Quality Assurance Project Plan

Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study Year 1 Activities

by

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and the Hood Canal Dissolved Oxygen Program home page at *www.hoodcanal.washington.edu/publications*.

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303(d) Listings Addressed in this Study:

Hood Canal, Lynch Cove (WA-PS-0260) – Dissolved Oxygen, pH
Hood Canal, South (WA-PS-0250) – Dissolved Oxygen

Ecology Project Code: 06-100

Approvals

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Abstract

The Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study was designed to quantify the relative magnitude of natural and anthropogenic factors contributing to increasing hypoxia (low oxygen concentrations). Over the last decade, data indicate that hypoxia in Hood Canal has become more severe than occurred historically. The University of Washington Applied Physics Laboratory and the Hood Canal Salmon Enhancement Group will lead the planned three-year project, which includes water quality data collection and model development and application. The purpose of this Quality Assurance (QA) Project Plan is to describe the first year of activities conducted by a team of federal, tribal, state, and local organizations. These activities include continuing ongoing monitoring programs, supplementing those programs with additional targeted monitoring programs, and initiating the development of modeling tools. These programs will continue beyond the one-year schedule described in the present document, and the information developed during this first year will be used to scope subsequent work. Future activities will be described in subsequent documents.

Introduction

Over the last decade, data indicate that hypoxia (low oxygen concentration) in Hood Canal has become more severe than occurred historically. Low dissolved oxygen in southern Hood Canal was recorded by the University of Washington (UW) during the 1950s and 1960s (Collias et al., 1974). Low oxygen concentrations were largely confined to Lynch Cove and southern Hood Canal and lasted primarily for three to six months. Studies by Oregon State University ((OSU) and the University of Washington (UW) evaluated oxygen in Hood Canal in the 1970s. Curl and Paulson (1991) noted that low oxygen concentrations in Lynch Cove appeared to be getting worse and posited that anthropogenic sources of nitrogen may be a factor. Newton et al. (1995) established that nitrogen limited phytoplankton growth. In the last few years (2002-2004), fish kills during low oxygen conditions resulted in unprecedented fishing closures by the Washington State Department of Fish and Wildlife.

During the 1990s, results for Department of Ecology-Puget Sound Ambient Monitoring Program (PSAMP) monitoring stations in both south (Sisters Point) and north (Bangor) Hood Canal showed more months with oxygen below biologically relevant thresholds (5 mg/L = biological stress; 3 mg/L = hypoxia upper limit) than were observed during the 1950s. As many as twelve months with hypoxia were recorded in the south; in the north, hypoxia was newly recorded and occurred in as many as six months with biological stress levels. These observations led Newton et al. (2002) to conclude "Similar to our previous assessment (Newton et al., 1998), four observations from the monitoring data indicate the possibility that DO conditions may be deteriorating in southern Hood Canal, that the spatial extent of low DO may be increasing northwards, and that eutrophication could be one of the processes contributing to this change. Impacts of other human activities (e.g., freshwater diversions), as well as natural cycles, must also be fully evaluated."

The Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study (Newton and Hannafious, 2005) was designed to quantify the relative magnitude of natural and anthropogenic factors contributing to increasing hypoxia. Elements include water quality data collection and model development and application. Other tasks relevant to the overall program include assessment of hypoxia on local biota, development of corrective actions, and citizen observation and stewardship.

The potential factors causing an increase in hypoxia include ocean, river, and local processes, described on pages 9 and 10.

Quantitative mechanistic models are necessary to assess which factors or processes are dominant or contributing on a significant scale. Complexities such as the impact of the temporal and spatial distribution of nutrients additions, of when freshwater inputs occur and how that drives circulation, and of co-limitation of production by nutrient and sunlight cannot be determined without a quantitative approach. Computer-based hydrodynamic and water quality models are routinely used for projects such as Total Maximum Daily Load (TMDL) studies, assessing impacts of proposed loading changes such as sewer outfalls, and for future scenario projections such as exploring climate change impacts. Ecology and University of Washington (UW) Puget Sound Regional Synthesis Model (PRISM) routinely use such models and are in a federally-funded (through the National Oceanographic Partnership Program) partnership, along with other member partners such as the U.S. Navy and King County, to develop, promote, and use modeling technology to address ecosystem health and resource management. These models can represent the complexities mentioned above and are the planned study approach for the Hood Canal Dissolved Oxygen Program (HCDOP).

To drive the models, data collected on appropriate time and space scales within both the marine waters and watershed are required. As described below, a team of federal, state, tribal, county, volunteer, and other local groups listed in Table 1 will collaborate to yield such necessary data.

Table 1. Hood Canal Dissolved Oxygen Program participants.

University of Washington, Applied Physics Laboratory (project co-lead)	Hood Canal Salmon Enhancement Group (project co-lead)
EnviroVision	Puget Sound Action Team
Hood Canal Coordinating Council	Puget Sound Marine Environmental Modeling
Jefferson Conservation District	Skokomish Tribe
Jefferson County	United States Corps of Engineers
Kitsap Conservation District	United States Environmental Protection Agency
Kitsap County Health District	United States Fish and Wildlife Service
Lower Hood Canal Watershed Implementation Council	United States Geological Survey
Mason Conservation District	United States Navy
Mason County Dept. of Environmental Health	University of Washington, School of Oceanography
National Oceanographic and Atmospheric Administration	Washington State Department of Ecology
Northwest Association of the Networked Ocean Observing System	Washington State Department of Fish and Wildlife
Northwest Indian Fisheries Commission	Washington State Department of Health
Pacific Northwest National Laboratory	Washington State Department of Natural Resources
Pacific Shellfish Institute	Washington Sea Grant
Paladin Data Systems	Western Washington University
Port Gamble S'Klallam Tribe	

The University of Washington Applied Physics Laboratory and Hood Canal Salmon Enhancement Group will lead the planned three-year project. In addition to the science team assembled for the Integrated Assessment and Modeling (IAM) Study, the project includes the Corrective Action and Education (CAE) group to implement activities immediately and in response to the IAM study findings. The purpose of this QA Project Plan prepared in accordance with Lombard and Kirchmer (2004), is to describe the first year of data collection and model development activities planned under the Hood Canal Dissolved Oxygen Program Integrated Assessment and Modeling Study by all project participants. Additional project plans will be developed for continuing work.

Project Objectives

The purpose of the HCDOP Integrated Assessment and Modeling (IAM) Study (Newton and Hannafious, 2005) is to quantify the factors that contribute to low dissolved oxygen levels in the marine areas using a combination of existing data compilation, supplemental studies, and development and application of terrestrial and marine models. Specifically, program results will be used to determine whether human activities currently decrease dissolved oxygen levels more than 0.2 mg/L below water quality standards, or below natural conditions if natural conditions result in concentrations less than the values in the water quality standards. The models also will be used to build an understanding of potential future conditions for Hood Canal.

During the first year of activities, approximately May 2005 through April 2006, the project tasks include the following:

- Continue several ongoing marine and freshwater data collection programs, including those conducted by UW, USGS, Ecology, HCSEG, and others.

- Supplement existing programs with new elements that increase the spatial and temporal resolution of marine water and freshwater data.

- Begin developing and applying freshwater and marine water models to the Hood Canal watershed.

These programs may result in a TMDL for Hood Canal and its watershed during subsequent years. If human activities decrease dissolved oxygen levels below the water quality standards target or more than 0.2 mg/L below natural conditions, the three-year project would provide the basis for setting load-reduction targets necessary to meet water quality standards throughout Hood Canal. Whether these targets will be advisory or will be included in a TMDL has not been determined.

Conceptual Model for Hypoxia

What is primary production?

Primary production refers to the creation of organic material by photosynthetic organisms. In marine waters like Hood Canal, this is done primarily by one-celled microscopic algae, known as phytoplankton. Phytoplankton live suspended in the water and need sunlight and nutrients, such as nitrogen and phosphorus, to grow. The amount of nitrogen tends to limit phytoplankton growth in marine waters.

How is phytoplankton growth related to dissolved oxygen levels?

Phytoplankton grow fastest when sunlight and nutrients are in ample supply. As these “blooms” grow and eventually die, the dead cells sink to the bottom where they are decomposed by bacteria. During decomposition, the bacteria consume oxygen, which may lead to depletion of oxygen near the bottom. Some oxygen diffuses into the surface waters from the atmosphere, but this tends to be a slow process. When seawater becomes layered or “stratified” because of density differences, oxygen cannot diffuse all the way to the bottom.

How is seawater stratification related to dissolved oxygen levels?

Light is brightest at the surface. Nutrients tend to be richer near the bottom because phytoplankton consume nutrients from the well-lit surface layer and bacteria release nutrients from sunken organic material upon which they feed near the bottom. If the surface and near-bottom waters are well-mixed, oxygen and nutrients are redistributed throughout the water column and cells might travel out of the zone where light is available. Forces such as tides and winds can cause strong mixing in Hood Canal. Alternatively, the water may have distinct density layers, due to fresh or warm water overlying cold, salty water. This layering, called stratification, inhibits the diffusion of oxygen from near the surface to the bottom waters. Strong stratification, coupled with high primary productivity, can lead to low dissolved oxygen levels near the bottom.

What is hypoxia?

When the water column is stratified and primary production is high, plenty of organic matter reaches the bottom waters of Hood Canal. Dissolved oxygen levels decline when bacterial consumption during decomposition exceeds replenishment by oxygen diffusing from the atmosphere. When oxygen levels reach about 5 mg/L, aquatic organisms experience biological stress. Hypoxia occurs when dissolved oxygen levels decline to below 2-3 mg/L in which many aquatic animals cannot survive.

What potential factors contribute to hypoxia in Hood Canal?

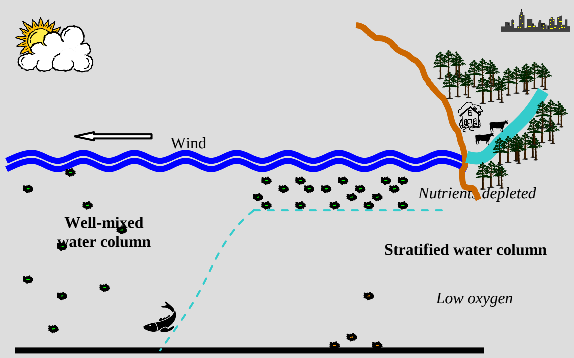
Both natural factors and human activities may affect Hood Canal dissolved oxygen levels. This can happen by changing the nutrient loads to Hood Canal, by altering sunlight, or by altering stratification.

Water exchanges between Hood Canal and Admiralty Inlet, Puget Sound, and the Pacific Ocean affect Hood Canal water quality. Both the amount of water exchanged and the water properties, such as density, temperature, salinity, available nutrients, and dissolved oxygen levels, influence Hood Canal circulation and primary production.

Rivers and streams also influence both stratification and organic matter loads. Natural and human factors alter the amount of inflows and the timing of those inflows, and watershed activities such as residential development, agriculture, and forestry may alter the nutrient loads and delivery of organic matter.

Similar to rivers and streams, groundwater conditions may influence Hood Canal water quality. Consumption and irrigation may reduce groundwater levels, while onsite wastewater disposal and fertilizer applications may increase the nutrient concentrations. Some groundwater discharges to Hood Canal along the shoreline but most discharges to rivers.

A few point sources contribute directly to Hood Canal. These include a privately owned wastewater treatment plant and the public



stormwater treatment and conveyance systems of the Washington Department of Transportation.

Climate and meteorological conditions also affect both mixing and nutrient loads. Precipitation affects stratification and contributes nutrient loads directly to Hood Canal, while wind conditions influence mixing. Large-scale climate fluctuations and changes may alter water properties and exchanges between Hood Canal and Admiralty Inlet. Seasonal and inter-annual changes in sunlight intensity affect primary production through light availability, while water temperature also affects growth conditions.

What local human activities influence Hood Canal dissolved oxygen levels?

One of the long-term goals of the Hood Canal Dissolved Oxygen Program is to determine what factors or processes, from among the potential contributors listed above, have the greatest influence on oxygen levels. Specifically, the program is designed to quantify the contribution from certain human activities based on data gathered and models applied during the study. This information is critical to evaluating effective potential corrective actions. To begin the study, the program must hypothesize what activities may be significant.

Human wastewater disposal affects water quality through wastewater treatment plant discharges as well as onsite wastewater disposal to groundwater. Nutrients may be delivered to Hood Canal via groundwater discharges to marine waters or via rivers as intermediate steps.

Several activities may contribute to increased nutrient loads from fertilizer applications. Residential and commercial landscaping often involves fertilizer applications. Agricultural applications include both domestic animal manure disposal and minor amounts of crop fertilization. Forestry practices may include fertilizer applications to enhance growth. Forestry and other development practices may have fertilized streams indirectly by the conversion of low-nitrogen loading conifer forests to high-nitrogen loading alder forests. Reduced natural salmon runs or concentrated carcass placement or disposal may have altered nutrient loads. Poorly applied or incorrectly timed residential, commercial, or forestry fertilizer applications may wash off during storm events. Increased impervious surfaces and stormwater conveyance systems generally enhance the connectivity of the landscape to freshwater and marine water bodies, reducing retention of nutrients on land surfaces and enhancing transport to water bodies.

Impervious surfaces and stormwater conveyance systems, coupled with groundwater consumption for domestic and agricultural uses, may alter the amount and timing of river discharges during low-flow summer conditions and high-flow winter storm conditions. How the water moves around relates to the amount of organic matter received, processed, retained, and delivered by rivers to Hood Canal. Changes in freshwater inflows may in turn affect short-term and long-term stratification in Hood Canal.

Naturally low nutrient levels limit phytoplankton growth, as commonly happens in summer, but additional nutrients cause more phytoplankton growth than normal. The dying algal cells will sink and accumulate on the seafloor, where bacteria will break down the organic material, consuming oxygen in the process. Thus, human-induced excessive algae growth can cause lower oxygen concentrations than would naturally occur. The extra load of nutrients from human activities can stimulate phytoplankton growth by providing more food. Excessive accumulation (blooms) can result in dangerously low oxygen concentrations in deep waters of Hood Canal. However, this phenomenon occurs only when low ambient nutrient levels limit growth, rather than other limiting factors such as low sunlight.

If cells have plenty of nitrogen available, then adding more will not have an effect. This is the situation found in well-mixed areas of Puget Sound, such as the Tacoma Narrows, where nutrient-rich deep waters are mixed with surface waters in contact with the atmosphere. But if the waters have layers that do not mix, then low-oxygen zones can develop from stimulated phytoplankton growth. This is the situation in places like Lynch Cove, where freshwater inflows cause density layering or where tidal mixing is gentler. Some areas are naturally more sensitive to nutrient loading than others, and the amount that water quality will be affected varies.

Background

Description of Study Area

Hood Canal (Figure 1) is a glacially carved fjord up to 200 m deep and 100 km long. The geology and bathymetry of Hood Canal influence water quality and hydrodynamics. The northern entrance to the canal is relatively shallow, with water depths of about 50 m. Just south of the entrance, water depth reaches 150 to 200 m. The northern sill impedes the exchange of water with Admiralty Inlet, and average water residence time within Hood Canal is on the order of a year or more. Hood Canal can be highly stratified due to differences in temperature and salinity in the water column. Stratification reduces vertical mixing, which contributes to the low exchange of oxygen between the atmosphere and the lower layer.

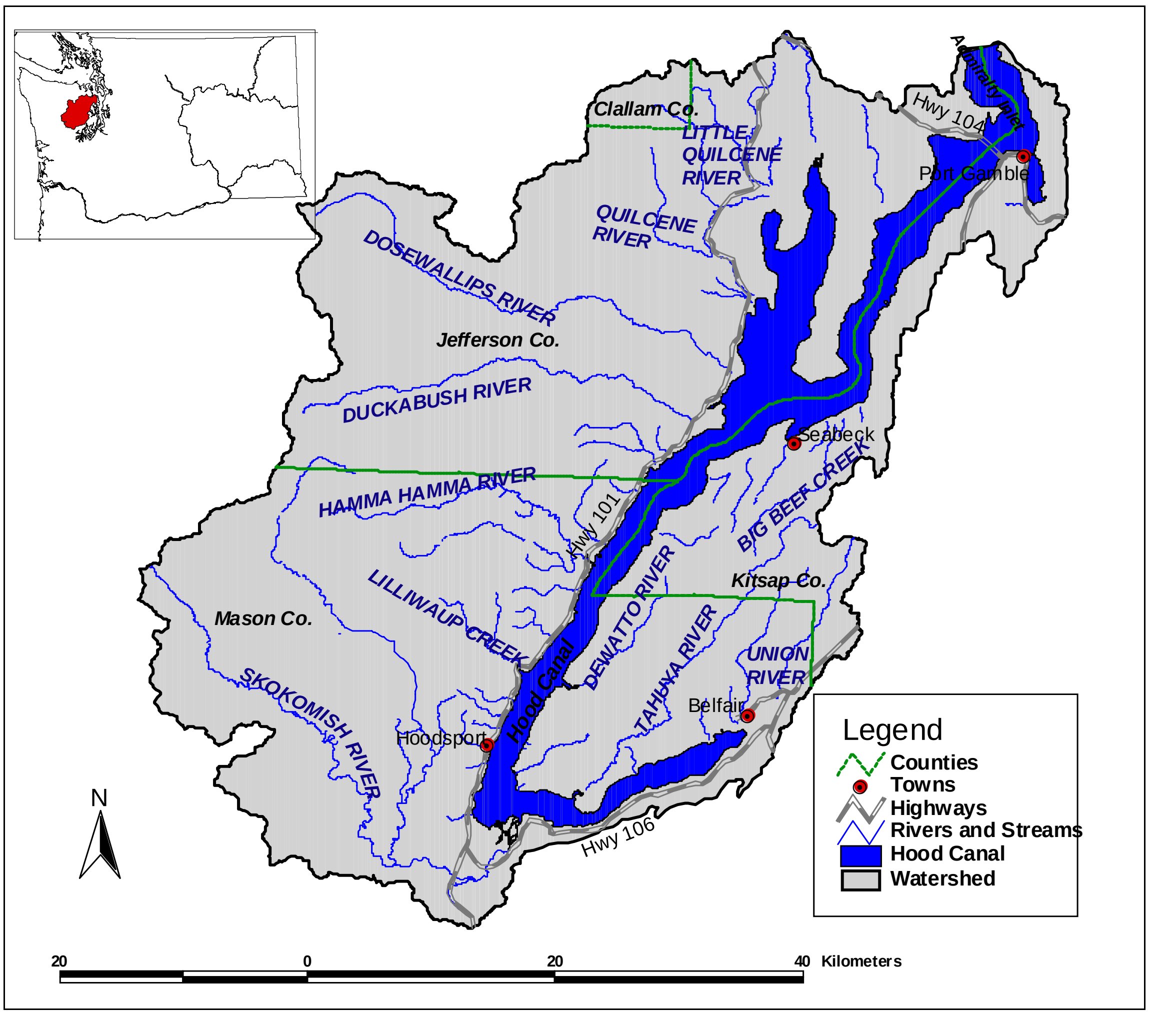


Figure 1. Hood Canal watershed, with major rivers identified.

Hood Canal receives freshwater inflows from rivers and streams as well as groundwater. Natural processes and anthropogenic activities affect the amount of nutrients in freshwater reaching Hood Canal. Terrestrial activities, such as autumn leaf drop, stormwater runoff from lawns and agriculture, effluents from septic systems, and wastewater treatment plant discharges, contribute nutrients. Marine activities, such as salmon carcass disposal, also provide a source of nutrients.

Water Quality Standards and Parameters of Concern

The Washington State water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, waterbody classifications, and numeric and narrative water quality criteria for surface waters of the state. Hood Canal is a Class AA (extraordinary) marine waterbody, per WAC 173-201A-140 (13).

Characteristic uses for Class AA waterbodies include fish and shellfish (salmonid and other fish migration, rearing spawning, and harvesting), wildlife habitat, recreation (primary contact recreation, sport fishing, boating, aesthetic enjoyment), and commerce and navigation. Numeric criteria for specific water quality parameters are intended to protect designated uses.

In Class AA marine waterbodies, dissolved oxygen must not fall below 7.0 mg/L at any time. When natural conditions, such as upwelling, occur that cause the dissolved oxygen concentration to decrease near or below 7.0 mg/L, natural dissolved oxygen levels may be degraded by no more than 0.2 mg/L by the combined effect of all human activities. In addition, the pH must be between 7.0 and 8.5 SU, with a human-caused variation within the above range of no more than 0.2 SU.

Ecology revised the state water quality standards in July 2003, although the marine dissolved oxygen criteria have not been reviewed or approved by the Environmental Protection Agency (EPA). The current status of EPA's review of the state standards does not affect the basis of this study. Under the revised water quality standards, the waterbody classification system was changed. However, the numeric water quality targets for DO and pH in Hood Canal have not.

A variety of factors affect dissolved oxygen levels in marine environments, including meteorology, water residence time, oxygen demand, etc. Previous studies (Newton et al., 1995) suggest that the amount of nitrogen added to the surface waters limits algal productivity in Hood Canal. Therefore, nitrogen is the primary nutrient parameter of concern.

Water Quality Impairments

The Department of Ecology develops and maintains a list of impaired waters, as directed under Clean Water Act Section 303(d). The 1998 303(d) list, the most recent list approved by EPA, includes several waterbodies within the Hood Canal watershed. Table 2 summarizes three listings related to algal productivity within Hood Canal:

In addition, the Skokomish River is listed for instream flow. However, instream flow is not considered a pollutant under the Clean Water Act, and must be addressed through other means, such as watershed planning as defined in the Watershed Planning Act (90.82).

Table 2. Waters that do not meet water quality standards and which are included on the 1998 303(d) list.

Waterbody	New ID	Old ID	Latitude/ Longitude	Parameter	1998 List?
Great Bend, Lynch Cove	390KRD	WA-PS-0260	47.395 / 122.925	Dissolved Oxygen	Yes
Great Bend, Lynch Cove	390KRD	WA-PS-0260	47.395 / 122.925	pH	Yes
Hood Canal (South)	390KRD	WA-PS-0250	47.535 / 123.015	Dissolved Oxygen	Yes

Historical Information Review

A variety of organizations have collected or compiled recent data relevant to water quality in Hood Canal. For a more extensive literature review, see Fagergren et al. (2004). The following programs represent the longest data collection efforts and the most recent compilations.

University of Washington PRISM and Historical Cruises

Under the Puget Sound Regional Synthesis Model (PRISM) program, 11 stations between the northern sill and the Great Bend have been visited twice each year since 1998, generally in June and December. Warner (www.hoodcanal.washington.edu/observations/historicalcomparison.jsp) compiled the recent and historical data, shown in Figure 2, for southern Hood Canal where in recent years, DO levels were lower than historically recorded values. Data sources include ongoing UW PRISM and Ecology data, as well as historical UW data. The PRISM data and the UW data from the 1950-60’s are available digitally.

Department of Ecology Ambient Marine and Freshwater Monitoring

The Department of Ecology has monitored water quality at four stations within Hood Canal on a monthly basis since 1975. Ecology established a network of core monitoring stations that are intended to be visited 12 times each year, although weather conditions have not allowed for these stations to be sampled each month. Ecology has also established a set of rotating stations that are incorporated in the monthly schedule every five years in both marine and freshwater systems. At each marine station, profiles of temperature, salinity, dissolved oxygen, light transmission, and pH are recorded, and discrete samples are collected at approximately 10-m intervals and analyzed for chlorophyll, phaeopigment, nitrate, nitrite, ammonium, orthophosphate, and silicate. Secchi depth is also recorded. In freshwater systems, grab samples are collected and analyzed for total nitrogen, nitrate plus nitrite, ammonium, total phosphorus, orthophosphate, fecal coliform, suspended solids and turbidity and *in situ* values of temperature, pH, conductivity, and dissolved oxygen recorded. Table 3 summarizes the period of record for data available by station. See Experimental Design for station locations.

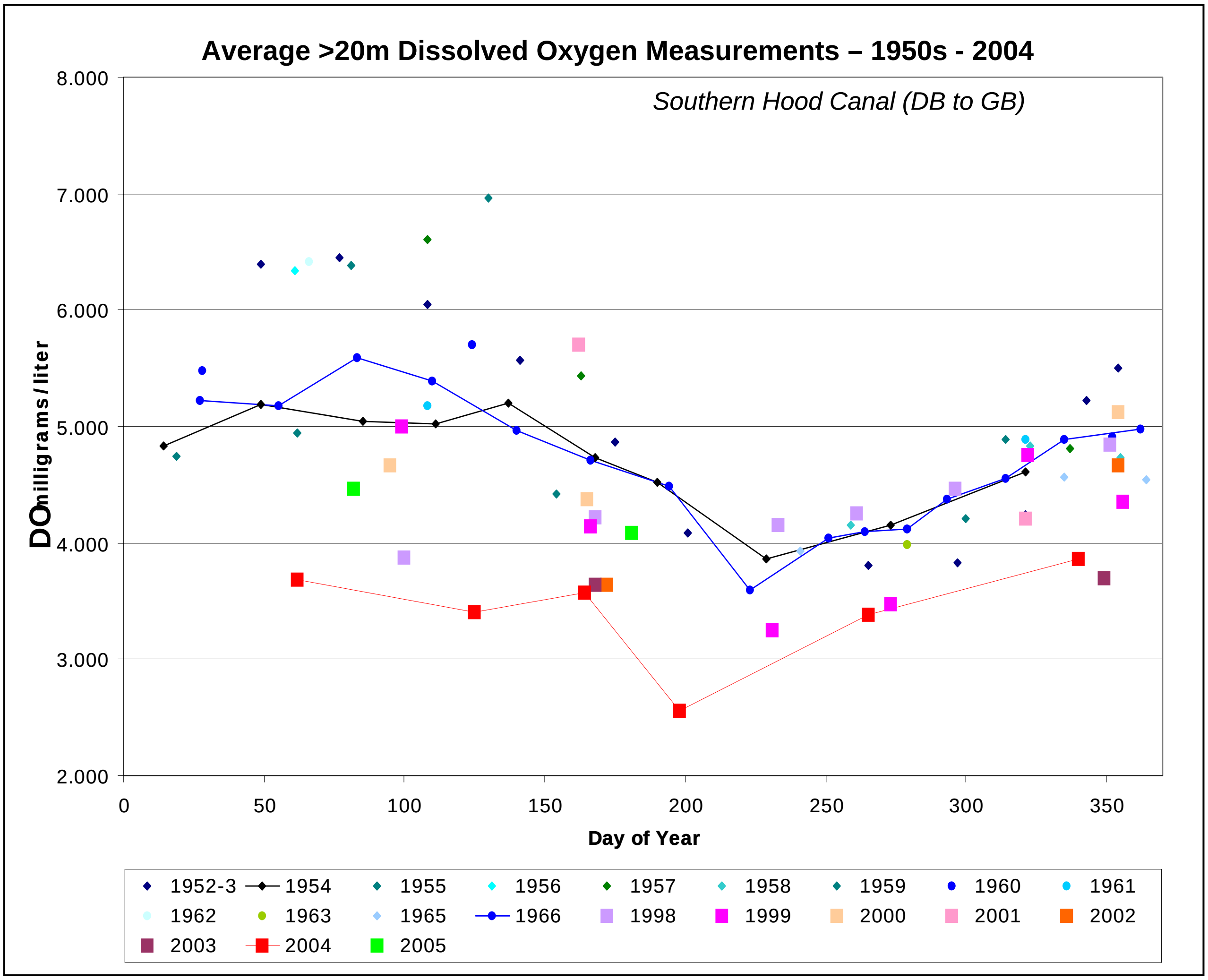


Figure 2. Historical and recent dissolved oxygen levels in southern Hood Canal. Source: M. Warner (UW), HCDOP website: www.hoodcanal.washington.edu/observations/historicalcomparison.jsp.

Table 3. Department of Ecology ambient monitoring stations for Hood Canal.

Station	Dates Available	Comments
HCB002 – Dabob Bay Pulali Pt	1975 through 1987	Discontinued station
HCB003 – Eldon, Hamma Hamma River	1976 through present	Rotating station*
HCB004 – Great Bend, Sisters Pt	1975 through present	Core station
HCB006 – King Spit, Bangor	1975 through present	Core station
HCB007 – Lynch Cove	1975 through present	Rotating station*
ADM001 – Admiralty Inlet, Bush Pt	1975 through present	Core station
ADM002 – Admiralty Inlet, Quimper Pn	1988 through present	Core station
16A070 - Skokomish River	1980s through present	Core station
16C090 - Duckabush River	1990s through present	Core station

*Rotating stations are visited at 5-year intervals.

U.S. Geological Survey 2004 Annual Nitrogen Load Estimates

U.S. Geological Survey (USGS) estimated annual dissolved inorganic nitrogen (DIN) as nitrogen loads from surface water and groundwater to Hood Canal, based on existing data (Paulson et al., 2004):

- Rivers and streams 421 ± 162 metric tons[1]
- Regional ground water 56 ± 30 metric tons
- Near-shore septic systems 28 ± 15 metric tons
- Atmospheric 30 ± 11 metric tons
- Other sources 20 ± 5 metric tons
- Marine (oceanic) 8,700 to 31,200 metric tons

The analysis was included as an appendix in Fagergren et al. (2004).

Puget Sound Action Team and Hood Canal Coordinating Council Preliminary Assessment and Corrective Action (PACA) Plan

Fagergren et al. (2004) identified and quantified nitrogen sources to Hood Canal influenced by human activities based on a collaborative effort among the Puget Sound Action Team; the Hood Canal Coordinating Council; national, state, and local governments; tribes; and other local representatives. The report summarized ranges of annual nitrogen loads totaling 86 to 319 tons per year, based on available data and best professional judgment:

- Human sewage 39 to 241 tons
- Stormwater runoff 12 to 24 tons
- Chum salmon carcasses 16 to 24 tons
- Agricultural waste 18 to 22 tons
- Forestry 0.5 to 5 tons
- Point source discharge 0.3 to 3 tons

The report summarizes current and historical monitoring efforts by Ecology, the UW PRISM effort, USGS, Kitsap County Health District, and more recent citizen monitoring through the Hood Canal Salmon Enhancement Group (HCSEG).

USGS National Water Quality Assessment (NAWQA)

Embrey and Inkpen (1998) estimated nutrient loads to Puget Sound from several major rivers based on existing nutrient concentrations and discharge data for the period 1980-1993. Dissolved inorganic nitrogen (DIN)[2] loads for rivers tributary to Hood Canal include the following:

- Dewatto River 14 tons
- Skokomish River 170 tons
- Hamma Hamma River 45 tons
- Duckabush River 28 tons
- Dosewallips River 47 tons

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[1] 1 metric ton = 1000 kg = 2204 lb = 1.10 English tons.
[2] Dissolved inorganic nitrogen is the sum of nitrate, nitrite, and ammonium fractions.

The watershed DIN yields, the load normalized by the watershed area, were lower for rivers tributary to Hood Canal than for east or south Puget Sound rivers, ranging from 0.5 to 0.9 tons/mi^2/year.

EnviroVision Freshwater Monitoring

EnviroVision Corporation monitored water quality in fourteen streams along the north and south shores from January through June 2005 (EnviroVision, 2005) through a grant from the WRIA Planning Unit. Watersheds are dominated by forest cover (56 to 98%). Grab samples were collected from each site during five wet and four dry season events. Samples were analyzed for biochemical oxygen demand (BOD), total suspended solids (TSS), fecal coliform (FC), total phosphorus (TP), and nitrate plus nitrite (NO23N). Discharge, temperature, pH, salinity, and specific conductance were determined *in situ*. Nitrogen concentrations were low in general, with the highest concentrations found in Happy Hollow (0.4 mg/L in wet season), Devereaux (0.3 to 0.7 mg/L wet season), and Mulberg (0.5 to 0.6 mg/L year-round) creeks. Annual average loads ranged from 0.001 to 3.6 tons of nitrate plus nitrite per year for a total of 10.1 tons/year from the 59 mi^2 contributing area. South shore watersheds had a higher yield (0.44 tons/mi^2/year) than north shore watersheds (0.17 tons/mi^2/year).

Kitsap County Health District

Kitsap County Health District (KCHD) monitors four tributary creeks to Hood Canal. Staff record temperature, dissolved oxygen, pH, conductivity, and turbidity, and collect fecal coliform samples on a monthly basis (J. Kiess, personal communication). Stations include Stavis, Seabeck, Big Beef, and Little Anderson creeks. Only Big Beef creek has had a minimum dissolved oxygen level below 8 mg/L; levels in the other three creeks generally exceed 10 mg/L, as shown in Figure 3.

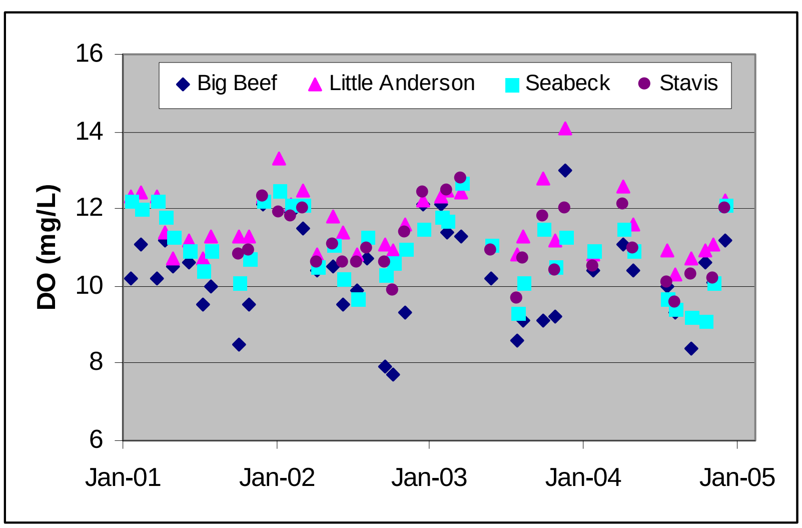

Figure 3. Dissolved oxygen monitoring data for four creeks tributary to Hood Canal. Source: KCHD, Kiess, personal communication.

Jefferson County Conservation District

The Jefferson County Conservation District (JCCD) has collected monthly water quality data, including nitrate-nitrogen, in Tarboo Creek and Donovan Creek in 2000, 2002, 2003-04. The next round of monitoring will be from October 2005 to September 2006. Flow data has been collected during most of the sampling dates. Nitrate-nitrogen was analyzed by Ion Selective Electrode (ISE) at the JCCD lab (not Ecology accredited).

The JCCD also have 1998 data including nitrate-nitrogen, total phosphorus, and flows for Leland Creek, a tributary of the Little Quilcene River, and for about 10 small streams flowing into Lake Leland. Nutrients were analyzed by an Ecology-accredited lab.

Mason County Environmental Health

The data are included in the EnviroVision section.

Mason Conservation District

Mason Conservation District has participated in monitoring of the Skokomish River with the Skokomish Tribe and Ecology. Information is included with other studies.

Hood Canal Salmon Enhancement Group (HCSEG)

The HCSEG will complete a Centennial Clean Water Grant, Lower Union River Restoration Study, by December 2005. This program collected monthly water samples at 25 tributary and main-stem stations in the lower Union River watershed which were analyzed for oil/grease, mercury, dissolved metals (cadmium, copper, lead, and zinc), organics, semi-volatile nitrogen/phosphorus pesticides, chlorinated herbicides, hardness, and TSS.

Sediment samples were collected in four stations in the Lynch Cove estuary and analyzed for priority pollutants metals, PCBs, grain size, and TOC. Twiss Analytical Laboratories analyzed the samples. The data are currently being reviewed and interpreted by the Department of Ecology personnel.

Project Description

The overall goal of the HCDOP IAM Study is to quantify the factors that contribute to low marine dissolved oxygen levels. The objectives of the first year of studies are to begin intensive water quality studies to supplement ongoing data collection programs and to begin developing models to simulate the terrestrial and oceanographic production and delivery of nutrients to Hood Canal and the response of marine dissolved oxygen.

Data collection includes a variety of marine and freshwater monitoring programs targeting specific potential sources. Marine monitoring is necessary to quantify ocean properties, including temperature, salinity, dissolved oxygen levels, and nutrient concentrations that establish boundary conditions. Freshwater monitoring will supplement the ongoing Mason County Environmental Health, Mason Conservation District, Skokomish Natural Resources, Jefferson Conservation District, Kitsap Health District, WRIA 16, USGS, UW, and Ecology data collection activities to quantify the freshwater flows and nutrient loads entering Hood Canal. These data collection activities support the development of and input to terrestrial and marine models, which are necessary to combine the influences of watershed and ocean processes on the productivity of Hood Canal. Figure 1 presents the geographic emphasis for the IAM study.

The information developed in the first year of the project will be used to scope the activities of the second year. The multiple years of data collection will support model development and model application to allow project participants to understand the roles various natural and anthropogenic factors play in low dissolved oxygen levels in Hood Canal. The study results will quantify the influence of ocean conditions, atmospheric inputs, land-use changes, point source discharges from wastewater treatment plants and nonpoint sources, including septic systems and agricultural, residential, and forestry fertilizer applications.

Organization, Funding, and Schedule

The Hood Canal Dissolved Oxygen Program includes representatives from a number of organizations funded through a variety of sources. Congressional funding was disbursed to UW-APL in 2005. The purpose of the congressional appropriation was to undertake the first year of a planned three-year scientific study of the factors contributing to low dissolved oxygen in Hood Canal. Funds were disbursed to the UW School of Oceanography and the Hood Canal Salmon Enhancement Group, which contracted with a variety of tribal, state, and county organizations to complete certain study elements. Figure 4 presents the project organization and Hood Canal DO Program congressional funding pathways under UW APL, while Table 4 lists specific roles for program participants.

The HCDOP effort also depends on separate funding efforts for portions of the data collection and model development. These additional resources include the following:

- USGS Washington Science Center has separate funding to evaluate groundwater loads of nitrogen to Hood Canal. The Washington Science Center also maintains stream gages within the watershed that provide fundamental hydrologic data.
- USGS Menlo Park has ongoing funding to develop and apply a coupled hydrodynamic and water quality model to Hood Canal.
- UW School of Oceanography leads the PRISM project, funded by external grants and partnerships, which maintains a marine water quality network and will develop the terrestrial and marine model of Hood Canal and its watersheds.
- State agencies, counties, and tribes operating various networks of marine and freshwater monitoring stations funded by a variety of sources. For example, Ecology's ambient monitoring network is funded by the State General Fund, Clean Water Act Section 106 funds administered by EPA, and miscellaneous project grant money.

The co-managers are responsible for overall project management and coordination among the various entities.

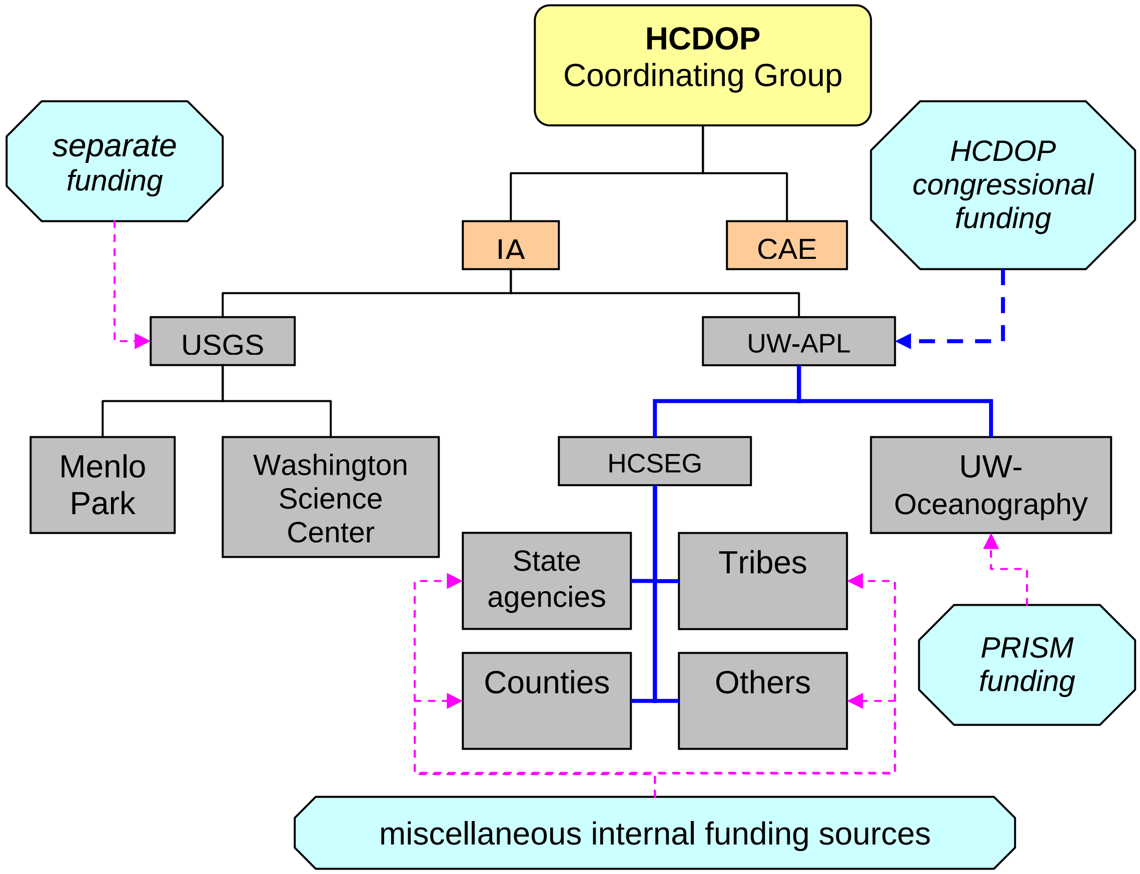

Figure 4. Hood Canal Dissolved Oxygen Program IAM study organization. Bold blue lines indicate HCDOP funding pathways, while dashed pink lines indicate other federal, state, and local funding pathways.

Table 4. Roles and responsibilities for HCDOP participants.

Name	Role	Affiliation	Responsibilities
Program Administration			
Jan Newton	Co-Manager and Principal Investigator	UW Applied Physics Laboratory	Oversees implementation of the IAM Study and leads scientific evaluation
Dan Hannafious	Co-Manager	Hood Canal Salmon Enhancement Group	Oversees implementation of the Integrated Assessment and Modeling Study
Gary Turney	Manager	USGS Washington Science Center	Coordinates USGS contributions to IAM
Marine Waters Sampling and Modeling Task			
Al Devol	Marine Lead and Investigator	UW School of Oceanography	Construction, installation, and maintenance of two new and one existing ORCA buoy
Matthew Alford	Investigator	UW Applied Physics Laboratory	Construction, installation, and maintenance of marine profiler
Mark Warner	Investigator	UW School of Oceanography	Analysis of historical and current marine data
Dan Hannafious and Renee Rose	Technical Leads	Hood Canal Salmon Enhancement Group	Volunteer citizen monitoring training and coordinator for transects and stream water quality monitoring
Brian Grantham and Skip Albertson	Technical Leads	Ecology, EA Program	Coordinate with Ecology marine ambient monitoring
Keith Dublanica and Lalena Amiotte	Technical Leads	Skokomish Tribe	Marine transects, stream water quality monitoring data collection
Dan Cheney & Aimee Christy	Technical Leads	Pacific Shellfish Institute	Identify phytoplankton species in HCSEG tows
Mitsuhiro Kawase	Marine Modeling Lead and Investigator	UW School of Oceanography	Develop theoretical basis for simulating dissolved oxygen in Hood Canal; develop marine water model
Ralph Cheng and Ed Josberger	Investigator	USGS Menlo Park and Washington Science Center	Develop Hood Canal hydrodynamic model
Freshwater and Terrestrial Sampling and Modeling Task			
Jeff Richey	Terrestrial/ Freshwater Lead and Investigator	UW School of Oceanography	Oversee development of the terrestrial model and freshwater data collection
Mike Brett	Investigator	UW College of Engineering	Oversee development of the terrestrial model and freshwater data collection. Coordinate stormwater sampling
Matthew Wiley	Terrestrial/ Freshwater Model Lead and Investigator	UW College of Engineering	Develop theoretical basis for simulating terrestrial and freshwater nutrient cycles; terrestrial model development

Name	Role	Affiliation	Responsibilities
Mike O'Neal	Investigator	UW PRISM	Geological mapping related to groundwater inputs
Tony Paulson	Investigator	USGS Washington Science Center	Nutrient loads study
Suzanne Osborne	Technical Lead	UW and USGS	Stream water quality monitoring data collection and coordinator for others
Pam Bennett-Cumming	Technical Lead	Mason County Environmental Health	Stream water quality monitoring data collection
Glenn Gately	Technical Lead	Jefferson County Conservation District	Stream water quality monitoring data collection
John Kiess	Technical Lead	Kitsap County Health District	Stream water quality monitoring data collection
Shannon Kirby	Technical Lead	Mason Conservation District	Stream water quality monitoring data collection
Rob Plotnikoff and Bob Cusimano	Technical Lead	Ecology, EA Program	Coordinate Ecology's Freshwater ambient monitoring program and assist with HCDOP stormwater efforts
Bill Simonds	Investigator	USGS Washington Science Center	Groundwater flows and nutrient loads study
Richard Tveten	Technical Lead	WSDOT	Maintain inventory of historical WSDOT stormwater quality data
Joy Michaud	Technical Lead	EnviroVision	Coordinate freshwater ambient monitoring program
Ted Labbe	Investigator	Port Gamble S'Klallam Tribe	Historical riparian forest cover datalayer development
Biota Task			
Maggie Dutch	Investigator	Ecology, EA Program	Benthic community assessment
Brian Grantham	Investigator	Ecology, EA Program	Benthic community assessment
Dave Shull	Investigator	Western Washington University	Benthic community assessment
Paul Hershberger	Investigator	USGS, Marrowstone Is	Fish pathology study
Emergency Response Task			
Dan Hannafious	Emergency Response Co-Lead and Responder	HCSEG	Coordinate response and water samples and biota collection
Lalena Amiotte	Responder	Skokomish Tribe	Water samples and biota collection
Martin Chen	Responder	WDFW	Fish pathology and sampling
Marcia House	Responder	NWIFC	Fish pathology and sampling
Paul Hershberger	Responder	USGS, Marrowstone Is.	Fish pathology
Aimee Christie	Responder	Pacific Shellfish Institute	Identify phytoplankton species in water samples
Jan Newton	Emergency Response Co-Lead	UW Applied Physics Laboratory	Post website notification and help to coordinate response

Name	Role	Affiliation	Responsibilities
Data Management			
Miles Logsdon	Data Lead	UW School of Oceanography	Data management
Sara Simrell	EKO Coordinator	Paladin Data Systems	Data coordination
QAPP			
Mindy Roberts	QAPP Lead	Ecology, EA Program	Develop Quality Assurance (QA) Project Plan for overall program
Karol Erickson	Unit Supervisor	Ecology, EA Program	Review and approve QA Project Plan
Kim McKee	Unit Supervisor	Ecology, WQ Program	Review and approve QA Project Plan
Will Kendra	Section Manager	Ecology, EA Program	Review and approve QA Project Plan
Bob Cusimano	Section Manager	Ecology, EA Program	Review and approve QA Project Plan
Cliff Kirchmer	Quality Assurance Officer	Ecology	Review and approve QA Project Plan

Table 5 summarizes the expected project schedule. Tasks for Year 2 and beyond are preliminary and contingent on securing additional funding.

Table 5. Hood Canal Dissolved Oxygen Program schedule for Year 1 activities.

Activity	Affiliation	Date	Ongoing*
Marine Monitoring			
Install and maintain ORCA buoys	UW Oceanography	January 2005 through March 2006	
PRISM cruises	UW PRISM	June and December 2005	X
Ambient marine water quality data collection	Ecology EA Program	April 2005 through March 2006	X
Ambient marine water quality data collection	UW APL	April 2005 through March 2006	
Marine transect monitoring	HCSEG	August 2003 through March 2006	
Freshwater Monitoring			
Stream water quality monitoring	UW, Skokomish Tribe, Jefferson Cty, Kitsap Cty, Mason Cty	April 2005 through March 2006	
Discharge monitoring	USGS, Ecology EA Program	April 2005 through March 2006	X
Ambient stream water quality monitoring	Ecology EA Program	April 2005 through March 2006	X
Groundwater flows and nitrogen loads	USGS	May through September 2005	X
West Shore discharge monitoring	Aspect	July 2004 through July 2005	
Terrestrial Model Development			
User interface for DHSVM	UW PRISM	April through March 2006	
Groundwater components	UW PRISM	April through March 2006	
Stream temperature simulation	UW PRISM	April through March 2006	
Biogeochemical processes	UW PRISM	April through March 2006	
Marine Model Development			
Develop and validate hydrodynamic model	UW PRISM	April through March 2006	X
Develop and validate hydrodynamic model	USGS	April through March 2006	X
Begin developing marine DO model	USGS	April through March 2006	X
Documentation and Reporting			
Quarterly reports submitted to HCDOP-IAM partners and posted to web-site	UW APL, HCSEG	Submitted July and Oct. 2005, Jan. and Mar. 2006	X

*Ongoing programs are in place and will continue in subsequent years under existing contracts and programs. Tasks expected to continue but funded through additional HCDOP contracts are not identified as ongoing.

Modeling Approach

A series of models will be applied to Hood Canal and its watershed. Data compilation and collection will support a model of the terrestrial and freshwater landscape, which will provide the input to two complementary marine models. The marine models will be used together, similar to the ensemble of models used for weather forecasting and climate simulations.

Through the UW PRISM effort, researchers at UW are applying a distributed hydrologic model to the Hood Canal watershed to simulate surface water contributions. Ongoing efforts will supplement the model capabilities to include groundwater contributions, stream temperatures, and surface water nutrient loads.

Two independent marine modeling efforts will simulate hydrodynamics and dissolved oxygen within Hood Canal. Researchers from UW PRISM have developed a coarse-resolution hydrodynamic model of the entire Puget Sound, including Hood Canal. During Year 1, a second finer-resolution model will be evaluated. In addition, a dissolved oxygen model will be coupled to the hydrodynamic model. Under a separate effort, USGS staff will apply a hydrodynamic model of Hood Canal during Year 1 and will begin developing the structure of a dissolved oxygen model that will be completed during subsequent years.

UW PRISM Terrestrial and Freshwater Model

To simulate the inflows of water, nutrients, and other parameters, new groundwater, stream temperature, and biogeochemical processes will be added to an existing hydrology model. The Distributed Hydrology Soil–Vegetation Model (DHSVM) was developed at the University of Washington and Princeton University to simulate land surface and subsurface processes (Wigmosta et al., 1994; Wigmosta et al., 2002). The model has been applied to Pacific Northwest conditions at a range of spatial scales.

Initial model development will focus on the addition of a user interface to facilitate input and output data management. In addition, UW PRISM will develop the theoretical framework for adding groundwater, temperature, and nutrient processes to DHSVM and will begin model development. An initial working version is scheduled during Year 1, with further refinement expected in subsequent years.

Description of Groundwater Approach

The groundwater component to be incorporated into DHSVM is envisioned as a three-dimensional, hydraulic-gradient-driven flow network. The limiting factors affecting rates of flow and storage capacity will be parameterized by the prevailing geologic features. Spatial data of the surficial geology types are available from the Washington State Department of Natural Resources (www.dnr.wa.gov/geology/dig100k.htm). The surficial geology polygons will be aggregated to a set of 10 to 15 predominant classes based on porosity, permeability, and potential aquifer thickness. The hydraulic parameters of the geology classes will be estimated initially based on published literature values, and further refined for the Hood Canal application based on field tests and available observed data.

Description of Stream Temperature Approach

Water temperatures within the DHSVM-simulated stream network will be modeled using a mass and energy balance approach that considers each segment of the stream network (typically a 150- to 600-m reach) as a single, well-mixed, one-dimensional element (Chapra, 1997). The energy balance, and consequently the water temperature, in each segment is affected by metrological conditions (solar radiation, wind speed, etc.), channel morphology, and by the temperature of incoming surface and subsurface flows. The temperatures of surface flow and subsurface flow within the soil layers are calculated within the hydrologic model, while the temperature of base flow from deeper groundwater will be estimated from observations.

Description of Biogeochemical Processes

A solute export module is being developed that will estimate the amount and concentration of basin dissolved carbon and nitrogen (nitrate, ammonium, dissolved organic nitrogen, dissolved organic carbon, and dissolved inorganic carbon) via subsurface flow and instream concentrations (J. Richey and P. Rattanaviwatpong, personal communication). This chemistry module is distributed and physically based and is designed for integration with DHSVM. The two entities share physical templates and spatial resolution. The DHSVM runs on a sub-daily timestep while the chemistry model operates on a daily basis. The solute export module consists of two main sub-modules: basin and stream. The control volumes in the basin are the soil solutions in each soil root zone and in the saturated lateral layer. Once the nutrients are routed into the stream network, the control volumes are individual stream segments.

Spatial and Temporal Scales

Currently, DHSVM is configured for 150-meter grids; however, the model is being scaled to achieve 30-meter resolution. The temporal resolution of the model uses a three-hour time step. Model output is typically aggregated to daily average values.

Model Inputs

Model inputs include the following (www.hoodcanal.washington.edu/models/land.html):

- Elevations—The effort will use the 10-meter digital elevation model (DEM) developed by UW-PRISM for western Washington. The DEM is based on the USGS ASCII DEM files digitized from contour lines at 40-foot or finer intervals from 7.5-minute maps.
- Stream Network—The datalayer will be developed from the 10-m DEM aggregated to 150-m resolution. Streams are defined as receiving at least 0.25 km^2 of contributing area.
- Soil Type—The state soil surveys (WAGDA, 2004) were used to define 18 potential soil types defined by texture class, vertical and lateral conductivity, maximum infiltration, and other relevant physical parameters.
- Land Cover and Vegetation—The datalayer is derived from NOAA's Coastal Change Analysis Program (C-CAP, www.csc.noaa.gov/crs/lca/ccap.html). Parameters such as impervious fraction, presence of overstory or understory, and fractional coverage (percentage of pixel in which overstory is present) will define 20 vegetation types. The 30-m resolution of the

C-CAP dataset may be aggregated to 150 m depending on model implementation. Changes to the land cover datalayer will define potential future scenarios.

- Soil Depth—Spatial distribution of soil depth will be developed based on slope, contributing area, and elevation. The information will be verified by comparing results to water well log records.
- Terrain Shadowing and Percent Open Sky—Topographic shade will be developed from the aggregated DEM described under Elevations above. The derivation of terrain shadowing is based on the slope, aspect, latitude, longitude, and time of year. Percent open sky is a fixed datalayer while the terrain shadow layers will vary monthly to incorporate seasonal solar position.
- Precipitation—Oregon State University developed the Parameter-Elevation Regressions on Independent Slopes Model (Daly et al., 1994; Daly et al., 1997; SCAS, 2004) to distribute precipitation from monitoring stations to a grid based on slope, elevation, and aspect.
- Meteorological Data—DHSVM requires the following meteorological parameters: air temperature, wind speed, relative humidity, incoming shortwave radiation, outgoing longwave radiation, precipitation (described above), and temperature lapse rate. Daily results will be temporally disaggregated to 3-hour intervals.
- Other Data—DHSVM requires several parameters to describe the landscape: ground and snow roughness, minimum and maximum temperature for snow, snow water capacity, wind reference height, rain and snow interception as a function of leaf area index (LAI), intercepted snow that can melt, and temperature lapse rate.

Other potential anthropogenic nutrient sources in the Hood Canal watershed include agricultural and residential fertilizer application, livestock and pet waste generation, forest biosolids application, and salmon carcasses. During Year 1, several data sources will be investigated to quantify these potential nutrient loads for incorporation into the terrestrial model.

UW PRISM Marine Model

A series of coupled hydrodynamic and water quality models will simulate dissolved oxygen in Hood Canal. The Princeton Ocean Model (POM) will simulate the hydrodynamics of the entire Puget Sound to provide boundary conditions for the Hood Canal Model. The Regional Ocean Modeling System (ROMS) will be applied to Hood Canal at a finer spatial scale than the POM grid of Puget Sound. Both the Aquatic Biogeochemical Cycle (ABC) model and ROMS simulate processes affecting dissolved oxygen within Hood Canal.

The UW PRISM project has developed and applied linked hydrodynamic and water quality models to Puget Sound. POM (Blumberg and Mellor, 1987; Mellor, 1996) simulates the motion of marine water in cells of resolution 360 m by 540 m in 14 layers to represent the water column. Boundary conditions and forcing functions include tides, freshwater inflows, meteorology, and hydrographic conditions at the model boundary in the Strait of Juan de Fuca (www.hoodcanal.washington.edu/models/marine.html). POM predicts the sea surface elevation, three-dimensional velocity structure, temperature, and salinity resulting from initial and boundary conditions using the primitive equations (hydrostatic approximation that the vertical pressure gradient offsets buoyancy). The model produces output every thirty minutes.

UW PRISM led a regional effort to develop the Aquatic Biogeochemical Cycle model to simulate the plankton food web. ABC has been coupled to the POM application in Puget Sound (Nairn et al., 2005). ABC simulates three zooplankton compartments, three phytoplankton compartments, refractory and labile particulate organic matter, dissolved organic matter, oxygen, nitrate, orthophosphate, and ammonium (squid.ocean.washington.edu:8080/foodweb/). The model runs on the same time scale as POM and utilizes a grid of resolution 1200 m by 1800 m.

Benthic fluxes of oxygen and nitrate will be specified as a boundary condition based on existing data from Dabob Bay (seasonal data; Devol unpublished data) and the main stem of Hood Canal (spatial distribution; Shull unpublished data).

ROMS was developed at Rutgers University and UCLA (Song and Haidvogel, 1994). ROMS also uses the primitive equations (hydrostatic approximation) to simulate the movement of water forced by tidal elevations at the model boundary, meteorology, and freshwater inflows. ROMS offers the ability to resolve high gradients near the surface that develop during stratification. The coupled POM-ABC system will develop the boundary conditions for the northern extent of the Hood Canal ROMS application.

ROMS will be applied to Hood Canal to simulate the hydrodynamics and oxygen dynamics at a finer spatial scale than offered by POM-ABC. The model uses a curvilinear quasi-orthogonal grid. Two versions of the grid have been developed. The coarser grid has a minimum cell size of 140 m and average of 300 m, and covers the Hood Canal domain with 48 x 288 horizontal cells and 25 vertical levels. The finer grid has the resolution twice that of the coarser grid in the horizontal (minimum cell size 70 m, average cell size 150 m, 96 x 576 cells) and has the same number of vertical levels. The high resolution model will be used for analyses of detailed dynamics, while the low resolution model will be used for parameter sensitivity studies and biogeochemical modeling.

The ROMS hydrodynamics model is forced by a specified tidal level at the entrance, and incorporates fresh water discharge from the UW terrestrial model, hydrographic boundary conditions from the ORCA buoy at the entrance, and meteorological forcing from mapped local observations. The model is validated against historical tidal records, ADCP current profiles and hydrographic measurements from profiling buoys. A particular attention will be paid to the mechanical energy balance of the Canal with energy inputs coming from tides and winds and driving turbulent mixing at the entrance sill and in the interior basin.

The biogeochemistry module of ROMS is based on a design described in Fasham et al. (1990). The model is nitrogen based, and simulates changes in the concentration of phytoplankton and zooplankton biomass, nitrate, ammonia, and detritus in the water column. As of the version 2.2, the model also predicts dissolved oxygen concentration. Particulate flux reaching the sediment is remineralized and returned to the nitrate pool to conserve total nitrogen. Oxygen is consumed in the process. Currently, mineralization is immediate, but a time delay may be incorporated as well as loss via burial. The model is forced with input of nutrients from terrestrial discharges and marine inflow, together with shortwave solar radiation penetrating into the water column. Air-sea flux of oxygen is calculated using bulk parameterization, and sedimentary fluxes of oxygen and nutrients are specified. Forcing parameters needed by the model will be supplied from the terrestrial hydrology model, the entrance ORCA buoy, and meteorological data.

USGS Marine Model

The USGS is presently constructing and calibrating a numerical hydrodynamic model of the Hood Canal system to understand the causes of low dissolved oxygen (DO) in the canal. The numerical model is a three-dimensional unstructured grid model, known as UnTRIM (Casulli and Zanolli, 2002; Cheng and Casulli, 2002), which is an extension from a family of semi-implicit finite-difference models developed by Professor V. Casulli in conjunction with USGS scientists and others (e.g., Casulli and Cheng, 1992). The capability of the unstructured grid model allows for accurate boundary fitting to the topography of Hood Canal with very fine resolution in areas of interest and complex bathymetry. This model treats wetting and drying of shallow regions in a simple and consistent way. The current model uses a horizontal cell size of 200 m. Thirty vertical layers vary in thickness and are placed strategically to resolve the vertical structure of the density and velocity fields, varies from 2 m for the first 10 layers to 20 m in the bottom two layers. The current grid uses 7,400 polygons and 150,000 computational prisms.

The model solves the coupled nonlinear three-dimensional shallow water equations, including baroclinic effects. Tides are introduced at the open boundary, along with fresh water input from rivers and surface wind stress resulting in changes in water density structure which may have great impact to DO. The basic objective of this study is to gain an understanding of the circulation and movement of water in Hood Canal and other factors that impact DO in Hood Canal. There are two phases in this modeling study: the first is to develop and validate the three-dimensional numerical model that accurately reproduces the circulation, and the second is to develop techniques to simultaneously model the temporal and spatial fluctuations of DO. Both the hydrodynamic and water quality components will use a 3-minute time step.

The first phase of the model development is focused on reproducing the tidal hydrodynamics, and on reproducing the mixing processes of fresh water introduced to the system from major rivers. There are eight historical tide stations in Hood Canal where tidal levels can be synthesized by harmonic constants for those sites. In September and October of 2004, the USGS deployed two Acoustic Doppler Current Profilers (ADCPs) in the Great Bend area, which provided continuous measurements of the vertical velocity profile for the two-month period. This phase of the model application is attempting to reproduce the available ADCP data and the synthesized tidal water levels at the eight stations distributed along the axis of Hood Canal and the presence of strong vertical stratification due to river inflow from the Dosewallips, Skokomish, Hamma Hamma, and Duckabush rivers. During Year 1, USGS will develop and calibrate the three-dimensional baroclinic hydrodynamic model. Model results will be documented in a report and published in the open literature in subsequent years.

The second phase of the modeling study is to add DO simulation to the hydrodynamic model. An accurate model of the DO must include an algal component and a nutrient component. The algal component includes the solar illumination, algal concentration, and the rates of growth, mortality, respiration, and settling for each algal component. At a minimum, the nutrient component needs to include the bioavailable phosphate, ammonia, and both nitrate and nitrite. DO model development will begin during Year 1 and will be finalized in subsequent years.

The model will include sediment oxygen demand; however, the process will be developed more thoroughly in the subsequent year’s activities.

Application of Models to Future Scenarios

The models will be used to simulate potential corrective actions, such as eliminating septic tank inputs or changing land-use patterns, as well as to simulate natural processes, such as variable ocean conditions or drought, to understand the sensitivity of Hood Canal oxygen content to these forcing functions and to evaluate the efficacy of potential corrective actions. Sensitivity testing will be conducted for the various forcings. The potential corrective actions to be tested will be determined based on the sensitivity results and on input from stakeholders in HCDOP and the Hood Canal community.

During the first year of the HCDOP, project managers and those responsible for model development and data collection will collaborate on strategies for simulating future watershed conditions as well as determining natural conditions relevant to both terrestrial and marine processes. The approach will be specified in subsequent project plans.

Experimental Design

A variety of agencies will conduct data collection programs in both marine areas and freshwater rivers and streams. Table 6 summarizes the programs, which are described in subsequent sections.

Table 6. Summary of data collection activities.

Program	Frequency	Location
Marine Monitoring Programs		
UW ORCA buoys	Continuous (2 hours)	3 stations
UW PRISM cruises	Twice per year	11 stations
Ecology / PSAMP marine monitoring	Monthly	4 stations in Hood Canal 2 stations in Admiralty Inlet 3 stations in Str. Juan de Fuca
UW-APL moored profiler	Continuous (30 minutes)	1 station
Ecology permanent mooring	Continuous (15 minutes)	1 station
HCSEG marine monitoring	Weekly	7 transects, 22 stations total
Freshwater Monitoring Programs		
Ecology stream water quality	Monthly	2 stations
Coordinated stream water quality monitoring (through June 2005)	Monthly	20 stations
Coordinated stream water quality monitoring (beginning July 2005)	Monthly	Skokomish Tribe – 20 stations Mason County – 8 stations Jefferson County – 4 stations Kitsap County – 4 stations
Ecology discharge and temperature monitoring	Continuous	Continuous – 7 stations Intermittent – 1 station
USGS discharge and temperature monitoring	Continuous (15 minutes)	8 stations for discharge 2 stations for water and air temperature
West shore streams discharge (through July 2005 by Aspect Consulting)	Continuous	10 stations
North shore streams discharge and temperature	Continuous	5 stations
USGS groundwater studies	Seasonal	3 locations
Stormwater monitoring	4 events	3 locations

Marine Monitoring Programs

UW Oceanic Remote Chemical Analyzer (ORCA) Buoys

Autonomous monitoring buoys will be established at three locations within Hood Canal during Year 1[3] to quantify dissolved oxygen levels and other water properties throughout the water column as well as meteorological parameters. At two-hour intervals, a Sea-Bird CTD package profiles the water column from the anchored floating buoy, and the data are transmitted to shore. Profile data are averaged into 1-m bins. In addition, a weather station provides air temperature, humidity, wind speed and direction, and solar radiation averaged into 10-minute bins and saved after each water column profile. The systems will be retrieved at the completion of the study.

Figure 5 presents locations of the ORCA buoys, including the Lynch Cove buoy that was deployed in January 2005 in 35 m of water. The second buoy will be deployed between Annas Bay and the Dewatto River outlet off Sund Rock in 120 m of water. The locations for the third buoy has not been finalized but will be deployed at the northern boundary to establish boundary conditions.

The ORCA buoys are instrumented with sensors to quantify the following chemical and physical parameters (www.ocean.washington.edu/research/orca/sensors.html):

- pressure
- temperature
- salinity
- density
- chlorophyll fluorescence
- dissolved oxygen
- nitrate plus nitrite[4]
- wind speed/direction
- relative humidity
- air temperature
- solar radiation

[3] Two additional sites, for a total of five, are expected during subsequent years.
[4] Nitrate sensor will be added to the Lynch Cove buoy by fall 2005 under HCDOP funding and will be part of the instrumentation for the other two buoys at deployment.

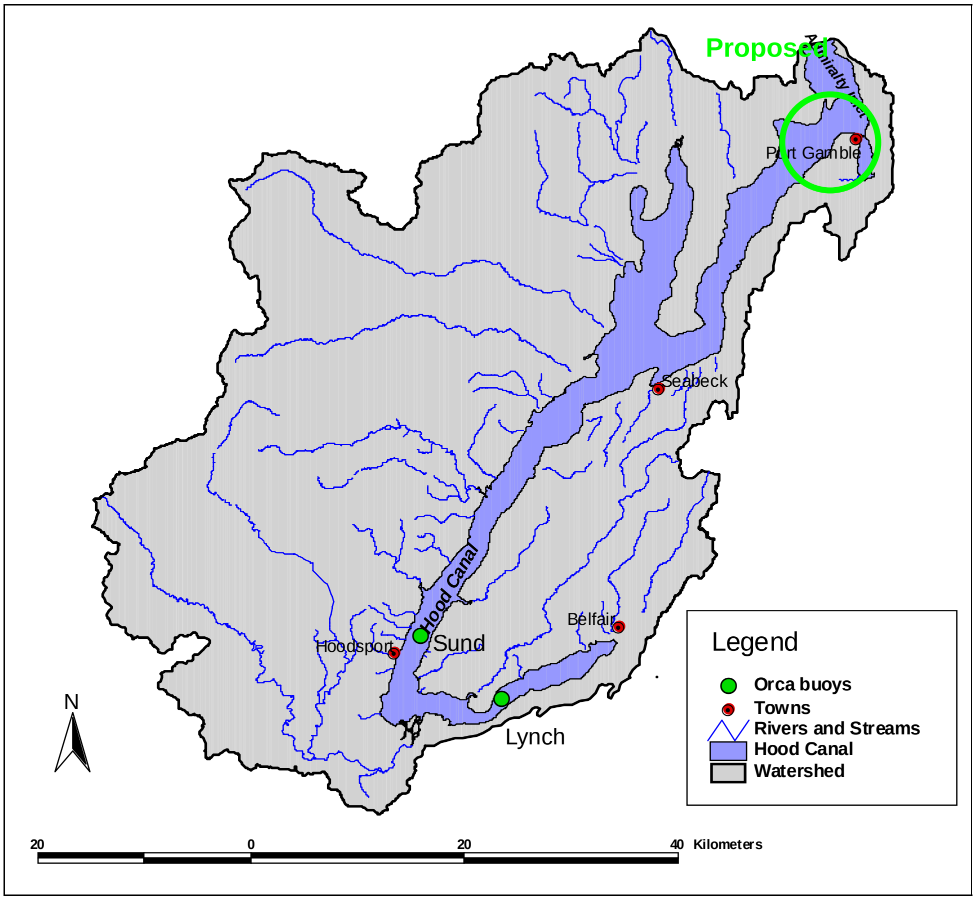

Figure 5. ORCA buoy locations.

University of Washington Puget Sound Regional Synthesis Model (PRISM) Cruises

The UW PRISM program includes semi-annual cruises that occupy 11 stations within Hood Canal (Figure 6). The stations will continue to be visited, generally in June and December of each year, to develop profiles of temperature, salinity, density, light transmission, backscatter, dissolved oxygen, and fluorescence using an *in situ* Sea-Bird CTD. Chlorophyll a and DO samples are analyzed during the voyage. Discrete samples are collected at depths of 0 m, 5, 10, 20, 30, 50, 80, 110, 140 m, and near-bottom, based on the station depth. The University of Washington Marine Chemistry Laboratory analyzes the samples for phaeopigments, nitrate, nitrite, ammonium, orthophosphate, and silicate. Discrete samples are collected at two stations for primary productivity studies.

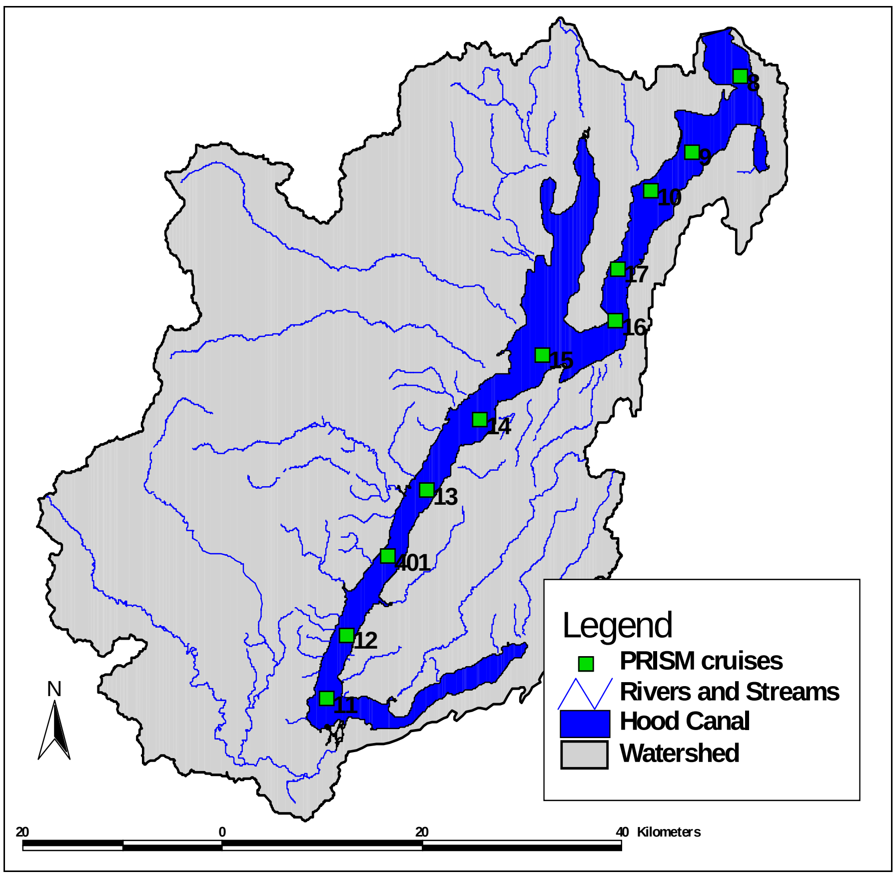

Figure 6. Hood Canal marine monitoring stations included in June and December annual cruises conducted under PRISM.

Ecology Marine Monitoring / Puget Sound Ambient Monitoring Program (PSAMP)

Under the larger Puget Sound Ambient Monitoring Program, Ecology has established a network of marine monitoring stations, including four stations in Hood Canal and two in Admiralty Inlet. The two Hood Canal core stations, HCB004 (Great Bend/Sisters Point) and HCB006 (King Spit, Bangor), have been visited regularly since 1975, while the two rotating stations, HCB003 (Hamma Hamma River) and HCB007 (Lynch Cove) have been visited since 1990. The Admiralty Inlet stations at Bush Point (ADM001) and Quimper Point (ADM002) have been monitored since 1992 and 1989, respectively.

Each station is occupied monthly, weather permitting. Profiles of temperature, salinity, density, dissolved oxygen, light transmission, chlorophyll *a* and pH are recorded using a Sea-Bird CTD. In addition, a Secchi depth reading is taken at each station. Discrete samples are collected at depths of 0, 10 and 30 m and analyzed for nitrate, nitrite, ammonium, orthophosphate, silicate, fecal coliform bacteria (0 m only), chlorophyll *a* (0 and 10 m) and phaeopigment (0 and 10 m). Samples are analyzed by the Department of Ecology Marine Waters Monitoring group, the Department of Ecology Manchester Lab, and the University of Washington Marine Chemistry Laboratory (Newton et al., 2002). Figure 7 presents the monitoring locations.

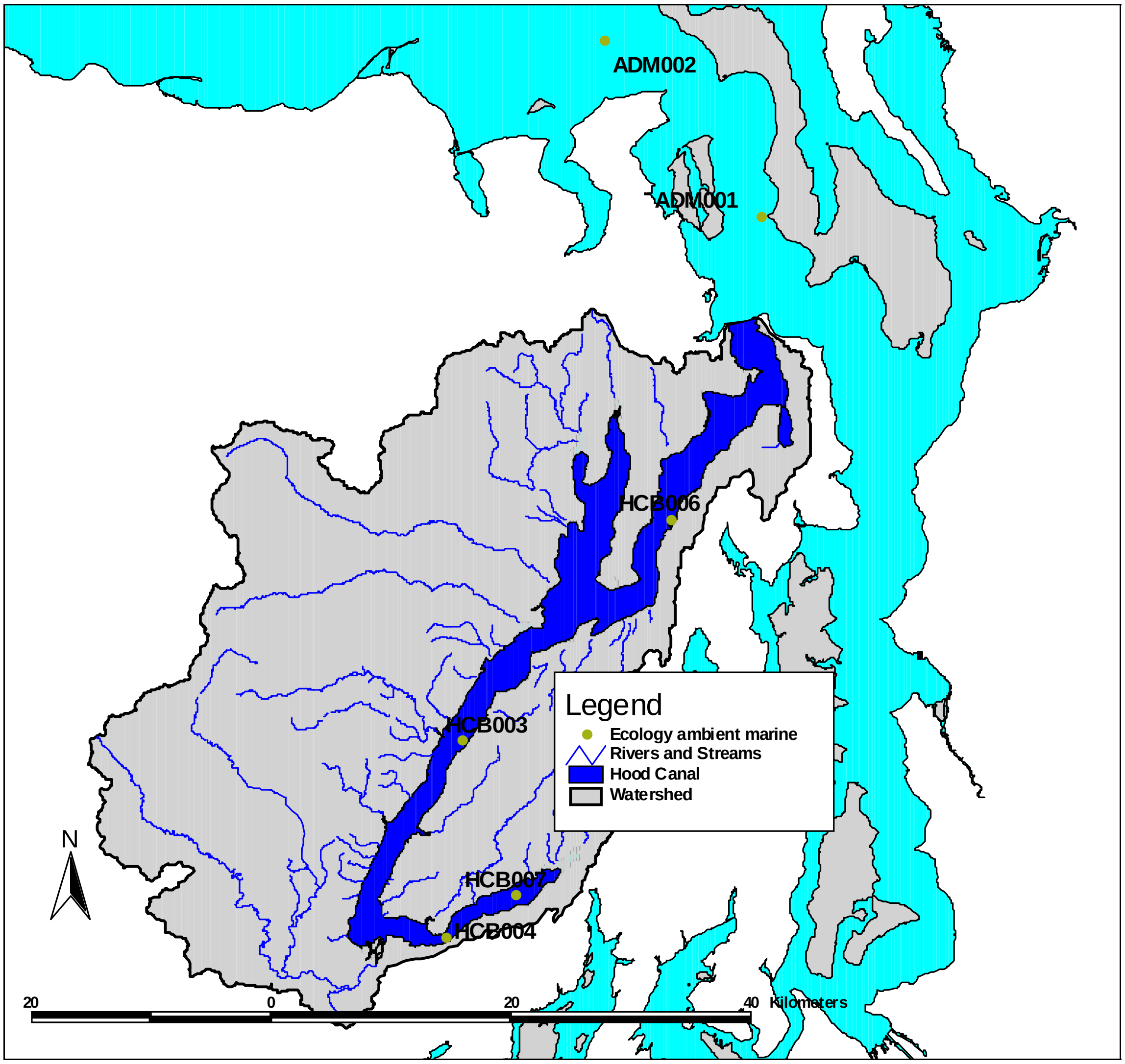

Figure 7. Ecology ambient monitoring in the marine waters of Hood Canal.

UW Applied Physics Laboratory Moored Profiler

UW Applied Physics Laboratory deployed a moored profiler (MP) system near Sund Rock in April 2005. The robotic profiler climbs up and down a standard mooring wire, recording temperature, salinity, pressure, velocity, and turbulent diffusivity every 30 minutes at 30-cm intervals throughout the water column between 3 m below mean lower low water (MLLW) and a depth of approximately 115 m (5 m above the bottom at 120-m depth). The system includes a Sea-Bird CTD and Falmouth Scientific Doppler current meter mounted to a McLane Research Laboratories, Inc. crawler that travels through the water column. An additional ADCP records velocities between 3 m below MLLW and mean high water (approximately 4 m above MLLW). The system will be retrieved in June and October, checked for integrity, recalibrated, and redeployed (Alford, personal communication). The system will be retrieved permanently in March 2006[5]. Moored profiler results, together with results from the ORCA buoys, will be used to infer lateral and vertical fluxes of oxygen and nitrate based on related measurements. Figure 8 presents the current deployment location, sited at 47.4271 N, 123.1082 W.

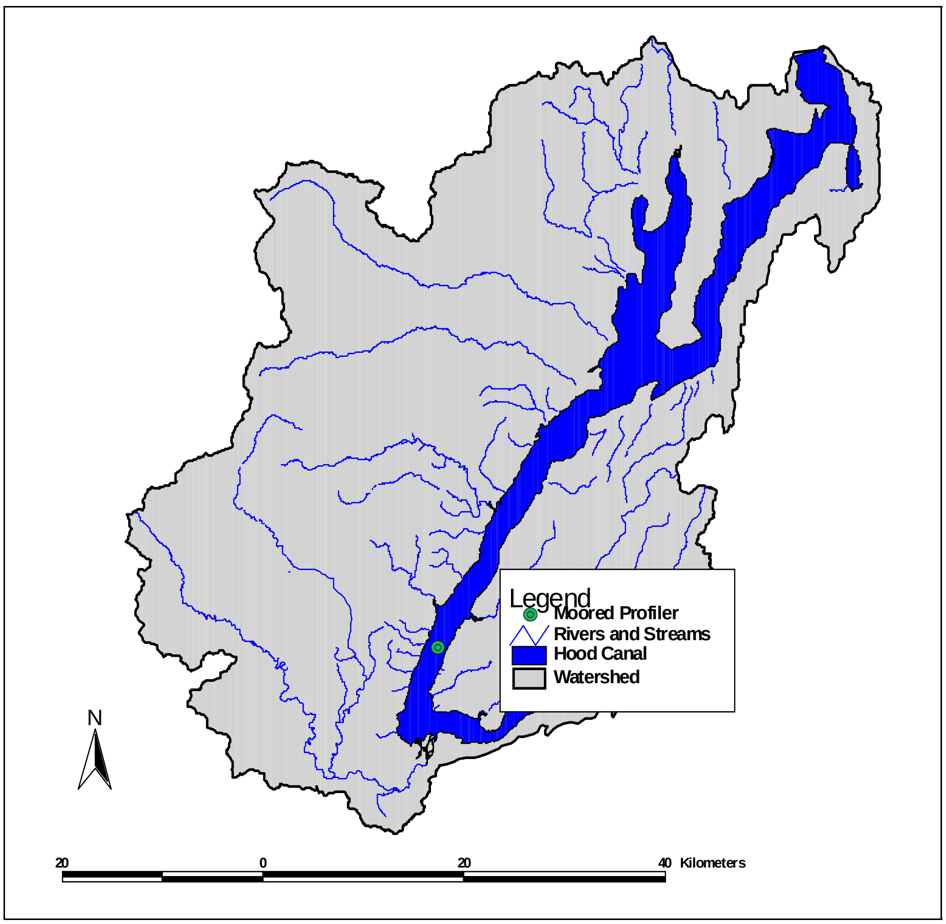

Figure 8. Location of moored profiler (blue dot). ORCA will be located at the green dot.

[5] The moored profiler will be compared with the ORCA buoys to determine which system will be used for the supplemental deployments planned in subsequent years.

Ecology Permanent Mooring

The Department of Ecology will establish a permanent near-shore (<10 m-depth) oceanographic monitoring station near Lynch Cove. Sea-Bird instruments located within 2 m of the bottom will record temperature, conductivity, and dissolved oxygen concentrations on a sub-hourly basis and transmit the data to a publicly accessible, web-based interface. Installation is tentatively scheduled for fall 2005. Figure 9 presents the expected and potential monitoring location.

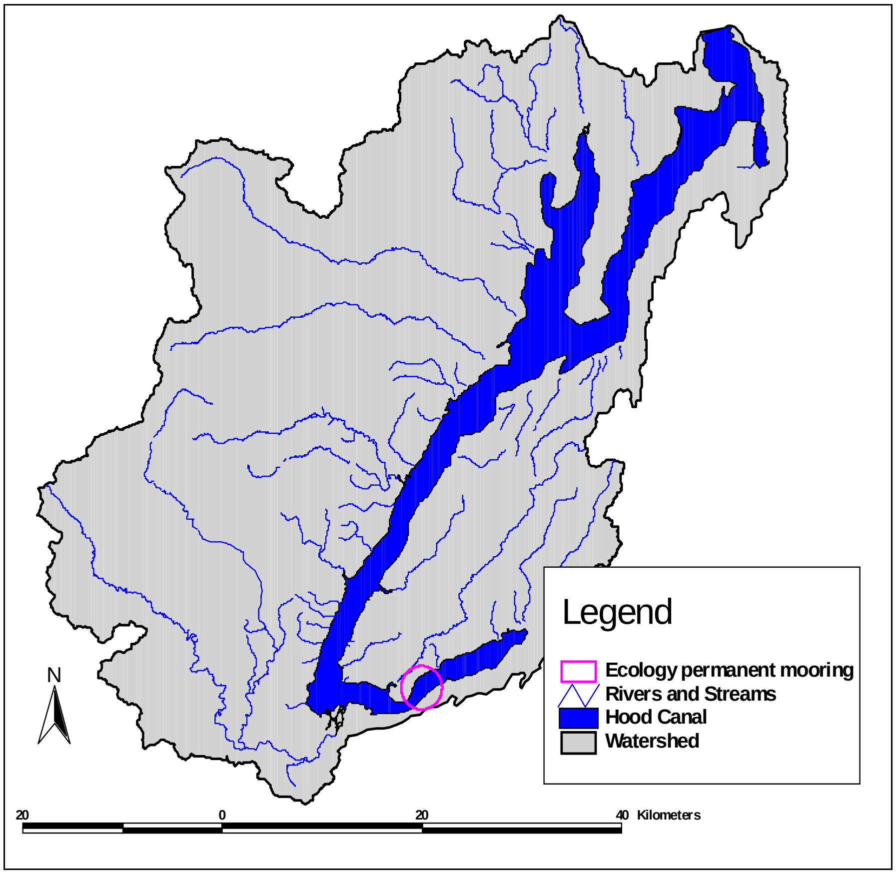

Figure 9. Ecology permanent mooring in southern Hood Canal expected in late 2005.

Hood Canal Salmon Enhancement Group Marine Monitoring

The Hood Canal Salmon Enhancement Group (HCSEG) initiated a volunteer monitoring effort in August 2003 to characterize dissolved oxygen levels at a finer spatial and temporal scale than had been available from historical marine sampling. Sampling stations represent a subset of established historical UW PRISM and Ecology locations to provide continuous and comparable datasets. Figure 10 presents the locations covered by the monitoring effort, while Table 7 summarizes the specific programs.

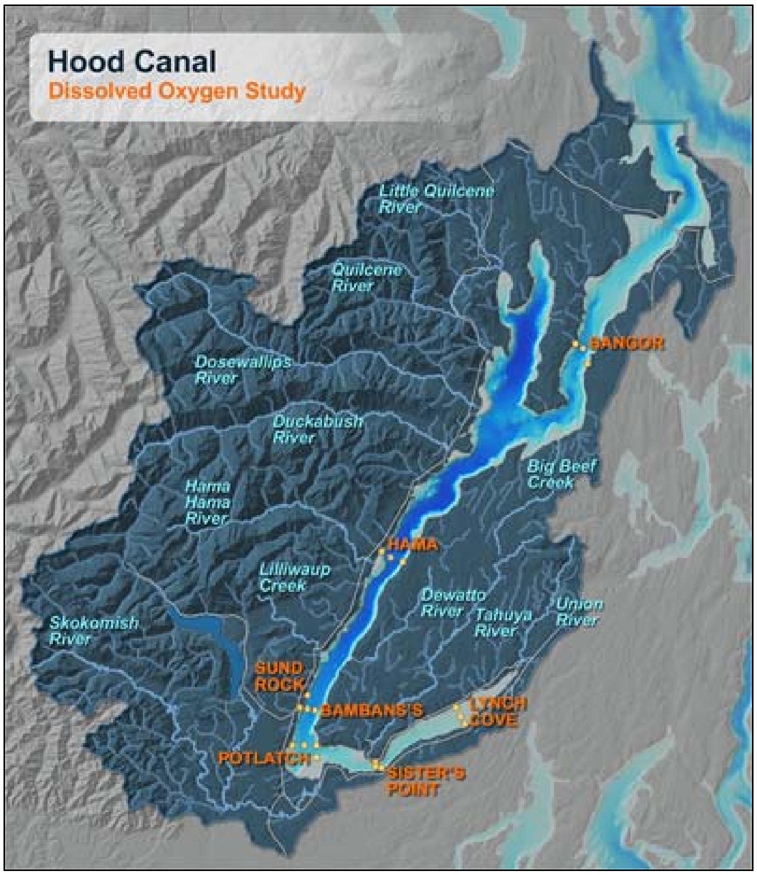

Figure 10. Station locations for HCSEG marine monitoring. Source: HCDOP website, www.hoodcanal.washington.edu.

Table 7. Hood Canal Salmon Enhancement Group marine monitoring efforts.

Stations	Lat/Long	Sample Depths	Frequency	*In situ* Parameters	Laboratory Parameters
BANGRW (Bangor transect, western shore)	47.7400, -122.7697	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile*	weekly	CTD	NA
BANGR (Bangor transect, center)	47.7347, -122.7528	1, 55, and 180 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile*	weekly	CTD	NA
BANGRE (Bangor transect, eastern shore)	47.7218, -122.7479	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile*	weekly	CTD	NA
HAMAW (Hamma transect, western shore)	47.5563, -123.0232	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile*	weekly	CTD	NA
HAMA (Hamma transect, center)	47.5458, -123.0069	1, 74, and 240 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5**
		profile*	weekly	CTD	NA
HAMAE (Hamma transect, eastern shore)	47.5388, -123.0025	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile*	weekly	CTD	NA
POTW (Potlatch transect, western shore)	47.3727, -123.1493	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile	weekly	CTD	NA
POTLCH (Potlatch transect, center)	47.3708, -123.1319	1, 41, and 135 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5**
		profile	weekly	CTD	NA
POTE (Potlatch transect, eastern shore)	47.3779, -123.1124	1 and 10 m	weekly	temp, Secchi	DO
				temp, Secchi	NUTS-5
		profile	weekly	CTD	NA
POTSO (Potlatch transect, near Union)	47.3612, -123.1014	1 and 10 m	weekly		
SUNDRK (Sund Rock, 20 ft depth)	47.3362, -123.1126	1 and 6 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile	weekly	CTD	NA
SUNDRK40 (Sund Rock, 40 ft depth)	47.3380, -123.1194	12 m	weekly	temp, Secchi	DO
		profile	weekly	CTD	NA
SUNDRK70 (Sund Rock, 70 ft depth)	47.4335, -123.1192	21 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile	weekly	CTD	NA
BAMBANW (Bamban transect, western shore)	47.7400, -122.7697	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile	weekly	CTD	NA
BAMBAN (Bamban transect, center)	47.4215, -123.1141	1, 62, and 205 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5**
		profile	weekly	CTD	NA

Stations	Lat/Long	Sample Depths	Frequency	*In situ* Parameters	Laboratory Parameters
BAMBANE (Bamban transect, eastern shore)	47.7218, -122.7478	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile	weekly	CTD	NA
SSTRN (Sister's transect, northern shore)	47.3715, -123.0176	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile	weekly	CTD	NA
SISTER (Sister's transect, center)	47.3567, -123.0233	1, 27, and 90 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5**
		profile	weekly	CTD	NA
SSTRS (Sister's transect, southern shore)	47.3640, -123.0060	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile	weekly	CTD	NA
LYNCHN (Lynch transect, northern shore)	47.4069, -122.9325	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile	weekly	CTD	NA
LYNCH (Lynch transect, center)	47.3983, -122.9283	1, 10, and 32 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5**
		profile	weekly	CTD	NA
LYNCHS (Lynch transect, southern shore)	47.3910, -122.9174	1 and 10 m	weekly	temp, Secchi	DO
			monthly	temp, Secchi	NUTS-5
		profile	weekly	CTD	NA
UW-17/BANGR	47.7347, -122.7528	profile	monthly	CTD	DO, NUTS-5
UW-16/HAZEL PT	47. 6917, -122.7651	profile	monthly	CTD	DO, NUTS-5
UW-15/SEABECK	47.7467, -122.8467	profile	monthly	CTD	DO, NUTS-5
UW-14	47.6056, -122.9417	profile	monthly	CTD	DO, NUTS-5
UW-13/HAMA	47.5458, -123.0069	profile	monthly	CTD	DO, NUTS-5
UW-12/HOODSPORT	47.4250, -123.1039	profile	monthly	CTD	DO, NUTS-5
UW-11/POTLCH	47.3708, -123.1319	profile	monthly	CTD	DO, NUTS-5

CTD refers to temperature, salinity, density, dissolved oxygen, chlorophyll fluorescence, and light transmission. NUTS-5 refers to nitrate, nitrite, ammonium, orthophosphate, and silicate.
* Profiles at center stations of Bangor and Hamma transects will begin summer 2005.
**Nutrients not collected at mid-depth.

Volunteers were initially recruited and trained to collect discrete water samples at six transects as well as three stations at Sund Rock on a weekly basis. Each of the six transects includes three cross-canal monitoring stations, shown in Figure 10, including one in the center and two located adjacent to each shore. Nearshore stations are sampled at the surface (1 m) and near the bottom (10 m), while center stations are sampled at the surface (1 m), at mid-level, and near the bottom. The depth of the mid-level and bottom stations varies with water depth at those locations. Three monitoring stations are grouped around Sund Rock at water depths of 20 ft, 40 ft, and 70 ft.

Conditions are recorded near the bottom at all three sites as well as at the surface at the 20-ft station for a total of four discrete sample locations near Sund Rock.

Volunteers record water temperature of each discrete sample collected using a standard thermometer and prepare dissolved oxygen samples for analysis by a modified Winkler titration. Water clarity is recorded using a Secchi disk. Once a month, samples collected at the surface and the bottom at all 18 cross-canal transect locations and at Sund Rock (from the surface at the nearshore station and from the bottom at the offshore station) are analyzed for nitrate, nitrite, ammonium, orthophosphate, and silicate by the UW Marine Chemistry Laboratory.

To complement the oxygen and nutrient data, chlorophyll samples will be collected within the top 5 to 10 m of water approximately every other week, with a more concentrated effort in the summer and fall during times of increased algal bloom activity. HCSEG staff will analyze the chlorophyll concentrations using the same protocols as UW PRISM and Ecology. In addition, HCSEG will conduct phytoplankton tows approximately every other week and in response to particular events. HCSEG will evaluate recent ORCA buoy data and CTD casts to identify the depth of the chlorophyll maximum. Plankton tows will begin below and continue through the chlorophyll maximum. Initially, phytoplankton taxa will be determined by the Pacific Shellfish Institute using methods documented in Tomas (1997) and Horner (2002). PSI lab protocols are presented in Appendix 3. HCSEG will be trained in taxa identification and some responsibility for phytoplankton identification may shift to HCSEG.

Since August 2004, the HCSEG has supplemented the discrete sampling conducted as part of the marine monitoring effort with continuous profiles recorded with a Sea-Bird CTD. The HCSEG has used the Sea-Bird CTD to record data at the lower Hood Canal center stations (i.e., all but the Bangor and Hamma Hamma transects) on a weekly basis since August 2004. The profiling has expanded to include all lower Hood Canal nearshore stations as well since January 2005. Weekly CTD profiles will continue during Year 1. The program will expand to include transects at Bangor and Hamma Hamma beginning in summer 2005.

In addition, monthly profiles will be recorded using the Sea-Bird CTD at nine center stations from the Hood Canal bridge to Potlatch to extend the oxygen inventory. The effort will occupy the UW PRISM stations to increase the temporal resolution of the oxygen inventory and better document annual variability.

The marine monitoring program initially enlisted volunteers trained by HCSEG in Ecology and UW PRISM standard field protocols (Newton et al., 2002). Filtered nutrient samples are frozen and delivered to the UW Marine Chemistry Lab for analysis. HCSEG volunteers preserve DO samples in the field and determine concentrations using modified Winkler titrations in the HCSEG laboratories by trained HCSEG staff. The discrete DO results are used to calibrate the DO sensor for the CTD profiles. Chlorophyll samples also will be analyzed at the HCSEG lab in Belfair using standard protocols (Newton et al., 2002).

The volunteer monitoring oxygen data will be distributed via the HCDOP website and presented as depth profiles for a given station as well as a time series at each station and depth since 2003. Nutrient and chlorophyll data will be made available also.

Freshwater Monitoring Programs

Several organizations collect stream data relevant to the Hood Canal Dissolved Oxygen Program. Specific efforts, with station locations, frequency of collection, and parameters, are described below.

Ecology Stream Water Quality Monitoring

Ecology maintains a state-wide network of streams and rivers, which are monitored on a monthly basis. The program includes two stations within the Hood Canal watershed, 16A070 (Skokomish River near Potlatch) and 16C090 (Duckabush River near Brinnon), monitored during Water Year 2005. Monitoring at the same locations will continue from October 2005 through September 2006 and beyond, and no rotating basin sites are expected to be added during Year 1. Figure 11 provides the monitoring locations, while Table 8 summarizes the experimental design. Hallock and Ehinger (2003) describe the monitoring program, and Ward et al. (2001) documents the sampling protocols.

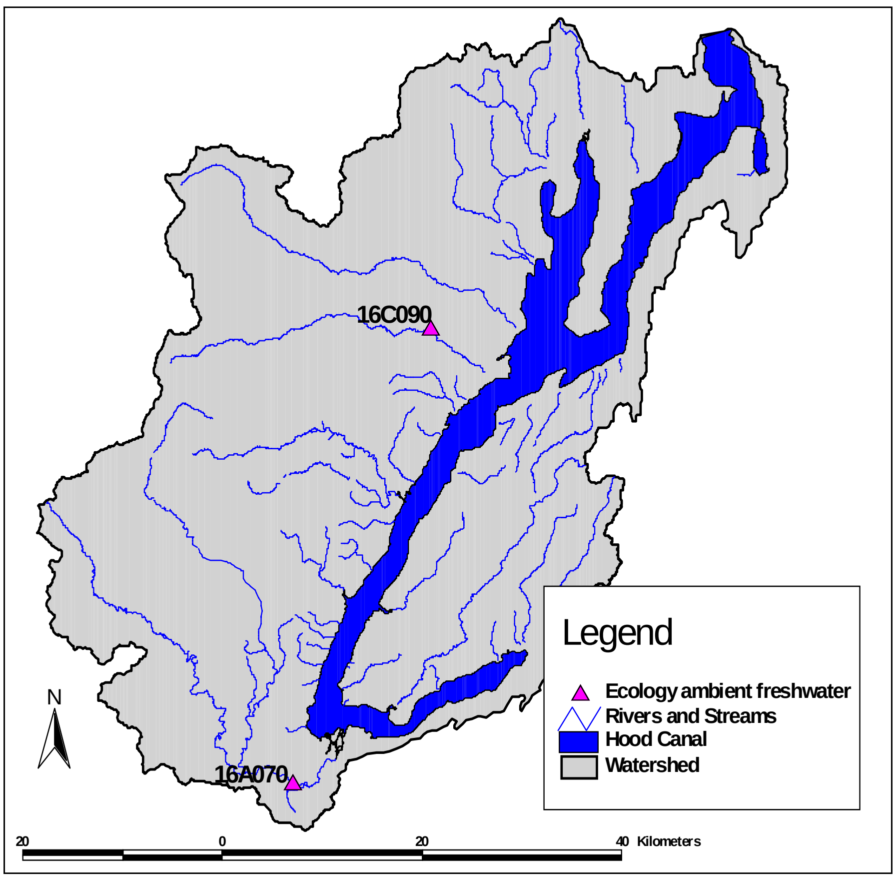

Figure 11. Ecology freshwater ambient monitoring stations in the Hood Canal watershed.

Table 8. Ecology freshwater ambient monitoring stations in the Hood Canal watershed.

Stations	Frequency	*In situ* Parameters	Laboratory Parameters	References
16A070 (Skokomish River) [47.31, -123.177]	monthly	temp, cond, DO, pH	NO23N, NH4N, TPN, OP, TP, turb, FC, TSS	Hallock and Ehinger, 2003; Ward et al., 2001
16C090 (Duckabush River) [47.68398, -123.012]	monthly	temp, cond, DO, pH	NO23N, NH4N, TPN, OP, TP, turb, FC, TSS	Hallock and Ehinger, 2003; Ward et al., 2001

Coordinated Stream Water Quality Monitoring

Several organizations have monitored streams within the Hood Canal watershed under a series of study designs and protocols. HCDOP coordinates much of these existing efforts under a coordinated HCDOP plan at 37 locations (Figure 12). The following organizations conduct sampling as part of the HCDOP Coordinated Monitoring effort coordinated by UW PRISM: EnviroVision (until June 2005), Mason County Health Department, Jefferson County Conservation District, Kitsap County Health District, Mason Conservation District, and the Skokomish Tribe. In addition, Ecology and USGS perform ambient monitoring as part of their agency programs.

HCDOP Coordinated Monitoring initially utilized a focused monitoring program developed by EnviroVision (2003) for the WRIA 16 Watershed Planning Unit to provide baseline monitoring data for a series of streams for which little water quality data exist. This plan was conducted through June 2005 and then transferred, with some changes, to the HCDOP coordinated effort. Plotnikoff (2004) describes the experimental design, while EnviroVision (2003) describes the field procedures. Table 9 summarizes the locations monitored.

UW PRISM coordinates the current monitoring effort for HCDOP, which is shared by many entities. The Skokomish Tribe conducts part of the HCDOP Coordinated water quality monitoring on a monthly basis. Table 10 describes the stations while Appendix 2 documents field protocols.

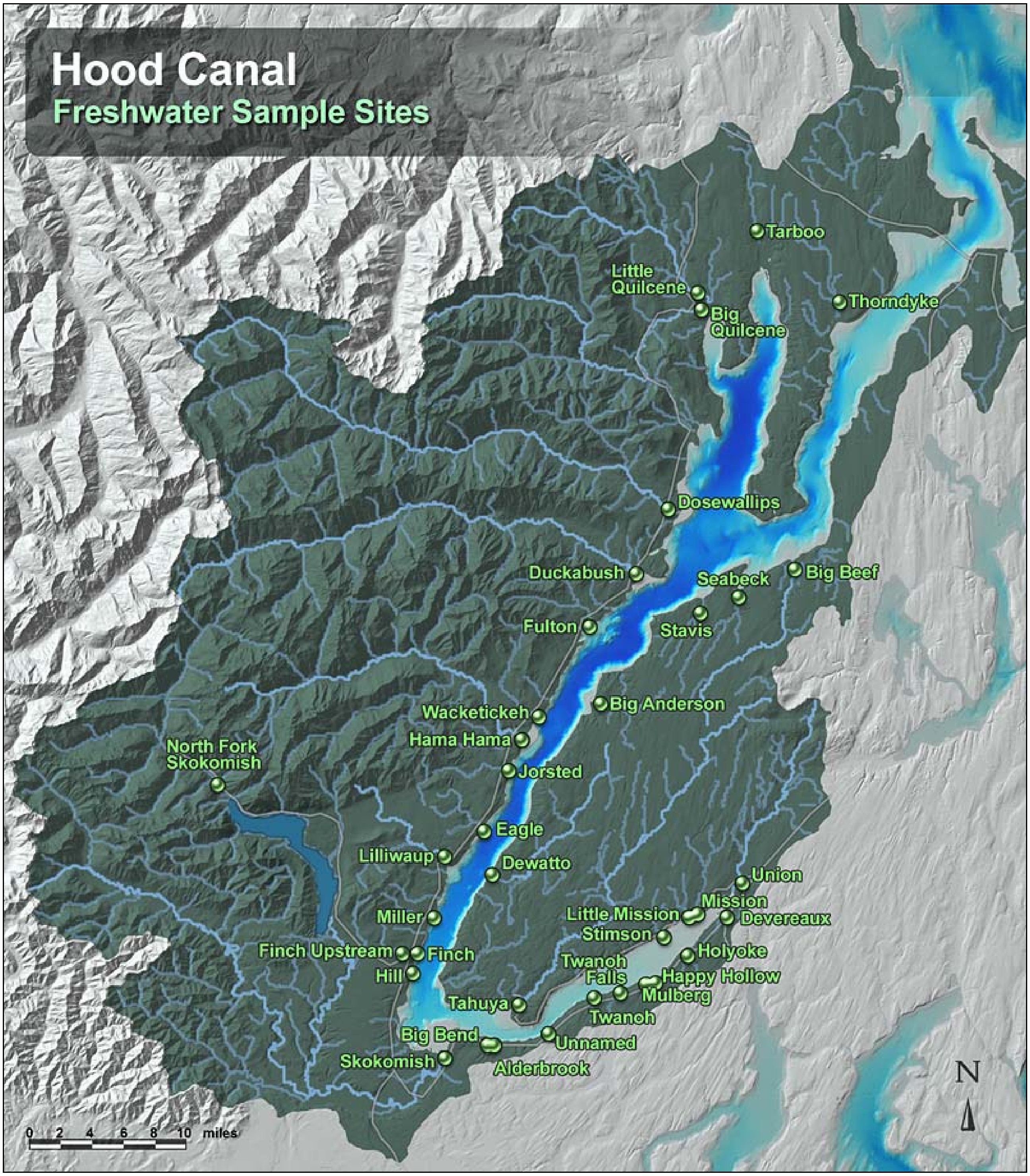

Figure 12. HCDOP Coordinated freshwater monitoring locations.

Table 9. Stream water quality stations monitored through June 2005 by EnviroVision.

Stations	Frequency	*In situ* Parameters	Laboratory Parameters	References
Monthly Monitoring Locations				
Alderbrook Creek [47.3479, -123.0682]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Big Bend Creek [47.3480, -123.0739]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Unnamed Drainage [47.3554, -123.0170]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Mulberg Creek [47.3872, -122.9250]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Happy Hollow Creek [47.3881, -122.9159]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Holyoke Creek [47.4061, -122.8861]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Devereaux Creek [47.3730, -122.9878]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Shady Beach Drainage [47.3730, -122.9878]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Twanoh Creek [47.3783, -122.9738]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Twanoh Falls Creek [47.3819, -122.9485]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Finch Creek (above dev) [47.4075, -123.1594]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Dosewallips River [47.6916, -122.9019]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Fulton Creek [47.6207, -122.9763]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Hamma Hamma River [47.5503, -123.0510]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Eagle Creek [47.4850, -123.0783]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Lilliwaup Creek [47.4689, -123.1156]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Jorsted Creek [47.5241, -123.0535]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Waketickeh Creek [47.5583, -123.0261]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Duckabush River [47.6550, -122.9456]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)
Miller Creek [47.4297, -123.1253]	monthly	Temp, Cond	NO23N, TSS, TP, FC, BOD	EnviroVision (2003)

Table 10. Coordinated HCDOP water quality monitoring stations monitored by the Skokomish Tribe.

Stations	Frequency	*In situ* Parameters	Laboratory Parameters*	References
Monthly Monitoring Locations				
Alderbrook Creek [47.3479, -123.0682]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Big Bend Creek [47.3480, -123.0739]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Unnamed Drainage [47.3554, -123.0170]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Mulberg Creek [47.3872, -122.9250]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Happy Hollow Creek [47.3881, -122.9159]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Holyoke Creek [47.4061, -122.8861]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Devereaux Creek [47.3730, -122.9878]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Union Store Creek [47.3478, -123.0744]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Twanoh Creek [47.3783, -122.9738]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Twanoh Falls Creek [47.3819, -122.9485]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Finch Creek (above dev) [47.4075, -123.1594]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Skokomish River [47.3099, -123.1767]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Dosewallips River [47.6916, -122.9019]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Fulton Creek [47.6207, -122.9763]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Hamma Hamma River [47.5503, -123.0510]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Eagle Creek [47.4850, -123.0783]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Lilliwaup Creek [47.4689, -123.1156]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Jorsted Creek [47.5241, -123.0535]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Waketickeh Creek [47.5583, -123.0261]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Duckabush River [47.6550, -122.9456]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Miller Creek [47.4297, -123.1253]	monthly	Temp, Cond, pH, DO, Salin, Q**	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2

*NUTS-5 includes orthophosphate, nitrate, nitrite, ammonium, and silicate. TNP refers to total nitrogen and total phosphorus. TDN is total dissolved nitrogen.
** The Skokomish Tribe takes staff gage readings at four stations (Duckabush, Fulton, Jorsted, and Eagle) and measures discharge *in situ* at the remaining stations.

Mason County Environmental Health conducts part of the Coordinated HCDOP water quality monitoring on a monthly basis. Table 11 lists locations.

Table 11. Coordinated HCDOP stream water quality monitoring stations monitored by Mason County.

Stations	Frequency	*In situ* Parameters	Laboratory Parameters*	References
Monthly Monitoring Locations				
Union River	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Mission Creek	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Little Mission Creek	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Stimpson Creek	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Dewatto River	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Hill Creek	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
N. Fork Skokomish R.	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
PUD Powerstation	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Tahuya River	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2

Jefferson County Conservation District conducts part of the Coordinated HCDOP water quality monitoring on a monthly basis. Table 12 lists locations.

Table 12. Coordinated HCDOP stream water quality monitoring stations monitored by the Jefferson County Conservation District.

Stations	Frequency	*In situ* Parameters	Laboratory Parameters*	References
Monthly Monitoring Locations				
Little Quilcene River	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Big Quilcene River	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Thorndyke Creek	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2
Tarboo Creek	monthly	none	NUTS-5, TDN, TNP, DOC, TSS	Appendix 2

Kitsap County Health District (KCHD) conducts part of the Coordinated HCDOP water quality monitoring on a monthly basis. Table 13 lists locations.

Table 13. Coordinated HCDOP stream water quality monitoring stations monitored by the Kitsap County Health District.

Stations	Frequency	*In situ* Parameters	Laboratory Parameters*	References
Monthly Monitoring Locations				
Stavis Creek	monthly	temp, pH, DO, cond, turb, and DO % saturation	FC, NUTS-5, TDN, TNP, DOC, TSS	APHA (1998), KCHD (2004), Appendix 2
Seabeck Creek	monthly	temp, pH, DO, cond, turb, and DO % saturation	FC, NUTS-5, TDN, TNP, DOC, TSS	APHA (1998), KCHD (2004), Appendix 2
Anderson Creek	monthly	temp, pH, DO, cond, turb, and DO % saturation	FC, NUTS-5, TDN, TNP, DOC, TSS	APHA (1998), KCHD (2004), Appendix 2
Big Beef Creek	monthly	temp, pH, DO, cond, turb, and DO % saturation	FC, NUTS-5, TDN, TNP, DOC, TSS	APHA (1998), KCHD (2004), Appendix 2

Stormwater Monitoring

UW will initiate a storm-event monitoring program during the first year of monitoring as part of a planned two-year program. The overall program, presented in Appendix 4, will include four composite storm samples each from eight stations. In addition, three events will capture the overall hydrograph variation in nutrient and TSS concentrations. The eight sites were selected from among 18 sites with active stream gages and represent a range of DIN concentrations, flows, and geographic locations. Table 14 summarizes the selected sites. During the first year of monitoring, described in the present document, at least four events at three stations will be captured. The three stations will be finalized from the full set of eight following reconnaissance and will be selected on the basis of ease of access and security.

Table 14. Storm-event monitoring stations managed by UW.

Stations	Frequency	*In situ* Parameters	Laboratory Parameters	References
Seabeck Creek	Storm event	none	TSS, NUTS-5, TDN, TNP, DOC	Appendix 2
Little Quilcene River	Storm event	none	TSS, NUTS-5, TDN, TNP, DOC	Appendix 2
Tahuya River	Storm event	none	TSS, NUTS-5, TDN, TNP, DOC	Appendix 2
Union River	Storm event	none	TSS, NUTS-5, TDN, TNP, DOC	Appendix 2
Dewatto River	Storm event	none	TSS, NUTS-5, TDN, TNP, DOC	Appendix 2
Duckabush River	Storm event	none	TSS, NUTS-5, TDN, TNP, DOC	Appendix 2
N.F. Skokomish River	Storm event	none	TSS, NUTS-5, TDN, TNP, DOC	Appendix 2
Eagle Creek	Storm event	none	TSS, NUTS-5, TDN, TNP, DOC	Appendix 2

Samples will be collected using autosamplers that are programmed to collect samples at pre-specified flow volumes, similar to the design used by Correll et al. (1999). Samples will be composited over the duration of the storm, defined post priori based on the stream gage record, and analyzed for conductivity, TSS, total nitrogen, nitrate, nitrite, ammonium, total phosphorus, soluble reactive phosphorus, total organic carbon, and dissolved organic carbon by the UW Marine Chemistry Laboratory. Discrete samples will be submitted to the laboratory for three events over the planned two-year effort to determine parameter concentration variation during a storm event.

The flow increments necessary to trigger discrete sample collection will be determined after reviewing historical discharge time series for each station. The flow increments also will be selected so that the sample bottles will not run out during moderately large storm events at each site. Each valid storm event must have at least six discrete samples collected during the event. Sample bottles will be collected and replaced following each storm event that triggers collection. Sample collection will follow the monthly sample collection protocols presented in Appendix 2.

Ecology Stream Discharge and Temperature Monitoring

Ecology's Stream Hydrology Unit operates seven continuous and one periodic discharge monitoring sites within the Hood Canal watershed (Figure 13). The program may expand to Little Anderson Creek during Year 1, although the station has not received permits to date. Discharge data are collected in accordance with standard protocols (SHU, 2005). In addition, all of the continuous discharge sites are instrumented with continuous temperature sensors, and five of the sites record air temperature. Table 15 summarizes the experimental design.

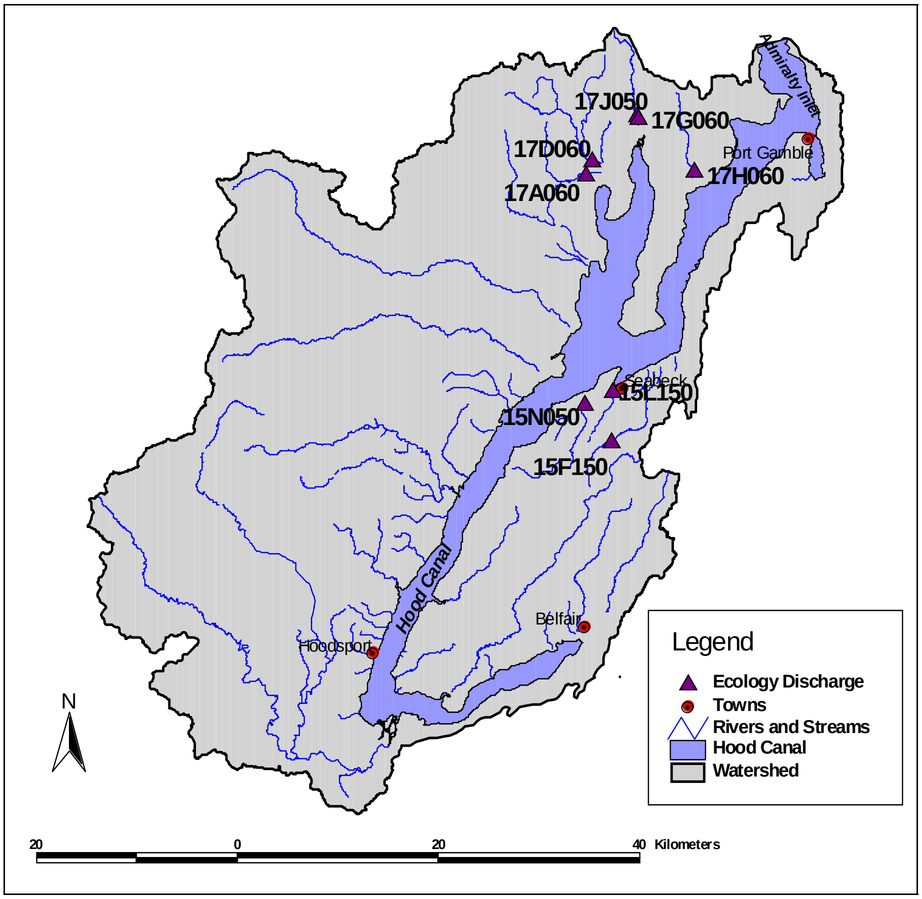

Figure 13. Ecology discharge and temperature monitoring sites within the Hood Canal watershed.

Table 15. Ecology discharge and temperature monitoring sites within the Hood Canal watershed.

Stations	Frequency	*In situ* Parameters	Laboratory Parameters	References
15F150 (Big Beef Crk) [47.5931, -122.8372]	continuous (15 min)	Discharge, temp	N/A	SHU, 2005
15L150 (Seabeck Crk) [47.6358, -122.8383]	continuous (15 min)	Discharge, temp, air temp	N/A	SHU, 2005
15N050 (Stavis Crk) [47.6242, -122.8747]	continuous (15 min)	Discharge, temp	N/A	SHU, 2005
17A060 (Big Quilcene) [47.8183, -122.8822]	continuous (15 min)	Discharge, temp, air temp	N/A	SHU, 2005
17D060 (Little Quilc) [47.8300, -122.8744]	continuous (15 min)	Discharge, temp, air temp	N/A	SHU, 2005
17G060 (Tarboo Crk) [47.8689, -122.8158	continuous (15 min)	Discharge, temp, air temp	N/A	SHU, 2005
17H060 (Thorndyke Crk) [47.8236, -122.7386]	continuous (15 min)	Discharge, temp, air temp	N/A	SHU, 2005
17J050 (Pheasant Crk) [47.8675, -122.8150]	weekly	Discharge	N/A	SHU, 2005

West Shore Discharge Monitoring

Aspect Consulting, funded by instream flow and water quality grants from Ecology, maintains seven continuous discharge monitoring stations on the west shore of Hood Canal (Figure 14). Discharge data are available beginning July 2004 (August 2004 for Jorsted Creek) for a one-year period. At present, all equipment will be removed in July 2005 and no additional monitoring is planned. In addition to discharge at the Dosewallips site, monthly grab samples are collected and analyzed for nitrate plus nitrite, total nitrogen, and fecal coliform; *in situ* parameters include temperature, conductivity, and dissolved oxygen (Lubischer and Miller, 2004).

The purpose of the program is to relate discharge at the seven sites to nearby long-term gaging records to develop regression relationships. Aspect Consulting will estimate long-term flow statistics for the seven gage locations. The regression relationships could be used to estimate flows during Year 1 monitoring activities following completion of the Aspect program.

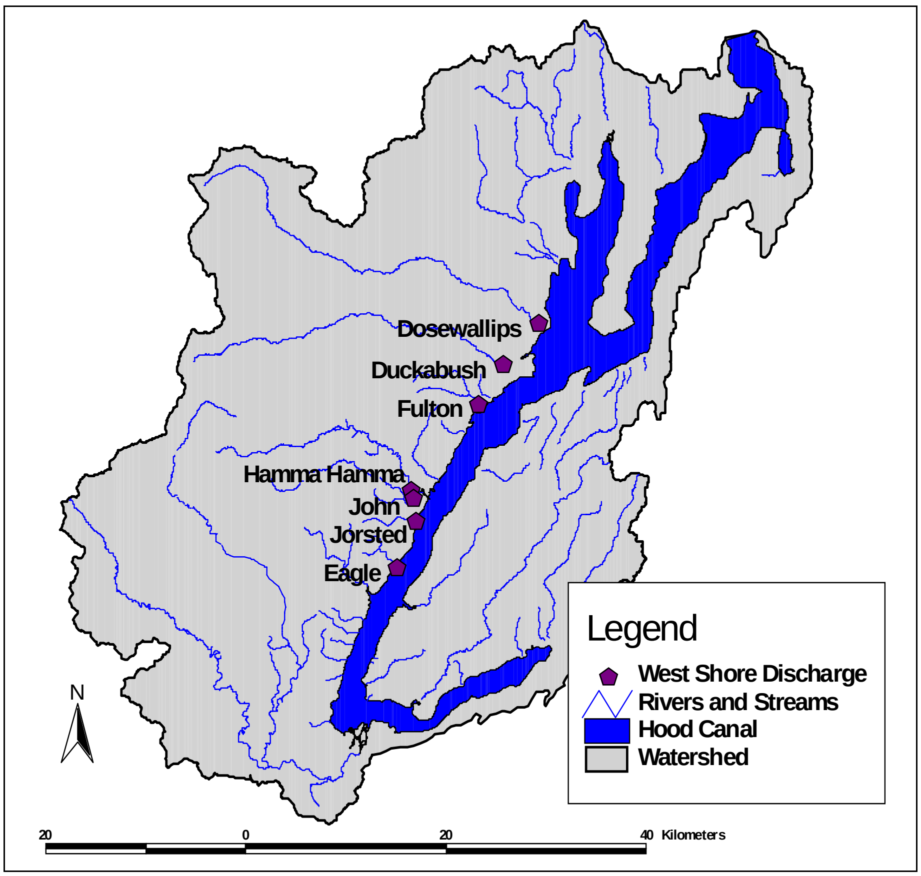

Figure 14. Continuous flow gaging sites for July 2004 through July 2005.

North Shore Discharge and Temperature Monitoring

The Hood Canal Salmon Enhancement Group maintains five continuous recording gages on the north shore of Hood Canal (Figure 15). The sites were originally established by the Kitsap Public Utilities District, although HCSEG took over operations several years ago. The stations will continue to be monitored during Year 1. The WaterLOG DH-21 instruments include a temperature sensor that records to 0.01°C and is accurate to within 1.0°C. Water level and temperature are recorded at 15-minute intervals. Data are downloaded monthly and processed using an Access application.

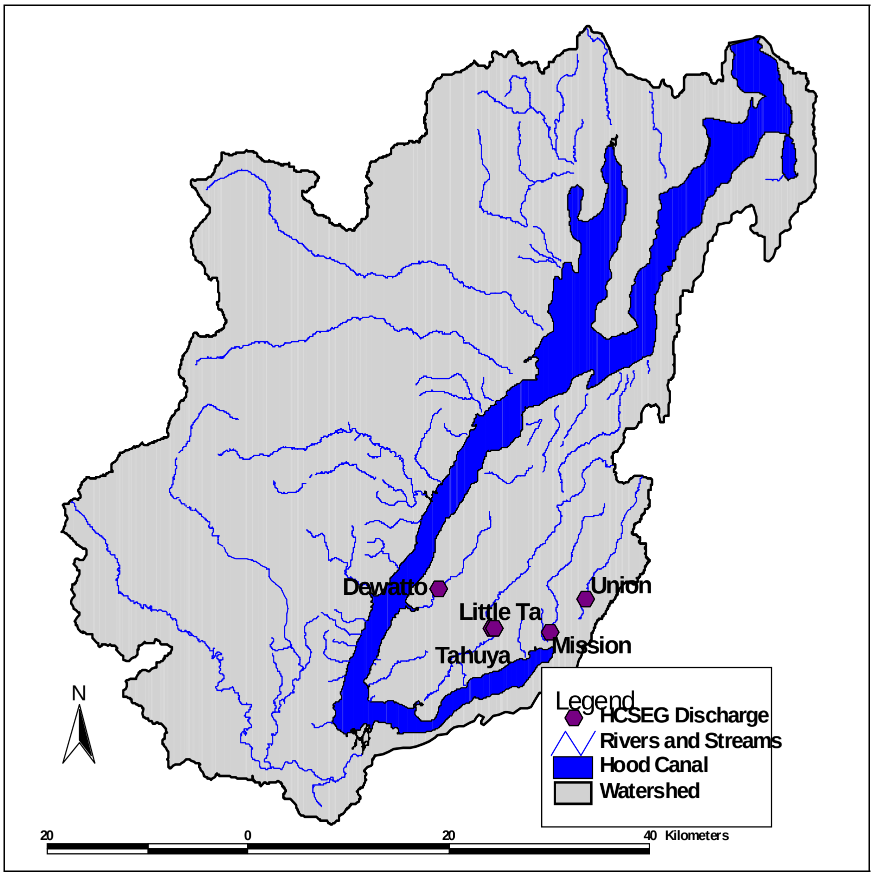

Figure 15. North shore continuous discharge monitoring stations operated by HCSEG.

Additional Discharge Monitoring

Hood Canal Salmon Enhancement Group may install face plates/staff gauges for an additional 17 sites by September 2006, working in collaboration with Department of Ecology. Sites will be determined as needed. The face plates will facilitate estimating flows during water quality monitoring events. The Skokomish Tribe Natural Resources and the HCSEG will work collectively to establish rating curves for the additional streams. Development of the rating curves will follow the procedures/protocols established by the Kitsap Public Utilities District (KPUD, 2000; KPUD, 2004).

USGS Discharge and Temperature Monitoring

USGS operates five real-time river gages within the Skokomish River watershed and three other gages within the East Olympic and Hood Canal watershed (Figure 16). Two of the stations within the Skokomish River watershed (12056500 and 12058800) include continuous water and air temperature data as well. Wagner et al. (2000) describe water quality data collection procedures and quality assurance, while Wahl et al. (1995) describe discharge data development.

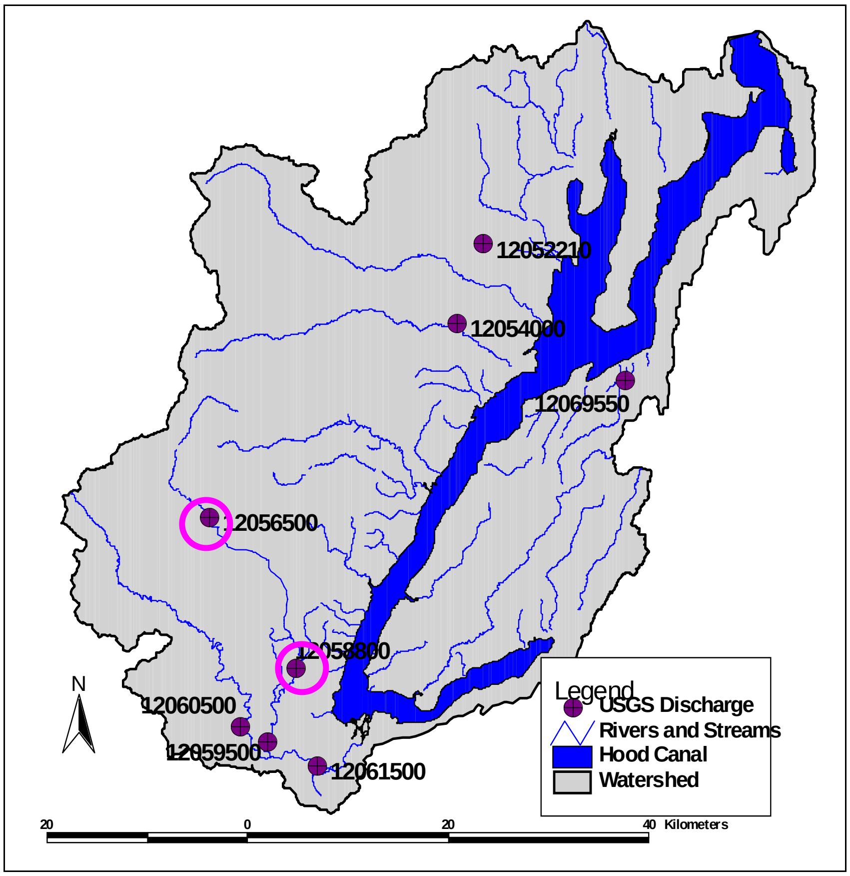

Figure 16. USGS discharge and temperature monitoring locations within the Hood Canal watershed. Temperature sites are indicated by open circles.

USGS Groundwater Monitoring

Personnel from the USGS Washington Water Science Center will continue to refine groundwater flow and nitrate load estimates for Hood Canal. Detailed study sites will be established at the shoreline of watersheds in three general areas within the southern extent of Hood Canal (Twanoh State Park, Sunset Beach and Landon Road). Each study site was selected to represent a range of land use and/or forest type within the adjacent watershed. At each study site, an array of seepage meters (55-gallon steel drums modified to capture groundwater discharge) was deployed, shallow piezometers were installed, and an electromagnetic seepage meter was installed to collect continuous ground-water flux data during the early and late summer of 2005. The array of piezometers (some of which were instrumented with water level data loggers) and seepage meters will provide data that will be used to describe the groundwater flow field in the intertidal and shallow subtidal zones and estimate flux rates. Approximately 13 additional sites were selected to obtain a greater distribution of data points around the southern arm of the canal. At each of these additional sites, a domestic well was sampled, a near-shore shallow piezometer was installed and sampled, and an off-shore seepage meter will be installed. The off-shore seepage meter will be used primarily to measure groundwater discharge rates; however, samples may be taken to determine the extent of seawater mixing and nutrient concentrations at the point of discharge.

Sampling goals

The goal of the USGS sampling program is to obtain a representative value for nitrate and other constituents in groundwater that discharges directly into Hood Canal. Another goal is to understand the spatial and temporal variability of nitrate and other constituents in groundwater that originate within a given land-use area or forest type. If possible, comparisons will be made between undeveloped and urban/suburban development and areas forested with alder (*Alnus rubra*) and areas forested with Douglas fir (*Pseudotsuga menziesii*). An additional goal is to better understand the sources of nitrate and the processes that affect its breakdown (de-nitrification) as it moves towards points of discharge along the canal.

Sampling design

The spatial variability of groundwater discharge will be assessed by collecting samples from approximately 16 sites on the Hood Canal east of the Great Bend. Sampling sites will be evenly distributed around the canal and will include both north and south shores. At each site, samples will be collected from a domestic well and, if possible, a near-shore shallow piezometer and an off-shore seepage meter.

Results from the first round of sampling will be used to determine if the temporal variability will need to be assessed by collecting another suite of samples during the winter wet season. Additional suites may be collected if it is determined that chemical variability occurs on shorter time scales.

The samples will be analyzed for the following constituents:

- Major Ions (NWQL schedule 1): acid neutralizing capacity (ANC); calcium; chloride; fluoride; iron; magnesium; manganese; pH (Lab); Potassium; silica; sodium; specific conductance (Lab); and sulfate.

- Nutrients + Total Phosphate and Nitrogen (NAWQA, schedule 2752): nitrogen, ammonia; nitrogen, nitrate; nitrogen, nitrite + nitrate; total nitrogen; phosphorus; phosphorus, phosphate, orthophosphate.

- A subset of samples with known concentrations of nitrate will be analyzed for oxygen and nitrogen isotopes (oxygen-18/oxygen-16 and nitrogen-15/nitrogen-14).

The results will be extrapolated to other areas in the southern part of the Hood Canal watershed. The Skokomish River Delta will not be considered during the Year 1 monitoring efforts due to its size and complexity, but may be evaluated in subsequent years. Table 16 summarizes the program and Figure 17 identifies potential monitoring locations. Field work will be conducted throughout the summer and may continue into the fall of 2005.

All sampling will be done in accordance with standard USGS sampling protocols and will include quality control samples (blanks and duplicates) as per USGS guidelines. All samples will be sent to the USGS National Water Quality Laboratory in Denver, Colorado. Samples of predominantly marine water or mixed marine and freshwater will be analyzed by the UW MCL in Seattle, Washington.

Table 16. Initial monitoring plan for regional-scale groundwater flux and nitrogen load studies.

Stations	Frequency	*In situ* Parameters	Laboratory Parameters	References
3 primary areas [Twanoh State Park, Sunset Beach and Landon Road]	Seasonal	groundwater discharge, water level, vertical hydraulic gradients, temp		W. Simonds (personal communication)
Approximately 16 additional sites	Seasonal	Specific conductance, ORP, DO, pH	Nutrients, major element chemistry, isotopes	W. Simonds (personal communication)

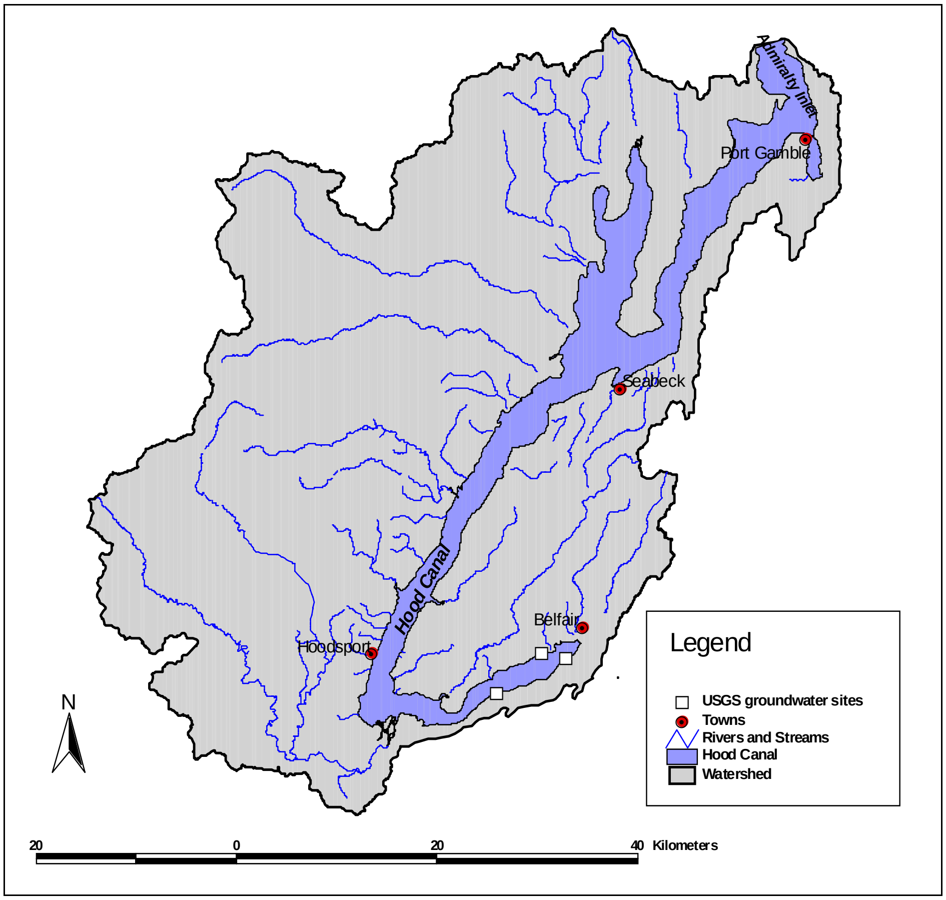

Figure 17. Potential monitoring locations for regional-scale groundwater flux and nitrogen load studies by USGS.

Other Data Development

Historical Riparian Land Cover Development

The Port Gamble S'Klallam Tribe will develop a land cover data set for the historical riparian conditions. The dataset incorporates General Land Office survey and historical timber cruise records from approximately 1870 and 1910, respectively. The GIS datalayer includes tree species composition, stand structure, and age class distribution. The tribe will validate the data using methods developed through the University of Washington River History Project (Collins et al., 2003; Collins and Montgomery, 2002; Collins et al., 2002).

Onsite Sewage System Inputs

The PACA report effort and USGS have developed initial estimates of onsite sewage systems nitrogen loads to Puget Sound. In addition, local health departments are evaluating the nitrogen removal of several types of systems under various projects funded by the Puget Sound Action Team. During Year 1, UW will evaluate methods of refining the estimates, with any field data collection or verification conducted during subsequent years and described in subsequent project plans.

The effort will quantify the number of residences, hotels, and businesses within the Hood Canal watershed that utilize onsite wastewater disposal. Using GIS datalayers, the systems will be subdivided using groundwater flow paths to determine those that likely contribute via groundwater to Hood Canal and those that likely contribute to rivers and streams. Monthly population estimates will be developed to account for seasonal usage of many residences within this area. As in previous efforts, total septic system nutrient discharges will be calculated by incorporating typical per capita nutrient loading rates for septic systems of different types. Recent regional and national research on nitrogen reduction will be incorporated into the loading estimates.

Wastewater Treatment Plant Discharge Data

The Alderbrook Resort and Spa discharges treated residential wastewater to the south shore of Hood Canal 1.25 miles east of Union under NPDES permit number WA0037753 (Ecology, 2004). The plant, originally built in 1978 but upgraded in recent years, treats wastewater using extended aeration and activated sludge and disinfects the effluent using ultraviolet radiation. The 2700-ft outfall discharges treated wastewater at a depth of 150 ft below MLLW. The diffuser has two 2.5-in. ports at 60-degree angles from each other. From 1998 through 2000, 11 violations of the permit conditions occurred, but none have occurred since then.

The most recent permit limits flow to 0.04 mgd for the average annual flow, with actual monthly average flows of 0.0258 mgd. Both BOD5 and TSS are limited to 30 mg/L or 7.5 lbs/day (monthly) and 45 mg/L or 11 lbs/day (weekly). The permit does not include limits for nutrient concentrations or loads or minimum dissolved oxygen concentrations. The pH must be greater than 6.0 SU.

In the permit fact sheet, the Department of Ecology found that "…[p]ollutant concentrations in the proposed discharge exceed water quality criteria with technology-based controls." A consultant modeled the proposed outfall diffuser and found that the diffuser provides dilution factors of 580:1 for the acute mixing zone and 641:1 for the chronic mixing zone. Therefore, the dilution factors are large enough that water quality standards should be met at the boundary of the mixing zone. Previous studies of the old outfall configuration, which provided a dilution factor of 165:1, indicated that the plant decreased dissolved oxygen outside of the mixing zone by 0.0015 mg/L (Parametrix, 1991; Parametrix, 1992), and the new outfall is expected to have greater dilution.

The facility monitors and reports effluent water quality parameters in a Discharge Monitoring Report, which must be submitted to the Department of Ecology monthly. Data for this facility will be compiled by the terrestrial modeling team for the period of interest for modeling. However, no nitrate, ammonium, or total nitrogen data are available for the facility.

Atmospheric Deposition Data

The National Atmospheric Deposition Program/National Trends Network was established in 1978 to quantify spatial and temporal trends in loading from precipitation. Annual maps of isopleths for precipitation pH, nitrate, ammonium, and other parameters are available in the form of concentrations (ug/L) and loads (kg/ha). Four stations are located in western Washington: Olympic National Park at the Hoh Ranger Station, North Cascades National Park at Marblemount, Mount Rainier National Park at Tahoma Woods, and LaGrande.

To supplement the NADP, UW will collect at least 30 samples of rainwater from the meteorological station installed at the Hood Canal Salmon Enhancement Group offices on Hood Canal. The NADP stations are representative of either non-Puget Sound conditions at the Hoh River station or downwind of much of the development for the other sites. However, Hood Canal is sometimes subject to atmospheric deposition influenced by air emissions from the developed areas. The purpose of this additional sampling is to compare Hood Canal atmospheric deposition with that from long-term stations and to collect total phosphorus data, which is not collected by NADP.

Sample bottles will be prepared and samples collected using the methods described in Appendix 2 for the monthly sampling rounds. The UW Marine Chemistry Laboratory will analyze samples collected following rainfall events large enough to supply sufficient sample volume. Samples will be analyzed for total nitrogen, nitrate, nitrite, ammonium, total phosphorus, and orthophosphate. Appendix 5 presents a detailed description of the atmospheric deposition data and approach.

Sediment Data Compilation

The Department of Ecology and WWU will collaborate to compile a database of existing sediment quality and dissolved oxygen data collected within Hood Canal, statistically analyze the relationships among variables, and identify data gaps. The proposed study results will be used to assess the significance of low dissolved oxygen levels on the resident benthic resources of Hood Canal and to test the hypothesis that the resident benthic resources of Hood Canal are incrementally and increasingly impaired by decreasing bottom water dissolved oxygen concentrations.

The study objectives include the following:

- Determine if the benthos of Hood Canal is adversely affected relative to reference area assemblages.
- Determine which species, taxonomic groups, and benthic indices are most affected in Hood Canal and are, therefore, most important indicators of impairment in the composition of the benthos.
- Determine the relationship between indices of benthic community composition and the concentrations of bottom water DO.
- Compare the benthos/DO relationships with those for other natural variables such as sediment texture, depth, and salinity to determine which relationships appear to be most important to the benthos.
- Identify the DO concentrations associated with the losses of important individual benthic species, sensitive taxonomic groups (e.g., classes), and major phyla from the benthic communities.
- Estimate the concentrations of bottom water DO that must be attained and/or maintained to protect the benthic resources of Hood Canal and their possible rates of recovery after attainment of these goals.

The first phase of the proposed four-year sediment quality study will occur during the first year of the HCDOP. Phase 1 includes the analysis of existing data and development of initial critical values/thresholds as indicators of adverse effects of lowered DO on benthos.

Phase 1 will be conducted jointly between the Department of Ecology and WWU. In this first phase, existing data will be compiled by Ecology personnel from previous sediment quality studies along with bottom water DO data collected throughout Hood Canal. Ecology will compare the abundance, diversity, and composition of the benthos to other variables such as water depth, sediment grain size, and organic carbon content. The relationships, if any, between the measures of benthic composition and the DO concentrations and other various physical-chemical variables will be examined with statistical and graphical methods, including the following:

- Bivariate correlation analyses
- Graphical analyses
- Regression analyses
- Multivariate analyses

The concentrations of DO associated with minor shifts in composition, significant decreases in diversity, losses of sensitive species, and losses of classes or phyla will be identified where possible. The data will then be sent to WWU to undergo further multivariate analyses. WWU and Ecology personnel will collaborate on final analysis and interpretation of these data.

To effectively and accurately identify the benthos/DO relationships, a robust database is necessary that covers a wide range in bottom water conditions. There should be no major gaps in the continuum of DO concentrations. There should be a reasonably close match both in space and time of the collection of the benthic samples and water column samples. Ecology has benthic data for approximately 60 samples collected during monitoring programs operated during the period 1989 to 2004 in Hood Canal. Bottom water DO data will be compiled from locations and times as close as possible to the benthic sampling locations. These compiled data should cover the entire length of the Canal. However, gaps in the data and mismatched benthic and DO data are anticipated. Therefore, in addition to the relational information provided with statistical analyses, a second product of the Phase 1 effort will include collaborative work by Ecology personnel and WWU to identify the data gaps that should be filled to provide a robust database with which to conduct more refined analyses.

A report will be prepared jointly by Ecology and WWU that describes the results of the Phase 1 data analyses. It will include the amount of matching benthic/DO data that was compiled. The kinds of benthic communities found in areas with high DO concentrations and their indices of health will be described. The species, taxonomic groups, and indices of benthic community composition that are most indicative of impacts to the benthos will be identified. The relationships between the benthic indices and DO concentrations and other physical-chemical variables will be described and illustrated. If possible with these historical data, the critical DO concentrations associated with minor and major impacts to the benthos will be identified. The data gaps to be filled to fully describe the benthic/DO relationships shall be identified and a detailed Phase 2 study design provided to fill these gaps in knowledge. The draft and final reports are expected in February 2006 and May 2006, respectively.

Subsequent phases will be scoped following completion of the first phase. Potential activities include field surveys to fill data gaps, benthic index development and refinement, and experimental surveys on colonization/recruitment of benthos to determine Hood Canal recovery time.

Measurement Quality Objectives

Measurement quality objectives (MQOs) refer to the performance or acceptance criteria for individual data quality indicators such as precision, bias, and lower reporting limit. MQOs provide the basis for determining the procedures that should be used for sampling and analysis.

Field studies are designed to generate data adequate to reliably estimate the temporal and spatial variability of that parameter. Sampling, laboratory analysis, and data evaluation steps have several sources of error that should be addressed by MQOs. Accuracy in MQOs can be more easily controlled than field sampling variability. Analytical bias needs to be low and precision as high as possible in the laboratory. Sampling variability can be somewhat controlled by strictly following standard procedures and collecting quality control samples, but natural spatial and temporal variability can contribute greatly to the overall variability in the parameter value. Resources limit the number of samples that can be taken at one site spatially or over various intervals of time. Finally, laboratory and field errors are further expanded by estimate errors in loading calculations and model estimates.

The HCDOP IAM Study includes a variety of parameters that are quite variable in the aquatic environment. Table 17 summarizes the measurement quality objectives for both laboratory measurements and *in situ* values. Individual sampling entities and laboratories are responsible for adherence to objectives. UW-APL and HCSEG will be responsible for verifying all MQOs are met.

Table 17. Measurement quality objectives for *in situ* values and laboratory analyses conducted by Ecology's Manchester Environmental Laboratory (MEL), UW's Marine Chemistry Lab (MCL), and UW's Civil and Environmental Engineering (CEE) Lake Lab.

Measurement	Field Equipment/ Laboratory	Accuracy (% deviation from true value)	Precision (relative standard deviation, RSD)	Bias (% deviation from true value)	Lowest Value of Interest
Field Measurements					
Velocity	Marsh-McBirney or Swoffer flow meter	0.1 ft/s	0.1 ft/s	N/A	0.05 ft/s
pH	CTD or Hydrolab	0.2 SU	0.05 SU	N/A	1 to 14 SU
Temperature	CTD	0.1 °C	0.025 °C	0.05 °C	0.1 °C
Temperature	TidBit	0.1 °C	0.025 °C	0.05 °C	0.1 °C
Dissolved Oxygen	CTD or Hydrolab	15%	5%	5%	0.05 mg/L
Specific Conductivity	CTD	10%	10%	5%	1 uS/cm
Secchi Depth	Secchi disk	0.5 m	0.5 m	N/A	N/A
Pressure	CTD	5%	5%	1%	0.1 db
Density	CTD	10%	10%	5%	0.1 σ_t
Chlorophyll Fluorescence	CTD	25%	10%	5%	0.1 FU
Light transmissivity	CTD	25%	10%	5%	0.01 %

Laboratory Measurements					
Dissolved Oxygen	Winkler	15%	5%	5%	0.05 mg/L
Marine Nitrate	UW Lab	10%	10%	5%	0.1 µM
Marine Nitrite	UW Lab	10%	10%	5%	0.03 µM
Marine Ammonium	UW Lab	10%	10%	5%	0.05 µM
Marine Orthophosphate	UW Lab	10%	10%	5%	0.03 µM
Marine Silicate	UW Lab	10%	10%	5%	0.1 µM
Chlorophyll a	MEL/MCL	N/A	10%	N/A	0.05 ug/L
Salinity	MEL/MCL	N/A	8%	N/A	0.01 PSU
Dissolved Organic Carbon	MEL/MCL	30%	10%	10%	1 mg/L
Total Organic Carbon	MEL/MCL	30%	10%	10%	1 mg/L
Total Persulfate Nitrogen	MEL	30%	10%	10%	25 ug/L
Ammonium- Nitrogen	MEL	25%	10%	5%	10 ug/L
Nitrate+Nitrite Nitrogen	MEL	25%	10%	5%	10 ug/L
Orthophosphate	MEL	25%	10%	5%	3 ug/L
Ammonium-Nitrogen	MCL	N/A	≤10%	N/A	0.05 uM
Nitrate-Nitrogen	MCL	N/A	≤10%	N/A	0.1 uM
Nitrite-Nitrogen	MCL	N/A	≤10%	N/A	0.03 uM
Orthophosphate	MCL	N/A	≤10%	N/A	0.03 uM
Silicate	MCL	N/A	≤10%	N/A	0.1 uM
Total Phosphorus	MEL/ UW CEE	25%	10%	5%	10 ug/L
Total Suspended Solids	MEL/ UW CEE	20%	10%	N/A	1 mg/L

In addition, ambient samples are split in the laboratory to isolate laboratory precision. MEL and MCL analyze laboratory control samples, or standards, as well as matrix spikes to verify that quality objectives are met (MEL, 2003; UNESCO, 1994).

USGS Discharge and Temperature Monitoring

USGS protocols will follow the “Work Plan for U.S. Geological Survey Studies Addressing Low Concentrations of Dissolved Oxygen in Hood Canal” (wa.water.usgs.gov/projects/hoodcanal/publications.htm) and their subsequent publications.

USGS Groundwater Monitoring

Water quality samples will be collected as outlined in the USGS national field manual for the collection of water quality data book 9. In accordance with USGS quality assurance and quality control guidelines, 10% of all samples will have field replicates sent to the lab for analysis. Several field blanks will be submitted to the lab to test for contamination related to equipment for both well and piezometer sampling.

Sampling Procedures

Marine Monitoring Programs

UW Oceanic Remote Chemical Analyzer (ORCA) Buoys

Researchers visit the buoy locations every three weeks to collect discrete samples, which are used to calibrate the sensor readings (Dunne et al., 2002; Ruef et al., 2004).

UW PRISM Cruises

PRISM sampling procedures for the cruises adhere to Newton et al. (2002) assuring consistency with Ecology and PSAMP.

Ecology Marine Monitoring/Puget Sound Ambient Monitoring Program (PSAMP)

Marine sample collection and processing protocols are described in Newton et al. (2002). After sample collection, samples are labeled and stored on ice in a cooler. Copies of field sample logs are delivered to the lab with the corresponding samples.

UW Applied Physics Laboratory Moored Profiler

Twice an hour, the moored profiler traverses a vertical wire from 6-m below MLLW to 5 m above the bottom. Onboard sensors sample temperature, salinity, dissolved oxygen, and velocity with 30-cm resolution. These data are used to monitor water-column properties, as well as to estimate lateral and vertical fluxes. An ADCP mounted in the subsurface float (6 m below MLLW) samples velocity in the upper 6 m at 25-cm resolution every five minutes. The remote profiler will be retrieved in June and October, checked for integrity, recalibrated, and redeployed (M. Alford, personal communication).

Ecology Permanent Moorings

Sampling procedures for the permanent moorings will be consistent with standard Ecology protocols. The project plan for the permanent moorings will specify the sampling procedures.

Hood Canal Salmon Enhancement Group Marine Monitoring

The HCSEG water quality staff were trained by Ecology and UW PRISM scientists on standard field protocols (Newton et al., 2002; Ward et al., 2001). The HCSEG subsequently trained community volunteer monitors in the collection of DO and nutrient samples. Sampling procedures are described above under Experimental Design.

Freshwater Monitoring Programs

Ecology Stream Water Quality Monitoring

Standard Ecology protocols will be used for sample collection, preservation, and shipping to the Manchester Environmental Laboratory (Ward et al., 2001; MEL, 2003). Samples are collected directly into pre-cleaned containers supplied by MEL or into syringes if the samples are to be filtered. Syringes are rinsed three times using ambient water from the collection site. Samples are stored in coolers filled with ice and are delivered to MEL for analysis within 24 hours of collection. A chain-of-custody record is maintained with the samples.

Coordinated Stream Water Quality Monitoring

The stream monitors will follow standardized field protocols summarized in Appendix 1. Filtered samples are collected in a syringe that has been rinsed three times with ambient water. Unfiltered samples are collected directly into pre-cleaned sample containers. Samples are placed in coolers filled with ice and transported to the appropriate laboratory by the field coordinators (S. Osborne, personal communication). A chain-of-custody record is maintained with the samples.

Stormwater Monitoring

Bottles will be prepared in accordance with the procedures developed for the coordinated monthly monitoring and presented in Appendix 1. Autosamplers will collect discrete samples at pre-defined flow increments, and discrete samples will be composited to develop event mean concentrations. Subsamples will be filtered and composited for dissolved nutrient analysis. Following compositing, samples are stored in coolers filled with ice and delivered to the UW Marine Chemistry Laboratory for analysis or storage. A chain-of-custody record is maintained with the samples.

Ecology Stream Discharge Monitoring

Ecology's Stream Hydrology Unit monitors stage and develops discharge rating curves using standard operating procedures (SHU, 2005).

West Shore Stream Discharge Monitoring

Aspect Consulting developed a QA Project Plan for quantifying flow from seven streams on the western shore of Hood Canal. Lubischer and Miller (2004) describe field methods and data analysis.

North Shore Stream Discharge and Temperature Monitoring

The HCSEG and the Skokomish Natural Resources monitor stage and develop discharge rating curves using standard operating procedures (Kitsap PUD, 2000).

USGS Discharge and Temperature Monitoring

Sampling procedures for discharge measurements and water quality data follow standard protocols outlined in Wahl et al. (1995) and Wagner et al. (2000), respectively.

USGS Groundwater Monitoring

Sampling procedures for water quality data follow standard USGS protocols outlined in Wagner et al. (2000). Laboratory Acid Neutralizing Capacity, pH, and specific conductance samples will be collected in 250 or 500-mL polyethylene bottles that have been rinsed with the unfiltered sample, and shipped to the National Water Quality Laboratory in Denver, CO, for analysis.

Chloride, silica, and sulfate samples will be filtered through a 0.45-micron filter, placed in a 250 or 500-mL polyethylene bottle that has been rinsed with the filtered sample, and shipped to the National Water Quality Laboratory in Denver, CO, for analysis.

Calcium, iron, magnesium, manganese, and sodium samples will be filtered through a 0.45-micron filter, acidified with nitric acid (HNO_3) to pH<2 and placed in a 250 mL acid-washed polyethylene bottle that has been rinsed with the filtered sample, and shipped to the National Water Quality Laboratory in Denver, CO for analysis.

Total nitrogen and total phosphorus samples will be filtered through a 0.45-micron filter, collected in a 125 mL brown polyethylene bottle that has been rinsed with the filtered sample, chilled and maintained at 4ºC ± 2ºC, and shipped immediately to the National Water Quality Laboratory in Denver, CO.

A subset of water samples with nitrate concentrations of at least 0.03 mg/kg as N will be sent to the USGS National Research Program Lab in Reston, VA, for Nitrogen-15/Nitrogen-14 isotope analysis. Nitrogen isotope samples will be filtered thru a 0.45-micron filter, collected in an untreated, 125-mL amber polyethylene bottle that has been field rinsed with the filtered sample and filled only ¾ full, and then frozen to prevent biological reaction of N-containing species.

Other Data Development

Atmospheric Deposition Data

Atmospheric deposition samples will be collected using the protocols described in Appendix 2 and will be consistent with procedures used by the NADP (Harding ESE, 2003).

Measurement Procedures

Laboratory Measurements

Manchester Environmental Laboratory

MEL (2003) describes analytical methods used by the laboratory. MEL maintains a series of Standard Operating Procedures (MEL, 2005) that document various quality control activities. Table 18 lists measurement procedures by parameter.

Table 18. Manchester Environmental Laboratory measurement procedures.

Analyte	Sample Matrix	Laboratory Analytical Method	Reporting Limit	Hold Time	Preservation Method	Expected Range of Results
Ammonia-nitrogen	water	SM 4500-NH3H	0.04 mg/L	28 days	Cool to 4°C H_2SO_4 to pH<2	0.010 to 20 mg/L
Nitrite+Nitrate-Nitrogen	water	SM 4500-NO3I	0.060 mg/L	28 days	Cool to 4°C H_2SO_4 to pH<2	0.010 to 20 mg/L
Total Persulfate Nitrogen	water	SM 4500-NB	0.06 mg/L	28 days	Filter; cool to 4C	0.010 to 20 mg/L
Total Phosphorus	water	EPA 200.8	0.004 mg/L	7 days	Cool to 4°C	0.010 to 10 mg/L
Orthophosphate	water	SM 4500PG	0.006 mg/L	48 hours	Filter; cool to 4°C	0.003 to 1 mg/L

University of Washington Marine Chemistry Laboratory

Krogslund (1998) includes all lab standard operating procedures, including quality control activities. Table 19 lists measurement procedures by parameter.

Table 19. Marine Chemistry Laboratory measurement procedures.

Analyte	Sample Matrix	Laboratory Analytical Method	Reporting Limit	Hold Time	Preservation Method	Expected Range of Results
Ammonia-Nitrogen	water	UNESCO (1994)	0.05 µM	28 days	Filter and freeze	0.010 to 20 mg/L
Nitrite-Nitrogen	water	UNESCO (1994)	0.03 µM	28 days	Filter and freeze	0.010 to 20 mg/L
Nitrate-Nitrogen	water	UNESCO (1994)	0.1 µM	28 days	Filter and freeze	0.010 to 20 mg/L
Orthophosphate	water	UNESCO (1994)	0.03 µM	28 days	Filter and freeze	0.003 to 1 mg/L
Silica	water	UNESCO (1994)	0.1 µM	28 days	Filter and freeze	0.010 to 20 mg/L
Total Nitrogen	water	Valderrama (1981) *	0.1 µM	28 days	Freeze	0.010 to 20 mg/L
Total Phosphorus	water	Valderrama (1981) *	0.1 µM	28 days	Freeze	0.010 to 10 mg/L

* The Marine Chemistry Laboratory has not been accredited by Ecology for these analyses.

USGS National Water Quality Laboratory

All sampling will be done in accordance with standard USGS sampling protocols and lab analyses in accordance with USGS National Water Quality Laboratory protocols (Pirkey and Glodt, 1998). All samples will be sent to the USGS National Water Quality Laboratory and analyzed using standard protocols (EPA, 365.1; Fishman, 1993; Fishman and Friedman, 1989; APHA, 1998; Patton and Kryskalla, 2003; USGS, 2003). Table 20 summarizes the methods.

Table 20. USGS National Water Quality Laboratory methods.

Analyte	Sample Matrix	Laboratory Analytical Method	Reporting Limit	Hold Time	Preservation Method	Expected Range of Results
Ammonia-Nitrogen	water	USGS I-2522-90	0.04 mg/L	28 days	Cool to 4°C H_2SO_4 to pH<2	0.010 to 20 mg/L
Nitrite-Nitrogen	water	USGS I-2540-90	0.008 mg/L	28 days	Cool to 4°C H_2SO_4 to pH<2	0.010 to 20 mg/L
Nitrite+Nitrate-Nitrogen	water	I-2545-90	0.060 mg/L	28 days	Cool to 4°C H_2SO_4 to pH<2	0.010 to 20 mg/L
Total Dissolved Nitrogen	water	USGS I-2650-03	0.06 mg/L	28 days	Filter; cool to 4C	0.010 to 20 mg/L
Total Phosphorus	water	USGS I-2650-03	0.004 mg/L	7 days	Cool to 4°C	0.010 to 10 mg/L
Orthophosphate	water	USGS I-2606-89	0.006 mg/L	48 hours	Filter; cool to 4°C	0.003 to 1 mg/L
Acid neutralizing capacity	water	USGS-2030-89	5 mg/L	30 days	Filter; cool to 4°C	>2 mg/L
Calcium	water	USGS I-1472-87	0.02 mg/L	180 days	Filter; HNO_3 to pH<2	0.01 to 400 ug/L
Chloride	water	USGS I-2057-85	0.20 mg/L	180 days	Filter; cool to 4°C	0.10 to 300 mg/L
Iron	water	USGS-I-1472-87	6 ug/L	180 days	Filter; HNO_3 to pH<2	6 to 5000 ug/L
Magnesium	water	USGS I-1472-87	0.008 mg/L	180 days	Filter; HNO_3 to pH<2	0.08 to 200 ug/L
Manganese	water	USGS I-1472-87	0.6 ug/L	180 days	Filter; HNO_3 to pH<2	0.6 to 5000 ug/L
pH	water	USGS I-2587-89	0.1 SU	30 days	Cool to 4°C	0.1 to 14 SU
Silica	water	USGS I-2700-89	0.2 mg/L	180 days	Filter; cool to 4°C	0.20 to 40 mg/L
Sodium	water	USGS I-1472-87	0.2 mg/L	180 days	Filter; HNO_3 to pH<2	0.20 to 400 mg/L
Specific Conductance	water	USGS I-2781-89	2.6 uS/cm	30 days	Cool to 4°C	2.6 to 12900 uS/cm
Sulfate	water	USGS I-2057-85	0.18 mg/L	180 days	Filter; cool to 4°C	0.08 to 300 mg/L
N-15/N-14	water	RSIL LC 2900	N/A	N/A	Filter; freeze	-5 to 20 per mil
O-18/O-16	water	RSIL LC 2900	N/A	N/A	Filter; freeze	-10 to 60 per mil

Marine Monitoring Programs *In situ* Measurements

UW Oceanic Remote Chemical Analyzer (ORCA) Buoys

The Sea-Bird CTD is factory calibrated for pressure, salinity, temperature, and density. Discrete samples collected at three-week intervals are used to calibrate the dissolved oxygen sensor, fluorometer, and nitrate sensor (W. Ruef, personal communication).

UW PRISM Cruises

PRISM CTD sampling procedures for the cruises adhere to those described in Newton et al. (2002) assuring consistency with Ecology and PSAMP CTD data.

Ecology Marine Monitoring / Puget Sound Ambient Monitoring Program (PSAMP)

Sea-Bird CTDs are used to determine vertical profiles for some of the measured parameters (e.g., temperature and dissolved oxygen). Ecology calibrates CTDs according to the schedule listed in Table 21.

Table 21. Sea-Bird CTD calibration and maintenance schedule.

Sensor	Monthly Calibration	Monthly Checks	Annual Factory Calibrations	Factory Calibrations every Two Years
Conductivity[6]		X	X	
Temperature		X	X	
Pressure		X		X
Dissolved Oxygen[7]	X			X
pH[8]	X			X
Light Transmissometer[9]	X			

[6] Conductivity cell is re-platinized bienially prior to factory calibration.
[7] During factory calibrations, dissolved oxygen sensor will be checked for membrane, module, internal electrolyte, and electrical connections. Probe likely replaced every two years.
[8] During factory calibrations, pH sensor will be checked for internal electrolyte and electrical connections. Probe will probably need to be replaced every two years.
[9] Light transmissometer will be sent to factory only when the light emitting diode (LED) and/or synchronous detector needs to be replaced.

UW Applied Physics Laboratory Moored Profiler

The remote profiler will be retrieved in June and October, checked for integrity, recalibrated, and redeployed (M. Alford, personal communication). The MP sensors were calibrated before deployment, and will be calibrated again after recovery. At each turnaround, data are checked versus PRISM and citizen monitoring data to monitor and correct for sensor drift.

Ecology Permanent Moorings

Measurement procedures for the permanent moorings will be consistent with standard Ecology protocols. The project plan for the permanent moorings will specify measurement procedures.

Hood Canal Salmon Enhancement Group Marine Monitoring

The Sea-Bird CTD is factory calibrated for pressure, salinity, temperature, and density. Discrete samples collected at weekly intervals are used to calibrate the dissolved oxygen sensor, and fluorometer. Filtered water samples are collected monthly for nutrient analysis

Freshwater Monitoring Programs *In situ* Measurements

Ecology Stream Water Quality Monitoring

Ecology stream water quality monitoring for *in situ* measurements follows standard protocols outlined in Ward et al. (2001). Table 22 summarizes equipment and reporting limits.

Table 22. Ecology monitoring equipment and reporting limits.

Parameter	Sample Matrix	Equipment	Reporting Limit	Expected Range of Results
Dissolved Oxygen	water	Hydrolab	0.1 mg/L	0.1 to 20 mg/L
pH	water	Hydrolab	0.1 SU	0 to 14 SU
Temperature	water	Hydrolab	0.1 °C	0 to 30 °C
Temperature	water	TidBit	0.1 °C	0 to 30 °C
Dissolved Oxygen	water	Winkler	0.1 mg/L	0.1 to 20 mg/L
Specific Conductivity	water	Hydrolab	1 uS/cm	1 to 1000 uS/cm

Coordinated Stream Water Quality Monitoring

Measurement procedures follow the protocols outlined in Krogslund et al. (2005).

Ecology Stream Discharge and Temperature Monitoring

Ecology stream discharge monitoring follows standard protocols outlined in SHU (2005).

West Shore Discharge Monitoring

Lubischer and Miller (2004) outline measurement procedures for discharge monitoring.

South Shore Discharge Monitoring

HCSEG follows the measurement procedures of Kitsap Public Utilities District (2000).

USGS Discharge and Temperature Monitoring

In situ measurement procedures for discharge measurements and water quality data follow standard protocols outlined in Wahl et al. (1995) and Wagner et al. (2000), respectively.

USGS Groundwater Monitoring

In situ measurement procedures for water quality data follow standard USGS protocols outlined in Wagner et al. (2000). *In situ* measurements will be made using a YSI multi probe. Parameters will include Dissolved Oxygen, Specific Conductivity, pH, and ORP. *In situ* measurements will be used to determine if sufficient purging of well volumes has occurred and to identify the extent of sea water mixing.

Quality Control

Quality control procedures refer to the routine application of statistical procedures to evaluate and control the accuracy of measurement data. The results for quality control samples determine whether the MQOs have been met. Table 23 details field and laboratory quality control procedures for most programs.

Table 23. Field and laboratory quality control procedures for the Hood Canal DO Program.

Analysis	Field Replicates	Lab Check Standard	Lab Method Blank	Lab Duplicate	Matrix Spikes
Field Measurements					
Velocity	1/run	N/A	N/A	N/A	N/A
pH	1/run	N/A	N/A	N/A	N/A
Temperature (CTD)	1/run	N/A	N/A	N/A	N/A
Temperature (thermometer)	1/run	N/A	N/A	N/A	N/A
Dissolved Oxygen (CTD)	1/run	N/A	N/A	N/A	N/A
Specific Conductivity	1/run	N/A	N/A	N/A	N/A
Secchi Depth	1/run	N/A	N/A	N/A	N/A
Pressure	1/run	N/A	N/A	N/A	N/A
Density	1/run	N/A	N/A	N/A	N/A
Chlorophyll Fluorescence	1/run	N/A	N/A	N/A	N/A
Nitrate plus Nitrite	1/run	N/A	N/A	N/A	N/A
Light Transmissivity	1/run	N/A	N/A	N/A	N/A
Laboratory Measurements					
Dissolved Oxygen (Winkler)	1/10 samples	N/A	N/A	N/A	N/A
Chlorophyll *a*					
Salinity					
Dissolved Organic Carbon	1/10 samples	1/run	1/run	1/10 samples*	1/20 samples*
Total Organic Carbon	1/10 samples	1/run	1/run	1/10 samples*	1/20 samples*
Total Persulfate Nitrogen	1/10 samples	1/run	1/run	1/10 samples*	1/20 samples*
Ammonium-Nitrogen	1/10 samples	1/run	1/run	1/10 samples*	1/20 samples*
Nitrate+Nitrite Nitrogen (MEL)	1/10 samples	1/run	1/run	1/10 samples*	1/20 samples*
Nitrate-Nitrogen (MCL)	1/10 samples	1/run	1/run	1/10 samples*	1/20 samples*
Nitrite-Nitrogen (MCL)	1/10 samples	1/run	1/run	1/10 samples*	1/20 samples*
Orthophosphate	1/10 samples	1/run	1/run	1/10 samples*	1/20 samples*
Silicate	1/10 samples	1/run	1/run	1/10 samples*	1/20 samples*
Total Phosphorus	1/10 samples	1/run	1/run	1/10 samples*	1/20 samples*
Total Suspended Solids	1/10 samples	1/run	1/run	N/A	N/A

*or at least one per run.

Collecting and analyzing replicate samples will assess total variation for field sampling and laboratory analysis. At least 10% of the total number of most laboratory samples and field measurements will be replicated. Field sampling and measurements will follow quality control protocols described in Ecology (Ward et al., 2001) and UW (Krogslund et al., 2005) documents. CTDs and Hydrolabs will be calibrated in accordance with standard Ecology protocols (Ward et al., 2001) and Puget Sound Monitoring Program protocols (PSWQA, 1988) as described in Newton et al. (2002). All water samples will be collected directly in pre-cleaned containers except filtered samples. These will be collected in a syringe and filtered into pre-cleaned containers. The syringe will be rinsed with ambient water at each sampling site three times before filtering.

Marine Monitoring Programs

UW Oceanic Remote Chemical Analyzer (ORCA) Buoys

No replicates, blanks, or matrix spikes are anticipated. Sensors will be calibrated using the discrete samples described under Sampling Procedures.

UW PRISM Cruises

The UW PRISM cruises collect field replicates as described in Table 23.

Ecology Marine Monitoring/Puget Sound Ambient Monitoring Program (PSAMP)

As described in Janzen (1992) and Newton et al. (2002), one station per marine flight survey is selected for field quality control procedures to assess variation associated with field replicates and laboratory analyses. Triplicate water samples are collected for pigment and nutrient analyses in three separate bottles filled at the 0.5-m depth. Field replicates are submitted to the laboratory as blind samples. The program collects field replicates as described in Table 23.

UW Applied Physics Laboratory Moored Profiler

No replicates, blanks, or matrix spikes are anticipated.

Ecology Permanent Moorings

Quality control procedures for the permanent moorings will be consistent with standard Ecology protocols. The project plan for the permanent moorings will specify quality control procedures.

Hood Canal Salmon Enhancement Group Marine Monitoring

The HCSEG Citizen Monitoring collects two DO field replicates in the lower five transects each week and one DO replicate in the upper two transects each sample period.

Freshwater Monitoring Programs

Ecology Stream Water Quality Monitoring

Ambient stream water quality monitoring follows standard Ecology quality control procedures (Ward et al., 2001).

Coordinated Stream Water Quality Monitoring

Coordinated stream water quality monitoring quality control procedures follow Table 23.

Ecology Stream Discharge and Temperature Monitoring

Stream discharge monitoring follows standard Ecology quality control procedures (SHU, 2005).

Stormwater Monitoring

Quality control procedures follow those of the coordinated stream water quality monitoring program specified in Table 23.

West Shore Stream Discharge Monitoring

No replicate flows were described in Lubischer and Miller (2004).

North Shore Stream Discharge and Temperature Monitoring

No replicate flows measurements are planned.

USGS Discharge and Temperature Monitoring

Quality control procedures for discharge measurements and water quality data follow standard protocols outlined in Wahl et al. (1995) and Wagner et al. (2000), respectively.

USGS Groundwater Monitoring

Quality control procedures for water quality data follow standard USGS protocols outlined in Wagner et al. (2000). Water quality samples will be collected as outlined in the USGS national field manual for the collection of water quality data book 9. In accordance with USGS quality assurance and quality control guidelines 10% of all samples will have field replicates sent to the lab for analysis. Several field blanks will be collected where possible and equipment blanks will also be collected at a well or piezometer during the sampling period.

Other Data Development

Atmospheric Deposition Data

Quality control procedures will be consistent with the Coordinated Stream Monitoring as well as with the NADP (Harding ESE, 2003).

Data Management Procedures

All phases of the HCDOP depend on data from a variety of sources. The HCDOP addresses the complex interaction of numerous spatially explicit ecosystem processes and functions and, therefore, the Information System must function across a range of spatial, temporal, and thematic scales. Integration of this type of diversity and solution to these and other issues requires attention to an information system architecture as well as a "program plan" for the partnership of agencies, institutions, and individuals.

Implementation of this program plan is based upon the participation of three coordinated data nodes, each dealing with well identified data sources, and each offering solutions to the needs of a targeted set of users (data sinks).

The initial data nodes are:

a. The Puget Sound Marine Environmental Modeling Program, (www.psmem.washington.edu).
   Responsible for oceanographic and marine data and model simulations.

b. The Puget Sound Regional Synthesis Model (www.prism.washington.edu/).
   Responsible for atmospheric, terrestrial and nearshore data and model simulations.

c. EKO-system (www.eko-system.us) Paladin Data systems.
   Responsible for local monitoring, citizen observers, county and local governmental data coordination, and ground truth validation data.

All federal, tribal, state, county, local, and citizen organizations and educational institutions will be coordinated through one or more of these nodes. Data collected by entities such as Ecology, USGS, and the National Weather Service will be maintained by those entities using their standard data management tools; analysts must contact data developers to obtain electronic data during the year. Integration of data into data nodes will be described in subsequent documents.

Marine Monitoring Programs

UW Oceanic Remote Chemical Analyzer (ORCA) Buoys

The data and information management requirements for ORCA are met by collaboration and partnership with the Puget Sound Regional Synthesis Model (PRISM-UW) and Puget Sound Marine Ecosystem Modeling (PSMEM) projects. These projects leverage the duties of shared system architecture for data and information management between a staff of approximately 2.5 FTE's. Beginning in March 2005, the partnership with HCDOP was initiated with preliminary exchange of database requirements and metadata schema. Currently, a metadata editor and style sheet have been distributed between all partners and validation of existing metadata is underway. A web-based interface for data source/sink profile management is being tested and ranks as a high priority within the working group. The DataStream & Informatics working group continues to investigate the use of OpenMI for model integration, OpenDAP for server functions, and OpenGIS for spatial reference system documentation.

UW PRISM Cruises

The data and information management requirements of the PRISM cruises are met by collaboration and partnership with the PRISM-UW and PSMEM projects. These projects leverage the duties of shared system architecture for data and information management between a staff of approximately 2.5 FTE's. Beginning in March 2005, the partnership with HCDOP was initiated with preliminary exchange of database requirements and metadata schema. Currently, a metadata editor and style sheet has been distributed between all partners and validation of existing metadata is underway. A web-based interface for data source/sink profile management is being tested and ranks as a high priority within the working group. The DataStream & Informatics working group continues to investigate the use of OpenMI for model integration, OpenDAP for server functions, and OpenGIS for spatial reference system documentation.

Ecology Marine Monitoring/Puget Sound Ambient Monitoring Program (PSAMP)

Newton et al. (2002) describes marine ambient data management. CTD data files are processed using Sea-Bird Electronic, Inc., SEASOFT (C) software. Following application of calibration coefficients, the results are averaged into 0.5-m bins. Profiles of salinity and density with depth are derived from measured values of temperature, conductivity, and pressure. All profile data are entered into Ecology's Marine Water Monitoring database using Microsoft Access (C). CTD parameter values from 0.5, 10, and 30-m depths are linked to results from discrete water sampling.

UW Applied Physics Laboratory Moored Profiler

After each turnaround, processed data will be archived and made available in ASCII and MATLAB formats on the HCDOP website.

Ecology Permanent Moorings

Data management will be described in subsequent QA Project Plans and will adhere to standard Ecology protocols.

Hood Canal Salmon Enhancement Group Marine Monitoring

CTD data files are processed at HCSEG using Sea-Bird Electronic, Inc., SEASOFT (C) software. Following application of calibration coefficients, the results are averaged into 0.5-m bins. Profiles of salinity and density with depth are derived from measured values of temperature, conductivity, and pressure. All profile data are send via email to the PRISM group for inclusion into their established database and utilized for the continued development of model parameters.

Freshwater Monitoring Programs

Ecology Stream Water Quality Monitoring

Laboratory data reduction, review, and reporting will follow procedures outlined in MEL (2003). Laboratory staff will be responsible for internal quality control validation and for proper data transfer and reporting data to the Ecology ambient monitoring program project manager via the Laboratory Information Management System (LIMS).

Coordinated Stream Water Quality Monitoring

Each sampling entity will be responsible for maintaining in situ data collected under the Coordinated Stream Water Quality Monitoring program. Data will be stored in field notebooks, spreadsheets, and/or agency-specific databases during the first year of monitoring. HCSEG will develop a common database structure to the collaborators for transferring data. HCSEG will be responsible for incorporating the results into the project database structure.

Ecology Stream Discharge and Temperature Monitoring

Stream gaging data, rating curves, and temperature data are stored within a Hydstra database maintained by the Stream Hydrology Unit. The software is used to develop rating curves and for additional data analysis.

Stormwater Monitoring

Field notes and compositing information will be maintained by UW. UW will compile laboratory data for the storm events.

West Shore Stream Discharge Monitoring

Stream gaging data and best-fit rating curves will be stored in Excel spreadsheets with the Skokomish Tribe.

North Shore Stream Discharge Monitoring

Stream gaging data and best-fit rating curves are being stored at HCSEG in Excel spreadsheets.

USGS Discharge and Temperature Monitoring

USGS discharge, temperature, and data management are described in Wahl et al. (1995) and Wagner et al. (2000).

USGS Groundwater Monitoring

All groundwater quality data, site descriptions, and water levels will be entered into the USGS GWSI data base. All other data sources will be published in the final report or in a data report as necessary.

Other Data Development

Atmospheric Deposition Data

UW will maintain laboratory results for atmospheric deposition samples. Data will be stored in spreadsheets.

Audits and Reports

Quarterly reports will be generated and posted on the HCDOP-IAM website. Monitoring and modeling data will be maintained in the University of Washington DataStream & Informatics through PRISM and PSMEM and portions accessed and stored EKO-System with regular (monthly) updates by the HCDOP-IAM partners.

Data Verification, Validation, and Usability Assessment

Procedures for verifying laboratory data have been established by the laboratory staff of the various laboratories utilized in this study, which are all Washington State Accredited Labs. Procedures for verifying field data by field personnel are outlined in the SOPs referenced in the field sampling text above. Verification of datasets will be assured if the MQOs are met. PRISM/PSMEM data validation procedures for datasets will be followed, as described above.

Agencies collecting data will be responsible for conducting data verification and validation during Year 1. Overall project data verification and validation will be documented in future publications.

A data usability assessment will be documented and conducted during subsequent project phases. The usability assessment is necessary to verify that MQOs have been met; or, if they have not been met, whether the data are sufficient to meet project objectives (Lombard and Kirchmer, 2004.). Methods and responsibilities will be described with other Year 2 activities.

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Appendix 1.

List of Acronyms

ABC	Aquatic Biogeochemical Model
ADCP	Acoustic Doppler Current Profiler
ANC	Acid-neutralizing capacity
APL	Applied Physics Laboratory
BOD	Biochemical oxygen demand
C-CAP	Coastal Change Analysis Program
CAE	Corrective Action and Education (part of HCDOP)
CEE	Civil and Environmental Engineering
CTD	Conductivity-Temperature-Depth meter
DEM	Digital elevation model
DHSVM	Distributed Hydrology Soil – Vegetation Model
DIN	Dissolved inorganic nitrogen (sum of nitrate and ammonium)
DO	Dissolved oxygen
DOC	Dissolved organic carbon
EAP	Environmental Assessment Program
ECY	Department of Ecology
FC	Fecal coliform bacteria
HCDOP	Hood Canal Dissolved Oxygen Program
HCSEG	Hood Canal Salmon Enhancement Group
IAM	Integrated Assessment and Modeling
JCCD	Jefferson County Conservation District
KCHD	Kitsap County Health District
MCL	Marine Chemistry Laboratory, UW School of Oceanography
MEL	Manchester Environmental Laboratory, Department of Ecology
MLLW	Mean lower low water
MP	Moored profiler
MQO	Measurement Quality Objective
NAWQA	National Water Quality Assessment
NH4N	Ammonia as nitrogen

NO23N	Nitrate plus nitrite as nitrogen
NOAA	National Oceanic and Atmospheric Administration
NWQL	National Water Quality Laboratory, USGS
OP	Orthophosphate
ORCA	Oceanic Remote Chemical Analyzer
ORP	Oxidation reduction potential
PACA	Preliminary Assessment and Corrective Actions
PCBs	Polychlorinated biphenyls
POM	Princeton Ocean Model
PRISM	Puget Sound Regional Synthesis Model
PSAMP	Puget Sound Ambient Monitoring Plan
PSI	Pacific Shellfish Institute
PSMEM	Puget Sound Marine Ecosystem Modeling
ROMS	Regional Ocean Modeling System
SOP	Standard Operating Procedure
TDN	Total dissolved nitrogen
TMDL	Total Maximum Daily Load
TNP	Total nitrogen and total phosphorus
TOC	Total organic carbon
TP	Total phosphorus
TPN	Total persulfate nitrogen
TSS	Total suspended solids
USGS	United States Geological Survey
UW	University of Washington
WAGDA	Washington State Geospatial Data Archive
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation
WWU	Western Washington University

Appendix 2.

Field Sampling Protocols for Puget Sound Streams

Combined NSF-PRISM and Hood Canal Projects

Prepared by Kathy Krogslund, Aaron Morello, Jeff Richey, and Suzanne Osborne

Last revised August 8, 2005

I. Rationale and Summary (taken from CAMREX 2002-2005)

The overall intention of the sampling procedures described here is to identify collection procedures for obtaining the highest quality samples of the dissolved and total nutrients of streams within Puget Sound. The protocol has been refined over time and seeks to optimize sampling efficiency while minimizing sample degradation and loss of accuracy with storage and transport.

There are three primary types of collection and analyses that may be required for each sampling location, each with a particular sequence of activities. The general sequence of collection and processing will be described.

1. **Dissolved Nutrients –** To be collected using 25 mm, 0.45-micron pore size, surfactant free cellulose syringe filter and to be analyzed for concentration of orthophosphate, nitrate, nitrite, ammonia, and reactive silica in the stream.
2. **Total Phosphorus (TP), Particulate Carbon/Nitrogen, and Total Suspended Solids (TSS)** – To be collected using 250-ml and 1000-ml sample bottles and to be analyzed for total concentrations of phosphorus, particulate carbon/nitrogen, and suspended solids in the stream.
3. **Dissolved Organic Carbon (DOC) and Total Dissolved Nitrogen (TDN) –** To be collected using 25-mm carbon cleaned GF/F syringe filter and to be analyzed for concentrations of DOC and TDN in the stream.

Regardless of the type of analysis selected, one sampling location should be determined for each site. A field notebook should be utilized to record sample number stream name, site descriptions, and current conditions that might affect analyses (i.e., weather, water color and clarity, terrestrial condition, ice formation, abundant salmon population (alive or dead), etc.) A log sheet that duplicates the information must be provided to the chemistry lab with samples. No samples will be analyzed without the log sheet. The details of exactly what to do at each location are contained in the following sections.

Advance preparation is a critical component to successful field sampling. A detailed list of supplies for each method of collection is given at the beginning of each procedure. The chemistry lab shall prepare all sample jars, syringes, and filter prior to distribution to field teams. There are two fundamental parts to field sampling: collecting and processing. Unless otherwise specified, processing needs to occur immediately after sampling. Transport of the samples will be arranged prior or during distribution of the materials.

II. Preparations for Field Sampling

Sample Containers – at each field station, you will need the following number of bottles and filters.

- 1 60-ml pre-numbered plastic bottle for dissolved nutrients
- 1 250-ml bottle for total phosphorus
- 1 40-ml glass, carbon clean vial for DOC and TDN
- 1 1000-ml plastic bottle for TSS and Particulate Carbon/Nitrogen
- 1 250-ml water bottle for distribution of water to syringe filtration apparatus
- 1 60-ml syringe filtration apparatus
- 1 25-mm, 0.45-micron pore size, surfactant free cellulose syringe filter for dissolved nutrients
- 1 25-mm carbon cleaned GF/F recombusted filter for DOC and TDN
- Colored electrical tape and Sharpie for labeling 250 and 1000-ml bottles
- Blank formatted labels and pen for DOC labeling
- Millipore filter forceps
- *Remember to bring extra filtes, just in case.*

III. Field Sampling and Processing Procedures

Section 1: Dissolved Nutrients – Field Collection and Processing Protocols

Field Supplies:

- Field notebook and log sheet with writing utensil
- 60-ml narrow mouth sample bottle
- 60-ml syringe filtration apparatus
- Surfactant free cellulose, 25 mm, 0.45-micron pore size, nalgene syringe filter
- Cooler with ice

At the field sampling station (all of these activities must be completed while at the filed site, unless otherwise specified.):

1) Remove the plunger from the syringe and rinse the syringe with stream water 3 times.
2) Fill the syringe fully with sample water, and then insert plunger. **(Do not remove plunger once filter is in place.)**
3) Invert syringe and expel air bubble.
4) Attach a filter to the syringe; filter approximately **5-10** ml of sample into sample bottle to rinse out. (**If not completed, dissolution of sample will be evident in the analysis at the lab.)**
5) Filter approximately **45-50** ml of sample into the prenumbered nutrient bottle… the bottle should be **no more** than 2/3 full. **(Do not overfill the bottle! Water expands when frozen and if the bottle is too full the ice will force its way out of the cap and take the nutrient ions with it.)**
6) Securely cap the bottle and place upright in the cooler.
7) Discard filter.

8) Make sure you have filled out field book and log sheets legibly. Record pre-numbered nutrient bottle number. Log sheets need to be included with the samples when they are transported to the lab for analysis. (**Note: no samples will be analyzed without legible logsheets.)**

Section 2: Total Phosphorus (TP). Particulate Carbon/Nitrogen & TSS – Field Collection Protocols

Field Supplies

- Field notebook and log sheet with writing utensil
- 250 ml and 1000 ml wide mouth sample bottles
- Cooler with ice

At the field sampling station (all of these activities must be completed while at the field site, unless otherwise specified):

1) Take water sample directly into the sample bottles (pre-rinse 3 times with sample.)
2) Securely cap the bottles and place upright in cooler.
3) Make sure you have filled out field book and log sheets legibly. Log sheets need to be included with the samples when they are transported to the lab for analysis. **(Note: no samples will be analyzed without legible log sheets.)**

Section 3: Dissolved Organic Carbon and Total Dissolved Nitrogen - Field Collection and Processing Protocols

Field Supplies:

- Field notebook and log sheet with writing utensil
- 40-ml glass carbon clean vials
- 60-ml syringe filtration apparatus (syringe plus filter holder)
- 25-mm pre-combusted carbon cleaned GF/F filter
- Cooler with ice
- Millipore filter forceps

At the field sampling station (all of these activities must be completed while at the field site, unless otherwise specified.):

1) Remove the plunger from the syringe and rinse 3 times with sample water.
2) Fill the syringe fully with sample water, and then insert plunger.
3) Invert syringe and expel air bubble.
4) Unscrew the filter holder. Pre-rinse with stream water, remove filter with millipore filter forceps from aluminum foil container and place filter on the screen, then place the black rubber gasket over the filter and screw it shut. Attach the filter holder to syringe. **(Do not remove plunger once filter is in place!)**
5) Fill out label legibly: date, time, site name, sampler's initials. Check other: filtered sample. Type of analysis: DOC/TDN. Preservative: NA
6) Slowly filter approximately 30 ml of sample through the carbon clean filter directly into the DOC vial. **(Do not pre-rinse doc vial! Do not completely fill the vial!)**
7) Securely cap the bottle and place upright in cooler.

8) Make sure you have filled out field book and log sheets legibly. Log sheets need to be included with the samples when they are transported to the lab for analysis. **(Note: no samples will be analyzed without legible log sheets.)**

Appendix 3.

Pacific Shellfish Institute Laboratory Protocols

Counting Whole Water Samples (Discrete Samples)

If the sample is dense, count the whole water directly, without any settling. Using a Palmer-Maloney counting chamber (0.1-ml chamber), fill the chamber with the preserved sample (2% Lugol's solution) using a pipette (be sure the preserved sample is thoroughly mixed before pipetting the sample to be counted). Count live cells only (live cells will have bright, golden-brown chloroplasts) at 200 magnification. Counting 300-500 cells per 0.1 ml is ideal for accuracy; at a minimum, count at least 150 cells.

If the sample is dilute, it will have to be settled before counting. Fill a glass sampling jar with preserved whole water to the 100-ml mark (calibrate the jar(s) before hand by marking the 100-ml level and 10 ml-level). Secure the lid on top of the jar and allow to settle, undisturbed, overnight. The next day, carefully remove the seawater until it reaches the 10-ml level on the jar. Be careful not to disturb the bottom where the cells have settled. You have now concentrated your sample 10 times. Mix the remaining 10-mls well before distributing sample to counting chamber. Count 0.1 ml of this concentrated sample and use this as your raw count. Calculate cells/ml taking into account the concentration factor and the counting chamber volume factor. Calculate cells/L by multiplying the cells per ml value by 1000.

Counting example: If the whole water sample was too dilute to count directly, the settled material will need to be counted. If 100 ml of whole water are allowed to settle and 90 ml are taken off with a pipette, this is a 10-fold concentration. If the raw count obtained is 350 cells in the 0.1 ml that is counted in the Palmer-Maloney slide and the sample was concentrated by 10X, here is your calculation: (350 cells/0.1ml) X (1/10) X (1000 ml/L) = 350,000 cells/L.

Net Tow Samples

View net tow samples under a microscope at 200 magnification using a Palmer-Maloney counting chamber and list all the species present. Highlight one to two species that are dominant (approx. 40-50% total species) and note one-to-two species that are prominent (sub-blooms).

The whole water samples are collected using a niskin bottle. Net tow samples are collected into 125-ml glass jars and preserved with 2-5% Lugol's solution. Samples are driven weekly to Pacific Shellfish Institute (PSI) for identification.

For samples that are collected as part of the "rapid response" portion of the project, fresh, live, unpreserved samples are delivered to PSI within 24 hours of collection. The samples are transported in a cooler with ice packs until placed in a refrigerator at approximately 4°C. Phytoplankton samples are immediately viewed under a microscope and the results, along with digital photographs, are e-mailed to Rita Horner for final identification confirmation and also reported to Jan Newton and Dan Hannafious.

Appendix 4.

Stormwater Monitoring

In order to obtain more accurate nutrient mass loading estimates to the HC, it will be necessary to sample some of the HC rivers and streams during storm events. This is necessary so that we[10] will have plausible nutrient concentration estimates (which are needed for the nutrient loading calculations) to associate with these peak flows. This is critical because some constituents, particularly those associated with particles, increase greatly in concentration during storm events. Because peak concentrations coincide with peak flows for some nutrients, a very disproportionate amount of their loading occurs in a small fraction of all days. For example, in a study of four Seattle area streams that were sampled daily for one year, Brett et al. (2005b) found 25% of all TP transport occurred in the 9 to 19 days with the heaviest loads.

Recent storm event sampling results for several Puget Sound area streams/rivers demonstrate the impact of storm flows on constituent concentrations (Brattebo and Brett 2005; Brett et al. unpublished data). In a summary of results from approximately 30 stormwater samples compared to 120 baseline samples collected from each of 17 Seattle area streams along an urban to second growth forest gradient, Brett et al. (unpublished results) showed that, on average, total suspended sediment (TSS) concentrations and Turbidity increased by 329% ± 198% (± 1 SD) and 242% ± 138%, respectively (see Figure A4-1).

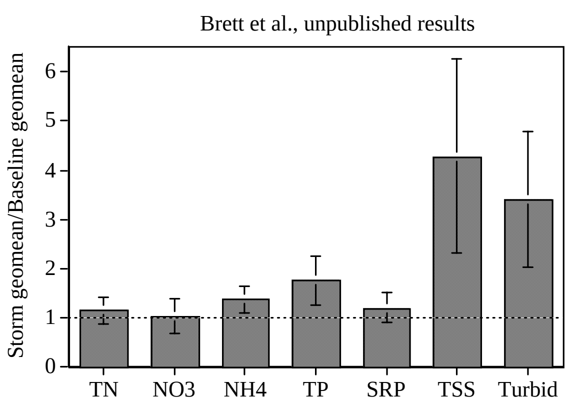

Figure A4-1. Comparison in concentrations between stormwater and baseline samples.

Total phosphorus increased by 77% ± 5%, whereas the soluble reactive phosphorus concentration only increased 21% ± 30% and o average nitrate concentrations did not change (3% ± 35% increase). Total nitrogen (TN) showed trends very similar to those for nitrate because nitrate on average constituted over 80% of the TN in these streams (Brett et al., 2005a). Although not shown in this figure, these data also suggest the storm responses of NO3 and SRP were related to land cover (i.e., r^2 = 0.62 and 0.46, respectively). In the six most forested streams in this dataset, nitrate concentrations increased by 33% ± 34% during storms, whereas in the six most urban streams nitrate concentration decreased by 24% ± 15% during storms. Similarly, SRP increased by 45% ± 34% in the forested streams during storms and by only 2% ± 11% in the urban streams.

[10] Written by Mike Brett, University of Washington.

The seasonal nutrient trends reported by Brett et al. (2005a) showed that, on average, nitrate peaked during the winter with concentrations 77% higher than the summer minimum values. Conversely, SRP peaked during the summer with concentrations 61% higher than the winter minimum values.

Brattebo and Brett (2005) documented trends in sediment concentrations, phosphorus concentrations and speciation, and conductivity in four small streams representing forested, agricultural, suburban and urban landcover during storm events. The results obtained for the forested stream are depicted in Figure A4-2 below. These results show suspended sediment and total phosphorus concentrations increased greatly during the leading edge of the hydrograph and decreased more precipitously on the falling edge. In contrast, total dissolved phosphorus was nearly constant during the hydrograph and conductivity decreased by 22% during the peak of the hydrograph. [Nitrate concentrations were not determined in this study].

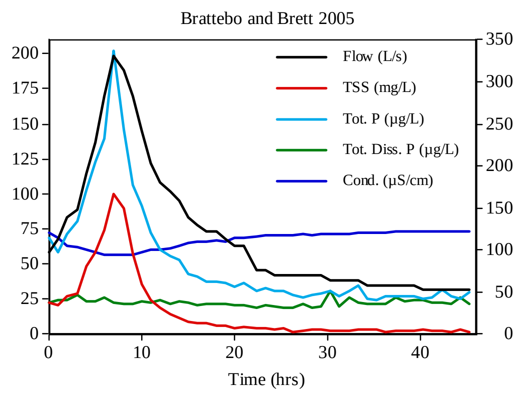

Figure A4-2. Parameter variation during storm events in a small forested stream.

The stormwater monitoring plan should have six components: site selection, sampling frequency targets, constituent selection and analysis, sampling event triggers, sampling event start and end points, and post-hoc event validation criteria. The first step in the storm event sampling process is site selection. At the HCDOP stormwater planning meeting help on August 12, 2005, it was decided that stormwater sampling should only be conducted on sites with active flow gauges. From the 18 sites within the HC watershed that fit this criteria, it was decided that eight sites, which represented a range of river/stream sizes, dissolved inorganic nitrogen concentrations, and geographic location should be selected for stormwater sampling. Table A4-1 below lists the sites selected:

Table A4-1. Characteristics for sites selected for stormwater monitoring.

Site	DIN (µg/L)	DIN category	Flow	Location
Seabeck Creek	588	High	mod	East
Little Quilcene River	495	High	mod	West
Tahuya River	144	Moderate	big	East
Union River	266	Moderate	big/mod	East
Dewatto River	112	Moderate	mod	East
Duckabush River	48	Low	big	West
N.F. Skokomish River	27	Low	big	West
Eagle Creek	75	Low	small	West

At the HCDOP stormwater planning meeting, it was also agreed that we should have a target of collecting four composite storm samples from each of the eight rivers/streams (n = 32), as well as complete hydrographs (i.e., sample every one or two hours throughout the event) one time for three "representative" sites (n = 3). This design is similar to that employed by Correll et al. (1999) when they sampled Chesapeake Bay tributaries during storm events. It is not necessary that all of these samples be collected in the same year; in fact it, is preferable if they are not. The samples collected during storm sampling will be analyzed for the same constituents monitored during the basic monthly monitoring program (i.e., suspended sediments, and dissolved and particulate constituents of nitrogen, phosphorus and carbon). The conductivity of these water samples will also be determined to obtain insights into the relative contributions of groundwater, subsurface flow, and overland flow to streamflow during these events. The same sample handling, processing, and analysis QA/QC guidelines previously described for the monthly stream water quality monitoring program will be followed for the stormwater sampling program.

One of the most problematic issues with this sampling plan is deciding when to initiate a sampling event. Past experience from the Benjamin Brattebo MSE thesis project (see Brattebo and Brett 2005) resulted in six successfully sampled storm events out of 30 attempts. This 20% success rate could also be the norm for the HCDOP especially considering that Brattebo had less distance to travel to his study sites than will be the case for the HCDOP, and he was quite flexible in the times when he was willing to initiate sampling (e.g., in the middle of the night and on weekends). This problem can be somewhat alleviated if autosamplers are pre-deployed and pre-programmed to collect samples during certain phases of the hydrograph as was done by Correll et al. (1999). These authors pre-deployed autosamplers that were programmed to be triggered by a rising hydrograph and collect samples at prespecified flow increments until the hydrograph returned to normal or the autosampler ran out of bottles. For this approach to work, it is essential that the autosampler be coupled to a flow gauge. Using this approach, it is only necessary to collect the sample bottles after storm events have occurred. For our purposes, we should program the autosamplers to begin collecting samples when the rising hydrograph exceeds 1.5 times the preceding baseflow, and to stop collecting samples when the hydrograph recedes to less than 1.5 times the baseflow. In order for a sampling event to be deemed "valid," it should include at least six discrete samples collected within the event, but would ideally include more. The flow increments necessary to trigger the successive collection of discrete samples should be decided after examining the historic hydrograph record for each of the study sites and should be selected so that the 24 sample bottles would not completely run out during a moderately large storm event (i.e., one where the peak flow is equivalent to the 90th percentile for daily peak flows for that month).

Appendix 5.

Atmospheric Deposition

A common approach when trying to estimate atmospheric nutrient loads is to apply the areal loading rate (in kg/ha-yr) observed at the nearest monitoring station or the average areal loading rate from several adjacent stations to the entire watershed being studied. This approach is adequate when the objective it to obtain a quick and rough estimate, as was the case for Paulson et al. (2004). However, in the current context, it will be necessary to provide nutrient loading estimates on a pixel-by-pixel basis to drive the watershed water quality model. Since precipitation varies greatly within the Hood Canal watershed, and variation in mean precipitation is the main source of variation in atmospheric areal nutrient loading estimate, it will be necessary for us[11] to calculate localized areal loading as the product of the site- and time-specific concentrations multiplied by site- and time-specific precipitation.

Wet (in rainfall) and dry nutrient fallout varies by proximity to sources of clean (i.e., the airflow coming off the Pacific Ocean) and polluted (especially that within the Vancouver to Tacoma air corridor) air, and elevation (due to the impacts of inversions and mixing layers on the vertical distribution of air pollutants) (Tim Larson, UW Civil and Environmental Engineering, personal communication). Rainwater nutrient concentrations (and presumably nutrient dry fallout as well) also vary strongly seasonally, with an inverse relationship with seasonal precipitation amounts. There are four EPA National Acid Deposition Program (NADP) monitoring stations located in western Washington, with the site at the Hoh Ranger Station in the Olympic National Park (ONP) closest to Hood Canal. There is also a nitrogen and sulfur dry fallout monitoring station maintained by the EPA's Clean Air Status and Trends Network (CASTNET) located within the ONP 46 km from the Hoh Ranger Station. NADP site. These sites report data for inorganic nitrogen (i.e., wet and dry forms of NO3 and NH4) but not for total nitrogen (TN). There is virtually no atmospheric wet or dry fallout data available for any species of phosphorus for the greater Hood Canal region.

The rainwater data presented in Figure A5-1 show Dissolved Inorganic Nitrogen (DIN; = NO3 + NH4) concentrations for the Hoh Ranger Station site averaged by month for the period from 1984 to 2004. This figure shows rainwater DIN concentrations had a minimum of about 90 µg/L during fall/winter months of November through January, and a peak of approximately 210 mg/L during the summer/fall months of July through September. These data also show that monthly average rainwater DIN concentrations were strongly inversely correlated with mean monthly precipitation. On average, 87% of this DIN was as nitrate and 13% as ammonium. It is not known what proportion of the TN is DIN. The DIN dry fallout data for the ONP CASTNET monitoring station show dry fallout is 27.5% of total (i.e., wet and dry) DIN fallout, which suggests rainwater DIN loading should be multiplied by a factor 1.38 to yield total DIN fallout. The monthly average rainwater concentrations for the NADP sites located at the North Cascades NP Marblemount Ranger Station and La Grande/UW Pack Forest (located in the foothills of Mount Rainier) suggest regional variation in rainwater DIN concentrations may be considerable, as these stations had rainwater DIN concentrations which were on average approximately three times higher than the

[11] Written by Mike Brett, University of Washington.

concentrations observed at the ONP Hoh Ranger Station. As previously noted, rainwater nutrient content also varies with elevation. To estimate how nutrient fallout varies with elevation, we will refer to the series of papers by R.J. Vong, Oregon S.U. Atmos. Sci Dept., (e.g., Vong et al., 1984).

Because wet and dry nutrient fallout is highly localized, and especially because we have no atmospheric TP and TP loading data, we will collect rainwater samples (for the subsequent determination of dissolved and total nitrogen and phosphorus) at the weather monitoring station to be maintained on site at the Hood Canal Salmon Enhancement Offices. At least 30 rainwater samples will be collected for rainfall events large enough to supply the volume of sample necessary for subsequent nutrient determinations at the UW Oceanography lab. Dry fallout samples will also be collected during the intervals between rainfall events. The wet and dry fallout samples will be collected in accordance with the CASTNET QA Project Plan procedures described in Harding ESE (2003).

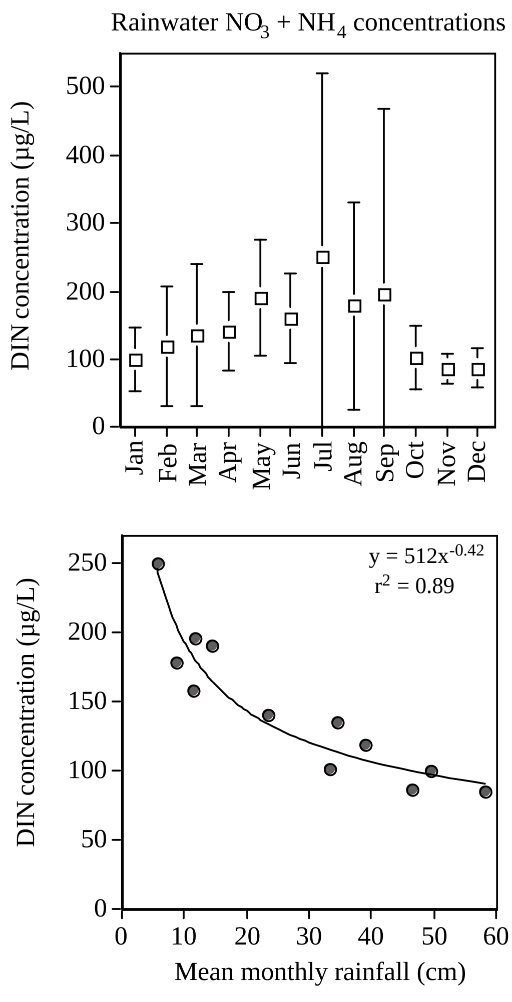

Figure A5-1. Seasonal rainwater DIN trends for the Hoh R.S. NADP site. The upper panel shows the monthly averages (± 1 SD) for the period 1984 to 2004 and the lower panel shows the monthly DIN concentration averages plotted against the monthly precipitation averages for the monitoring station.