike recovery - result may be biased low.
UR	indicates compound was analyzed for but not detected at the given detection limit, and the spike recovery was low so the actual detection limit may be higher.

Appendix A-11. Results from light-dark bottle experiments on the Snoqualmie River in 1989.

Site	River Mile	Date	Time In	Time out	Sample	Dissolved Oxygen (mg/L) Initial (mg/L)	Light Bottle (mg/L)	Dark Bottle (mg/L)	Light-Dark (mg/L)
200 m above Snoqualmie WWTP outfall	40.75	8/30	1023	1644	1	9.40	9.40	9.30	0.10
					2	9.40	9.40	9.40	0.00
200 m below Snoqualmie WWTP outfall	40.7	8/30	1013	1637	1	9.25	9.35	9.30	0.05
					2	9.30	9.40	9.20	0.20
Upstream of Fall City	36.5	9/13	1030	1445	1	10.50	10.35	10.30	0.05
					2	10.10	10.35	10.35	0.00
Upstream of Carnation	26.0	9/13	1140	1540	1	10.20	10.05	--*	--*
					2	10.15	10.25	10.20	0.05
		9/28	1200	1500	1	10.05	10.05	10.05	0.00
					2	10.00	10.10	10.10	0.00
Downstream of Carnation	23.5	9/13	1345	1645	1	10.50	10.50	10.50	0.00
					2	10.50	10.60	10.60	0.00
Upstream of Duvall	11.2	9/14	1030	1430	1	9.65	9.45	--*	--*
					2	9.70	9.60	9.60	0.00
		9/27	1130	1500	1	9.90	9.90	9.90	0.00
					2	9.90	9.70	9.90	-0.20
Downstream of Duvall	9.5	9/14	1000	1400	1	9.70	9.60	9.60	0.00
					2	9.60	9.70	9.65	0.05
		9/27	1030	1430	1	9.80	9.80	9.80	0.00
					2	9.70	9.80	9.75	0.05

* Sample not taken.

Appendix A-12. Snoqualmie River periphyton results (9/12 and 9/25/89).

Sampling Site	River Mile	Date	Depth (ft)	Flow (fps)	TOC* (mg/L)	TSS (mg/L)	TVSS (mg/L)	TP* (mg/L)	TN* (mg/L)	Chl.*a*** (ug/L)
S.F. Snoqualmie River	SF 1.8	9/12/89	1.6	1.01	17	190	64	0.3	1	980.7
upstream of North Bend		Repl.	1.6	0.93	23	210	68	0.4	1	430.4
WWTP outfall		9/25/89	1.6	0.74	21	280	100	0.5	2	257.5
		Repl.	1.4	1.06	33	260	92	0.9	4	186.0
S.F. Snoqualmie River	SF1.6	9/12/89	1.6	1.55	20	190	72	0.4	2	779.9
downstream of North Bend		Repl.	1.6	1.23	31	220	98	0.7	3	869.6
WWTP outfall		9/25/89	1.5	1.46	40	220	110	1.1	4	181.0
		Repl.	1.1	1.60	38	240	108	1.1	4	496.0
Downstream of Fall City	33.5	9/12/89	1.6	1.09	10	910	48	0.9	2	270.0
corner of W. River Rd		Repl.	1.9	1.21	10	710	46	0.7	2	235.7
		9/25/89	1.5	1.10	14	1,700	86	1.3	2	203.3
		Repl.	1.7	1.36	9	600	36	0.9	1	145.3
200 m below Carnation	22.9	9/12/89	1.7	1.72	11	130	34	0.2	2	59.1
Farms Rd.		Repl.	1.8	1.56	17	270	82	0.3	1	281.1
		9/25/89	1.5	1.64	19	140	56	0.7	2	237.5
		Repl.	1.7	1.38	18	130	56	0.4	1	131.3
200 m upstream of Duvall	9.9	9/12/89	1.8	1.63	22	230	66	0.7	2	PNQ
Bridge		Repl.	1.3	1.10	22	150	44	0.6	2	349.4
		9/25/89	1.4	2.20	30	270	104	1.0	2	418.8
		Repl.	1.3	1.05	30	440	92	1.1	2	339.3
Filter river water		9/12/89	--	--	3	<1	<1	0.007	0	<0.1
		9/25/89	--	--	3	<1	1	<0.002	0	<0.1

* = Values corrected for filtered river water concentration
** = Chlorophyll corrected for pheophytin
Repl. = Replicate value
PNQ = Present but not quantified

Appendix A-13. Benthic macroinvertebrate abundance (no./ft^2) for Snoqualmie River stations (8/16/89).

	River Mile														
	SF 1.8	SF 1.8	SF 1.8	SF 1.6	SF 1.6	SF 1.6	33.5	33.5	33.5	22.9	22.9	22.9	9.9	9.9	9.9
Sample Depth (ft)	1.27	1.43	1.30	1.32	1.12	1.18	1.65	1.20	1.40	1.43	2.00	1.95	1.28	1.62	1.67
Velocity (fps)	1.30	1.40	2.13	1.94	1.50	2.35	1.68	1.26	2.49	2.02	1.61	1.77	2.01	1.87	1.20
Diptera (flies, midges)															
Ceratopogonidae					2					1	4	3	2	2	
Chironomidae	130	144	25	40	46	38	134	105	132	114	215	227	297	348	424
Psychodidae											1		1		
Rhagionidae	3	1	2		1	1			1		3		2	3	1
Simuliidae	2	2					1	1	1		1				
Tabanidae											1				
Tipulidae	8	14	1	12	9	8	5	7	1	1	2	3	1		2
Ephemeroptera (mayflies)															
Baetidae	14	11	110	105	108	168	22	13	35	100	15	19	165	144	137
Ephemerellidae	25	21	35	34	35	23	15	7	25	37	122	99	7	7	5
Heptageniidae	9	11	48	47	28	24	13	7	76	117	16	38	13	3	7
Leptophlebiidae								1		2		2			
Tricorythidae		4	5		3			1	1	2	5				
Plecoptera (stoneflies)															
Chloroperlidae	7	13	9	13	11	9	9	8	4	4	2	3	8	2	3
Nemouridae									1						
Perlidae															
Perlodidae			5				1		1		1	1			
Pteronarcyidae													1		
Trichoptera (caddisflies)															
Brachycentridae	1	2	1			6	65	34	80	5	3	6	130	106	25
Glossosomatidae							8	12	6		2	8	5	7	3
Hydropsychidae		2	2	3	2		16	2	30	6		3	6		2
Hydroptilidae															
Lepidostomatidae				2											
Limnephilidae			1			2			1						
Rhyacophilidae						1			13	4			1		
Amphipoda (scuds)															
Talitridae											1				
Coleoptera (beetles)															
Elmidae	2	3	1		1	2	3	4	1	4	13	5	26	19	18
Others (adults)				1			1	1							
Gastropoda															
Ancylidae (limpets)															
Pelecypoda (clams, mussels)															
Margaritiferidae															
Collembola (springtails)		5	2												
Hydracarina (water mites)	47	51	13	9	5	13	6	9	16	5	13	9	19	11	28
Hirudinea (leeches)															
Nematoda (roundworms)							1		1		1				
Oligochaeta (earthworms)	18	19	15	10	41	16	7	15	2	1	9	13	62	85	74
Ostracoda (seed shrimp)	1												1		
Ammocoetes (lamprey larvae)*					64										
TOTAL	267	303	275	276	292	311	307	227	428	403	430	439	747	737	729

Appendix A-13. Benthic macroinvertebrate abundance for Snoqualmie River (9/22/89).

	River Mile														
	SF 1.8	SF 1.8	SF 1.8	SF 1.6	SF 1.6	SF 1.6	33.5	33.5	33.5	22.9	22.9	22.9	9.9	9.9	9.9
Sample Depth (ft)	1.47	1.72	1.38	1.58	1.78	1.33	1.58	1.70	1.50	1.18	1.22	1.65	1.10	1.32	1.20
Velocity (fps)	1.64	1.70	1.37	1.71	1.57	1.73	1.23	1.68	1.97	2.08	1.99	2.26	2.03	1.96	1.08
Diptera (flies, midges)															
Ceratopogonidae		1					1		1	1	1	1			
Chironomidae	244	199	155	118	107	38	90	54	54	104	259	120	216	225	246
Psychodidae			1												
Rhagionidae															
Simuliidae	1	1				2	1				3				
Tabanidae	1														
Tipulidae	14	20	9	19	19	24	3	2	5	3	1				
Ephemeroptera (mayflies)															
Baetidae	90	108	179	144	83	153	28	39	37	39	37	67	14	26	4
Ephemerellidae	3	2	6		3	3	42	11	43	11	3	3	3	2	1
Heptageniidae	49	29	98	92	46	95	44	239	257	169	163	184	25	5	20
Leptophlebiidae						1		1	2		1				
Tricorythidae															
Plecoptera (stoneflies)															
Chloroperlidae	54	23	45	41	30	41	17		15	16	6	6	3	2	
Nemouridae			3	2			1		1		1	1			
Perlidae															2
Perlodidae	2		5	4			1	5	4					1	1
Pteronarcyidae									1						
Trichoptera (caddisflies)															
Brachycentridae	25	27	35	24	13	17	47	46	26	23	21	20	13	23	35
Glossosomatidae			1				17	107	130	82	115	111	24	12	11
Hydropsychidae	3		8	10	4	4	5	7	24	6	4	20	1	5	
Hydroptilidae	3	1	1				10	3	2	3	2	8	4	1	8
Lepidostomatidae															
Limnephilidae			1			1									
Rhyacophilidae	1		1					4	3	4	2				2
Amphipoda (scuds)															
Talitridae										4			1		
Coleoptera (beetles)															
Elmidae	2	2	2	8		1	3	1	1	12	18	16	15	24	27
Others (adults)					1			1						1	
Gastropoda															
Ancylidae (limpets)														3	2
Pelecypoda (clams, mussels)															
Margaritiferidae													1	2	4
Collembola (springtails)	1														
Hydracarina (water mites)		39	29	42	14	9	13	40	18	21	7	17	5	25	2217
Hirudinea (leeches)					2										
Nematoda (roundworms)		1													
Oligochaeta (earthworms)	15	30	20	33	9	25	13	6	2	2	6	7	61	122	70
Ostracoda (seed shrimp)															
Ammocoetes (lamprey larvae)*															
TOTAL	556	474	612	509	326	418	362	545	628	486	660	569	407	476	450

* Lamprey larvae not included in total invertebrate count.

Appendix A-14. Results of two-way factorial analysis of variance for invertebrate abundance data.

Analysis of Variance for Log10 Invertebrate Abundance

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS					
Site (fixed)	.1829575	4	.0457394	0.804	.5813
Date (random)	.0894115	1	.0894115	16.416	.0006
2-FACTOR INTERACTIONS					
Site X Date	.2276214	4	.0569054	10.448	.0001
RESIDUAL	.1089289	20	.0054464		
TOTAL (CORR.)	.6089193	29			

Means and 95% C.I. for Log10 Invertebrate Abundance

Level	Count	Average	Stnd. Error (internal)	Stnd. Error (pooled s)	95 Percent Confidence* for mean	
Site						
1	6	2.5924819	.0661549	.0301287	2.5296192	2.6553445
2	6	2.5400273	.0419206	.0301287	2.4771647	2.6028900
3	6	2.5946121	.0664762	.0301287	2.5317495	2.6574748
4	6	2.6904217	.0334963	.0301287	2.6275591	2.7532844
5	6	2.7573216	.0502377	.0301287	2.6944589	2.8201842
Date						
1	15	2.5803800	.0442179	.0190551	2.5406222	2.6201379
2	15	2.6895658	.0227734	.0190551	2.6498080	2.7293236
Site by Date						
1 1	3	2.4490955	.0165916	.0426085	2.3601943	2.5379967
1 2	3	2.7358682	.0323642	.0426085	2.6469670	2.8247694
2 1	3	2.4663508	.0149760	.0426085	2.3774496	2.5552520
2 2	3	2.6137039	.0559835	.0426085	2.5248027	2.7026051
3 1	3	2.4915360	.0795367	.0426085	2.4026348	2.5804372
3 2	3	2.6976882	.0717264	.0426085	2.6087870	2.7865895
4 1	3	2.6270793	.0111926	.0426085	2.6648629	2.7159806
4 2	3	2.7537642	.0383731	.0426085	2.7789373	2.9567398
5 1	3	2.8678385	.0030636	.0426085	2.7789373	2.9567398
5 2	3	2.6468046	.0198932	.0426085	2.5579034	2.7357058
Total	30	2.6349729	.0134740	.0134740	2.6068599	2.6630860

* Fisher's Least Significant Difference.

Appendix A-15. Results of two-way factorial analysis of variance for habitat data.

Analysis of Variance for Velocity

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS					
Site (fixed)	.4471533	4	.1117883	1.547	.3414
Date (random)	.0093633	1	.0093633	.063	.8069
2-FACTOR INTERACTIONS					
Site X Date	.2890200	4	.0722550	.487	.7452
RESIDUAL	2.9675333	20	.1483767		
TOTAL (CORR.)	3.7130700	29			

Analysis of Variance for Depth

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS					
Site (fixed)	.1784533	4	.0446133	.242	.9007
Date (random)	.0004033	1	.0004033	.010	.9206
2-FACTOR INTERACTIONS					
Site X Date	.7366133	4	.1841533	4.779	.0072
RESIDUAL	.7706000	20	.0385300		
TOTAL (CORR.)	1.6860700	29			

Appendix A-16. Compounds analyzed for but detected in fish tissue samples collected during the 1989 BWMP.

Parameter	Detection Limit ug/Kg (< or =)
alpha-BHC	8
beta-BHC	8
delta-BHC	8
gamma-BHC (Lindane)	8
Heptachlor	8
Heptachlor epoxide	8
Endosulfan I	8
Endosulfan II	8
Endosulfan sulfate	16
Endrin	8
Endrin Ketone	16
Endrin aldehyde	16
Methoxychlor	80
gamma-Chlordane	80
Toxaphene	150
Aroclor-1016	80
Aroclor-1221	80
Aroclor-1232	80
Aroclor-1242	80
Aroclor-1248	80
Aroclor-1254	150
cis-Nonachlor	8
trans-Nonachlor	8
Oxychlordane	8
Mirex	8
DCPA	80
Tetradifon	8

Appendix A-17. Snoqualmie River QUAL2E-UNCAS Sensitivity Analysis. Dissolved Oxygen.

Parameter(s) Perturbed	QUAL2E Reach 1	3	4	6	11	17	24
Headwater BOD	-0.005	-0.005	-0.015	-0.035	-0.02	-0.01	-0.015
SOD	0.0	0.0	-0.06	-0.18	0.02	0.0	0.0
Streamflow	-0.02	0.01	-0.04	-0.16	-0.02	-0.01	-0.04
Pointload BOD	0.0	0.0	-0.01	-0.02	-0.03	-0.02	-0.06
Headwater DO	-2.31	-1.64	-0.57	0.0	0.0	0.0	0.0
CBOD Decay	-0.01	-0.01	-0.02	-0.05	-0.02	0.0	0.0
NH_3 Decay & NO_2 Decay	0.0	0.0	0.0	0.0	0.0	-0.01	-0.01
Velocity Coeff on Q	-0.01	-0.01	-0.09	-0.25	0.0	0.01	0.01
NH_3 Pointload & NH_3 Decay & NO_2 Decay	0.0	0.0	0.0	0.0	-0.01	-0.01	-0.02
Initial Temperature	-0.36	-0.32	-0.85	-1.15	-1.50	-1.46	-1.46

Future design point source loads, calibrated nonpoint loads, and 7Q10 streamflows were used for these simulations.

All values represent the change in dissolved oxygen (mg/L) from a 25% perturbation of the given parameters.

SOD = sediment oxygen demand (/day)
Q = streamflow (cfs)

Appendix A-18. Snoqualmie River QUAL2E-UNCAS Sensitivity Analysis.
Total Phosphate Phosphorus (TPO_4-P)

	QUAL2E Reach						
Parameter(s) Perturbed	1	3	4	6	11	17	24
TPO_4 settling	0.09	0.02	0.43	1.26	4.07	6.47	9.27
Streamflow 7Q10	26.7	-0.04	5.30	11.24	8.96	3.71	2.81
Pointload TPO_4	20.56	0.17	6.11	13.08	13.60	10.48	11.16

Future design point source loads, calibrated nonpoint loads, and 7Q10 flows were used for these simulations.

All values represent the change in total phosphate phosphorus (TPO4-P) from a 25% perturbation of the given parameter(s).

Total phosphate phosphorus was modeled as an "arbitrary non-conservative" constituent in the model, subject to a first-order settling (removal) rate.

Appendix A-19. Snoqualmie River QUAL2E-UNCAS Sensitivity Analysis. Total Ammonia (NH_3-N)

Parameter(s) Perturbed	QUAL2E Reach 1	3	4	6	11	17	24
Headwater NH_3	2.95	2.04	1.95	1.82	1.36	0.78	0.55
Pointload NH_3	11.75	0.51	4.01	8.14	11.86	9.23	10.78
Pointload ON & ON Decay & Headwater ON	0.10	0.0	0.48	1.44	5.95	10.10	15.00
NH_3 Decay	0.07	0.04	0.33	0.75	3.19	6.77	10.84
Pointload ON & Pointload NH_3	11.75	0.51	4.01	8.14	11.86	9.23	10.78
Streamflow 7Q10	15.34	0.06	3.47	7.86	11.88	8.32	9.85

Future design point source loads, calibrated nonpoint loads, and 7Q10 flows were used for these simulations.

All values represent the change in ammonia (μg/L NH_3-N) from a perturbation of the given parameter(s).

ON = organic nitrogen as N (μg/L)
NH_3 = ammonia nitrogen (μg/L NH_3-N)

Appendix A-20. Snoqualmie River QUAL2E-UNCAS Sensitivity Analysis. Fecal Coliforms (cfu/100mL)

	QUAL2E Reach						
Parameter(s) Perturbed	1	3	4	6	11	17	24
Pointload FC	1.54	0.85	1.19	1.78	46.85	18.34	10.39
Streamflow 7Q10	1.72	0.31	0.10	0.23	24.60	5.23	-3.21
Velocity Coeff ON Q	0.17	0.16	0.77	1.57	23.60	15.44	19.36
FC Decay	0.21	0.21	0.98	2.01	30.21	20.69	25.80
Initial Temperature	0.26	0.27	1.26	2.70	42.86	32.10	41.2

Future design point source loads, calibrated nonpoint loads, and 7Q10 flows were used for these simulations.

All values represent the change in fecal coliforms (cfu/100mL) from a 25% perturbation of the given parameter(s).

FC = fecal coliforms (cfu/100mL)
Q = streamflow (cfs)
cfu = colony forming units

APPENDIX B

APPENDIX B

Community primary productivity was estimated using the free-water diurnal curve method (APHA, 1985). The diurnal curve method is based on the premise that interactions between photosynthetic production, respiration, diffusion, and inflowing surface and ground water result in daily oxygen changes in a segment of flowing water. Observed daily rates of oxygen change corrected for diffusion and drainage accrual can be used to calculate rates of productivity and respiration. To simplify this process, sites with negligible surface and ground water flux are usually selected. Phytoplankton contributions to primary productivity in those areas were estimated and separated from the benthic productivity with a series of light and dark bottle experiments (APHA, 1985).

Two different approaches are commonly used for the diurnal curve method in flowing water. More accurate estimates are obtained using a two-station analysis which measures change in dissolved oxygen for a parcel of water as it moves from one region of a stream to another. The less accurate single-station method measures rate of change at a single point and assumes stream homogeneity for productivity and respiration above the measurement point. Methods for the single-station and two-station analyses are identical, except the rate of change in the two-station method is obtained by subtracting the upstream D.O. concentration from the downstream concentration after correcting for time of travel.

Reaeration rates were calculated for each site using the equation derived by O'Connor and Dobbins (EPA, 1985). This equation uses hydraulic data and is best suited for moderately deep rivers. Reaeration rates were corrected to ambient temperatures and used to calculate gas transfer coefficients for each site. The gas transfer coefficient in mg/L/hr (= $g/m^3/hr$) was determined by multiplying the reaeration rate times the D.O. concentration at saturation and dividing by 24 hours.

Hourly temperature and dissolved oxygen data were tabulated and the hourly rate of D.O. change and percent saturation determined. Saturation deficits for each hour were calculated. Diffusion of oxygen into or out of water is dependent on saturation deficits and gas transfer coefficients. Diffusion rates in mg/L/hr were determined by multiplying the saturation deficit times the gas transfer coefficient and dividing by 100.

The measured rates of D.O. change were then corrected for diffusion to allow determination of productivity and respiration. For example, when D.O. saturation was less than 100 percent, atmospheric oxygen diffused into the water, and instream D.O. increased. To measure productivity levels, this increase must be subtracted from the instream rates of D.O. change. Conversely, when instream D.O. saturation exceeded 100 percent, oxygen diffused from water to atmosphere. Thus, the D.O. lost must be added to the instream rate of D.O. change.

The corrected rate of change curves were then plotted as step graphs (Appendix B, Figure 1). The night time respiration line is the part of the graph that occurs during darkness and usually falls beneath the zero rate of change line, while the daytime rate of change line occurs between the sunrise and sunset points. An estimate of daytime respiration is obtained by connecting a line between the sunrise and sunset rate of change points. This is called the daytime respiration line. Gross productivity (mg/L/day) is the area of the graph above the daytime respiration line and below the daytime rate of change line. Community respiration (mg/L/day) is the area above the night time respiration line and the daytime respiration line, but below the zero rate of change line. Net productivity is defined as gross productivity minus community respiration. Areas for each graph were determined using computerized planimetry. Step plots for single and two-station sites are shown in Appendix B, Figures 2 - 4.

Phytoplankton contributions toward total productivity were estimated using a series of light-dark bottle experiments (Slack *et al.* 1973). Clear and opaque BOD bottles were suspended on a rack within one meter of the surface at each site. Bottles were incubated for 3-4 hours during mid-day. The concentration of D.O. was recorded at the beginning of the incubation period. Changes in the oxygen concentration of the enclosed samples were interpreted in terms of productivity and respiration. Pelagic productivity could then be separated from benthic productivity by subtracting phytoplankton productivity from total productivity as measured by the diurnal curve method.

Dissolved oxygen, temperature, and pH were monitored at seven sites by installing continuously recording probes (with data loggers) over a period of 24 hours.

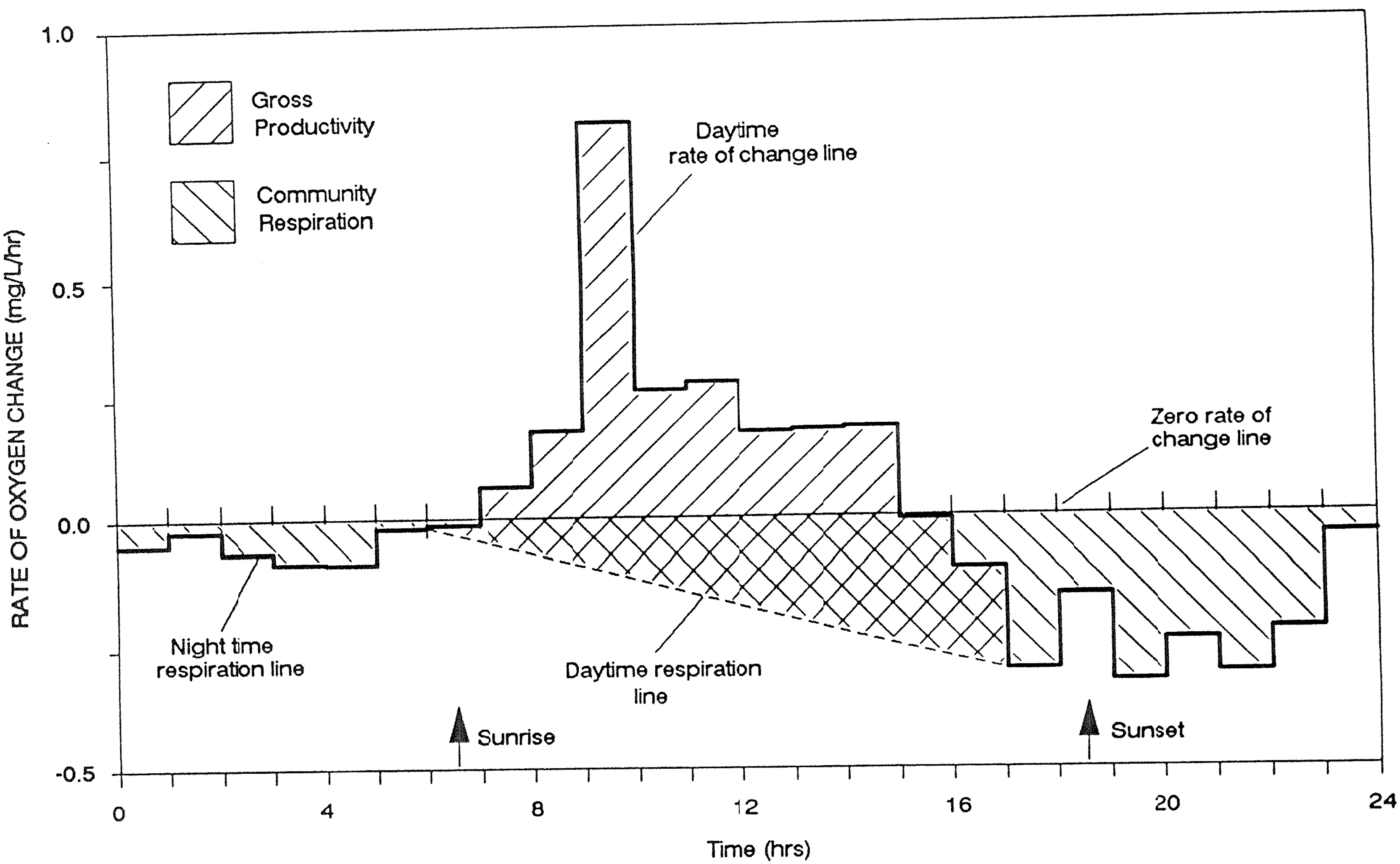

Figure 1. Example of diurnal rate of change curve for determining primary productivity and community respiration.

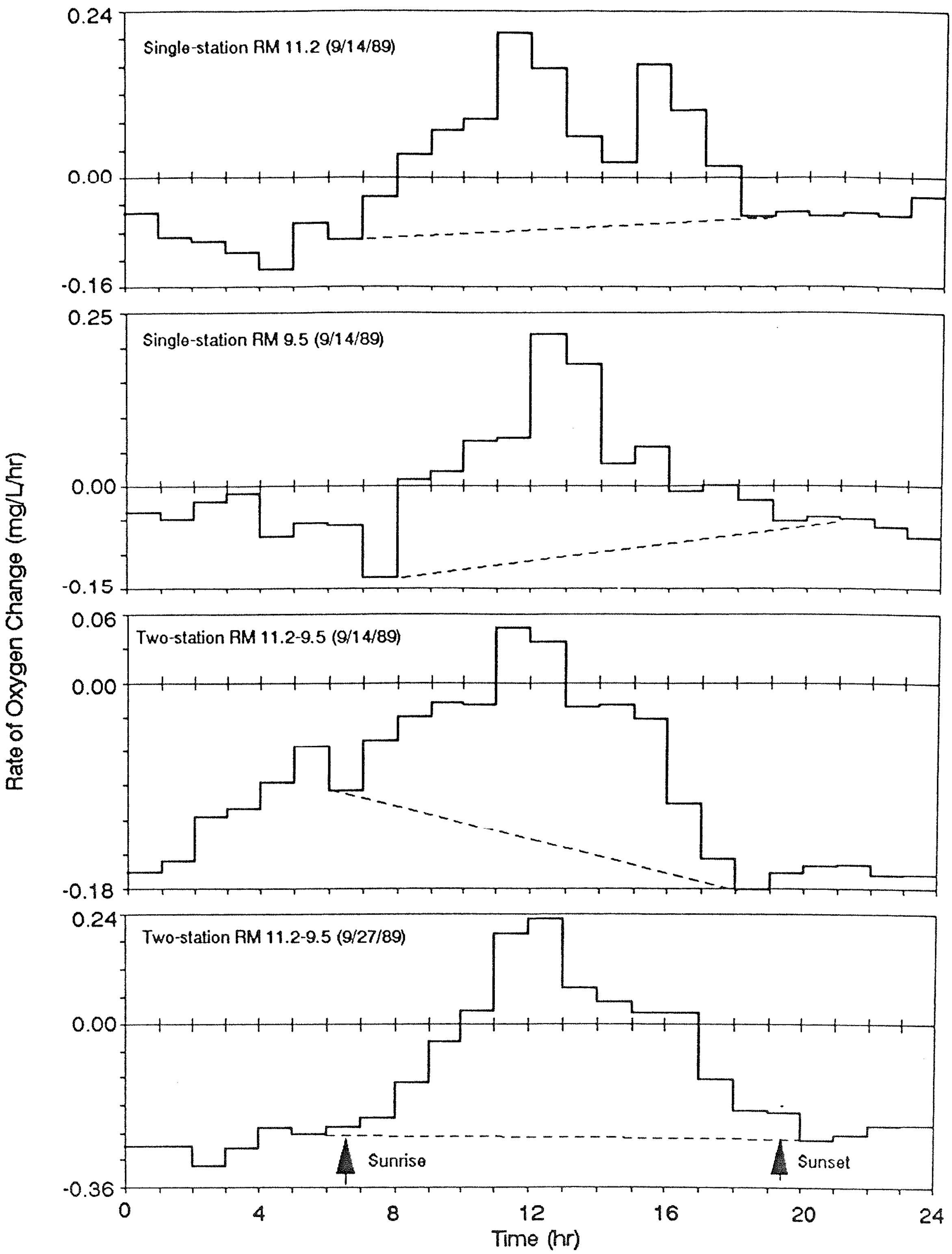

Figure 2. Diurnal (24-hr) rate of oxygen change for sites above and below Duvall.

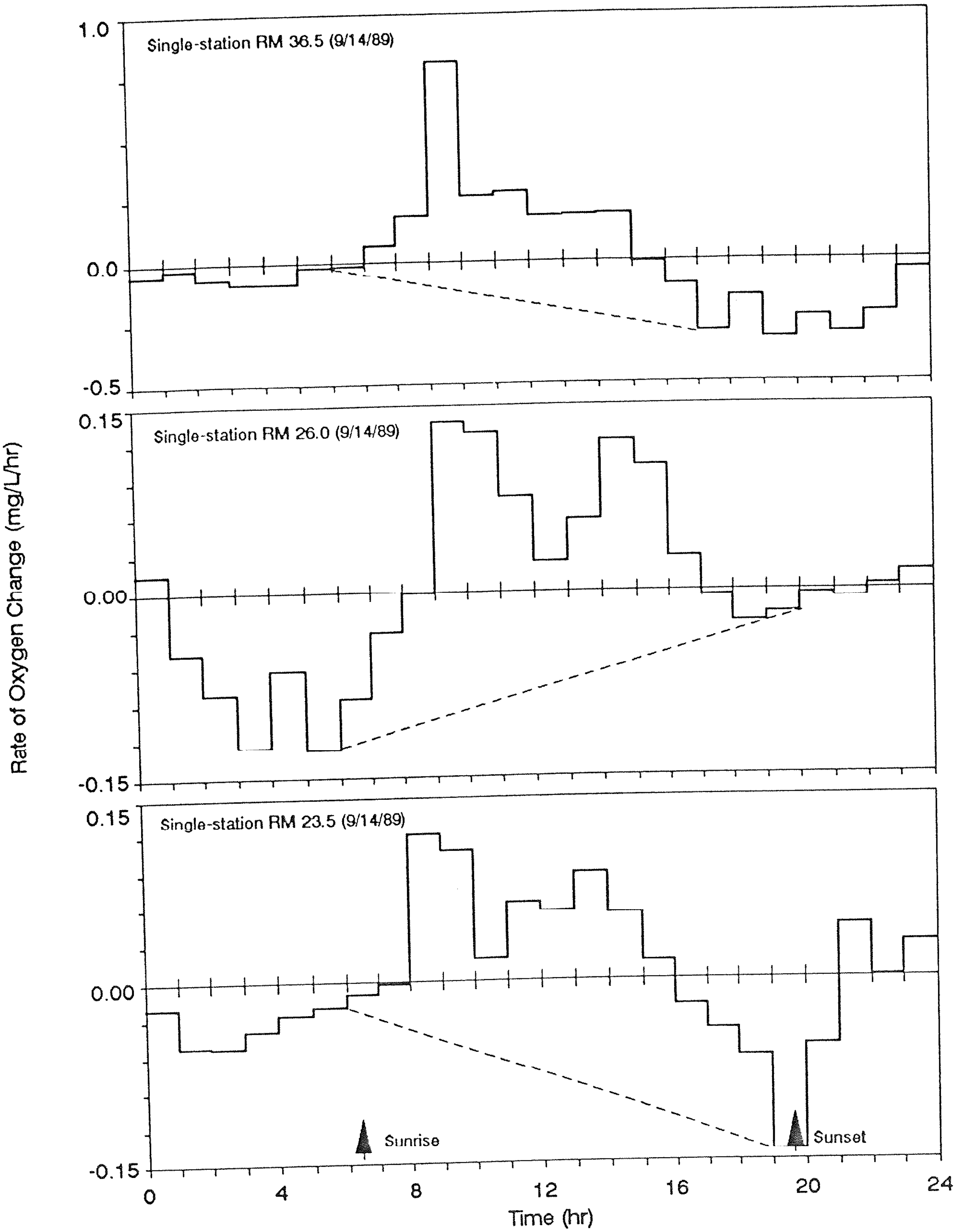

Figure 3. Diurnal (24-hr) rate of oxygen change for sites above and below Carnation and above Fall City.

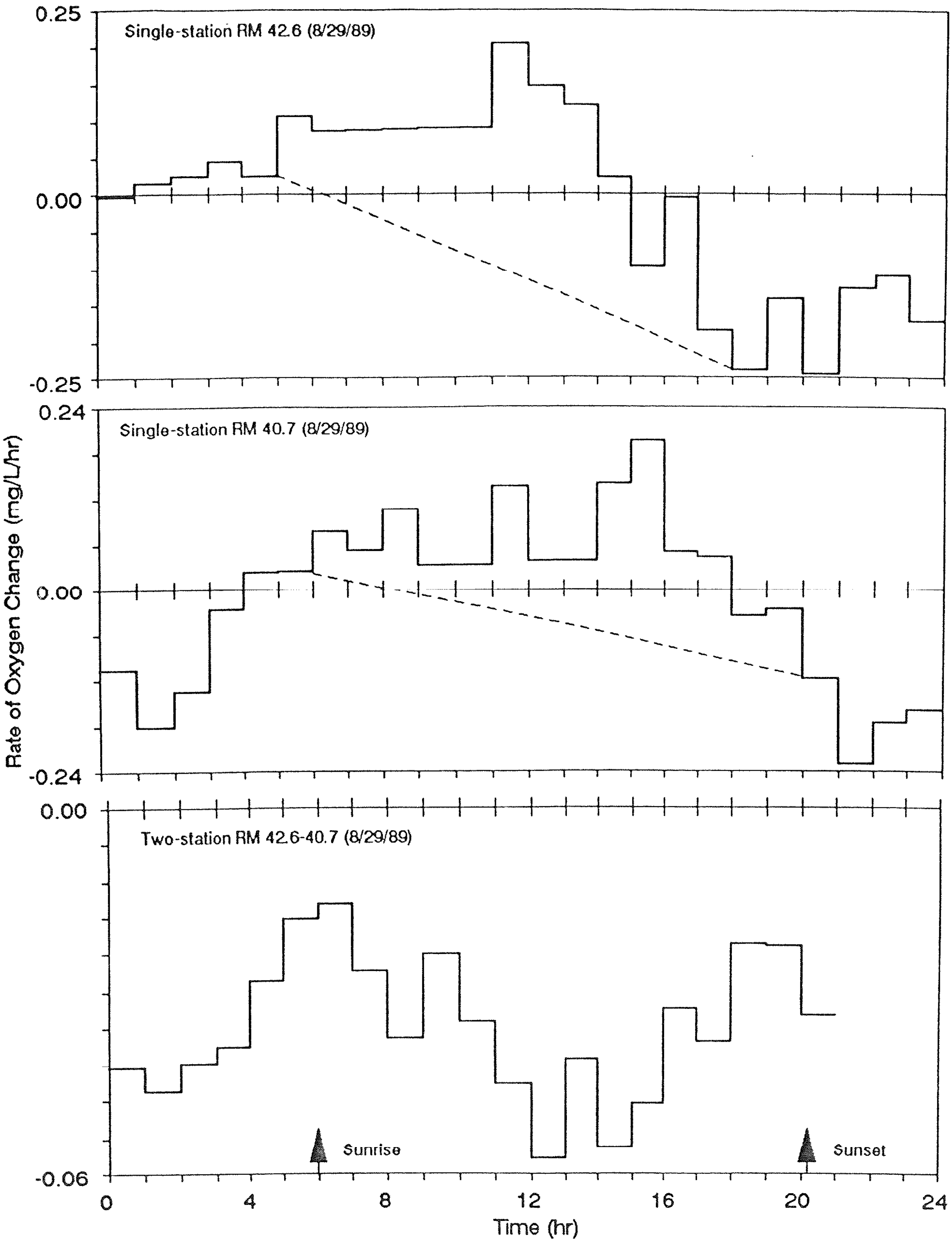

Figure 4. Diurnal (24-hr) rate of oxygen change for sites above Snoqualmie Falls.