Work Plan for U.S. Geological Survey Studies Addressing Low Concentrations of Dissolved Oxygen in Hood Canal

<u>Introduction and Problem</u>.—In September 2002, it was observed that the fish on the west side of Hood Canal near Hoodsport (fig. 1) were under stress from low concentrations of dissolved oxygen. This observation prompted the Washington State Department of Fish and Wildlife to temporarily close parts of Hood Canal to some types of fishing during the month of October. In 2003, low dissolved oxygen conditions worsened, some fish kills were observed as early as June, and by October large fish kills were reported. It was estimated that about 30 percent of rockfish were killed in October. Low concentrations of dissolved oxygen in Hood Canal during late summer and early fall have been observed as far back as the 1950s. Available data suggest that even though concentrations vary from year to year, they have been trending lower over time, and the duration of low concentrations is more persistent.

Poor deep circulation and the decomposition of large amounts of algae are two primary factors that contribute to the low concentrations of dissolved oxygen in Hood Canal. The sluggish circulation and stratified water column of Hood Canal produce characteristics that are similar to classic fjords (Warner and others 2001; Paulson and others, 1993). Hood Canal (fig. 1) is 110 km (kilometer) long and is between 2 and 4 km wide over most of its length. Sills, which rise to within about 50 and 75 m (meters) of the water surface, separate Hood Canal from the main basin of Puget Sound. Landward of the inner sill, the depth of Hood Canal increases to about 175 m. In the vicinity of the Great Bend, the bottom shallows to about 40 m, and depths in the segment of Hood Canal extending from the Great Bend to Lynch Cove are 40 m or less.

Unlike many fjords with shallow sills, the bottom waters of Hood Canal are not as anoxic as the middle layer because cold, saline, oxygenated ocean water sinks to the bottom as it spills over the sills (Paulson and others, 1993). Because fresh water inflows from rivers and streams tend to stay on the surface of the canal, the oldest water is confined to the middle layer where it stagnates because mixing between layers is limited. Poor circulation and stratification set up conditions so that the re-oxygenation rate is not sufficient to meet the demand for oxygen caused by decomposition of algal biomass produced in the surface layer. Nutrients, especially nitrogen compounds, entering Hood Canal from a variety of sources, accelerate algal production and increase the amount of biomass, which eventually settle and decay increasing the demand for oxygen. Low nitrogen levels typically limit algal growth in marine waters.

Study Objectives.—Recently, the U.S. Geological Survey (USGS) has been asked by Congress to become actively involved in the study of the causes of low dissolved oxygen concentrations in Hood Canal. A meeting between the USGS, local groups and governments, agencies, tribes, and the University of Washington was held on January 8, 2004, and it was agreed that the USGS could make a significant contribution to the overall efforts to determine the causes and solutions of the low dissolved oxygen concentrations in Hood Canal by assessing the sources and quantifying the amounts of nitrogen compounds discharged by those sources to Hood Canal.

Study Approach and Methods.—Assessing sources and quantifying amounts of nitrogen compounds discharged to Hood Canal will be accomplished by 1) using available information and data to make initial estimates of the amounts and spatial distribution of nitrogen compounds discharged to Hood Canal from all sources, 2) using the results of initial estimates to design and conduct focused studies needed to better quantify nitrogen loading from major sources to sensitive areas of Hood Canal, and 3) applying the results of the focused studies to improve the overall estimates nitrogen loading to Hood Canal.

Initial Estimates of Nitrogen Loading to Hood Canal.—Loads of nitrogen compounds discharged to Hood Canal from rivers and streams will be estimated by 1) using previous load calculations, such as those done by Embrey and Inkpen (1998), 2) calculating loads discharged from streams for which monitoring and gaging data are available (Washington State Department of Ecology and other sources), and 3) determining the statistical relation between land use, drainage area, and calculated loads to estimate loads discharged from streams that have not been previously sampled or gaged. The rating-curve method, which uses instantaneous sample concentrations and daily or unit streamflow data (Crawford, 1991 and 1996), will be used to compute stream loads if such data are available; otherwise, a simplified method will be used. Similar to the approach taken by the Washington State Department of Ecology in estimating nitrate loading to South Puget Sound in ground-water discharges (Pitz, 1999), nitrogen compounds contained in ground water discharged to streams will be included as part of the stream loads.

Point or permitted sources of nitrogen compounds discharged directly to Hood Canal will be estimated using available data on discharge allocations, measured discharges, and results of studies that have made similar assessments. Part of this task will be to identify all such sources, such as aquaculture.

Loads of nitrogen compounds entering Hood Canal from septic system effluent that is not transported via ground-water flow to sampled rivers and streams (for which loads have already been computed) will be estimated by separating the remaining septic systems into two groups. The first group includes septic systems located along and near the shoreline that discharge almost directly to Hood Canal. The second group includes septic systems located farther from shore, the effects of which will be better represented by estimating the flux of nitrogen compounds transported to Hood Canal in shallow ground water. A method to segregate the two groups will be developed. Possible methods include the use and testing of multiple buffer widths to determine the effects of changing widths on loading assumptions, and the use of an existing model of the Bangor ground-water system (van Heeswijk and Smith, 2002) to estimate travel times, which would then be used to help make decisions about how to partition the septic systems into the two groups.

Loads of nitrogen compounds discharged to Hood Canal from septic systems located along and near the shoreline (the first group) will be estimated by developing a spatial database of houses and using literature values for septic system discharges along with occupancy data to compute loads from individual septic systems. Loads from individual septic systems can be summed to compute septic system loading to Hood Canal or any segment of Hood Canal. Because previous studies indicate that most of the nitrogen discharged from properly operating septic systems is in the form of nitrate, which is not subsequently denitrified in ground water (Porter, 1980; Alhajjar, 1985; Frimpter and others, 1988), it will be assumed that there is no degradation of nitrogen compounds in the shallow ground water. The number and location of houses will be determined using GIS data for tax parcels or from digital orthophoto maps augmented with field reconnaissance data. The field data will be obtained from vehicle and vessel surveys, during which USGS personnel using a computer interfaced to a global positioning system (GPS) receiver will record locations of houses. Available information on the occupancy and duration of occupancy of houses will be obtained from county records. The effects of septic systems belonging to the second group (farther from shore) will be assessed as part of the estimate of nitrogen loading from adjacent slopes and areas outside sampled drainage basins.

Loads of nitrogen compounds discharged to Hood Canal from adjacent slopes and areas outside sampled drainage basins will be calculated by estimating the volume of water and the concentration of nitrogen compounds in water discharged by these areas. Digital elevation maps will be used to delineate the areas, and spatial data and satellite images of surficial geology, land-use and land-cover will be used to categorize them. The categorization scheme will be based on the diversity and extent of land use and cover within the areas. Many of the adjacent slopes are forested or recently logged, which can be differentiated using multispectral satellite images. Multispectral techniques, or a comparison of satellite images taken during different seasons, can differentiate Alder forest (nitrogen fixing) from coniferous forests. Most of the water discharged to Hood Canal from the adjacent slopes is probably ground water, either expressed in small surface seeps, intermittent streams, or direct inflow. Available recharge estimates (Vaccaro and others, 1998), or recharge equations (Bidlake and Payne, 2001) applied to these areas will be used to make rough estimates of ground-water discharge by assuming that the system is at steady state and that discharge is equal to recharge. Available data and/or literature values will be used to estimate concentrations of nitrogen compounds in the ground water.

The flux of nutrients added to Hood Canal from advection of Admiralty Inlet water will be estimated based upon all available nutrient and flow data for the deep waters in the reach around the Hood Canal Bridge. Nutrient data will include those from Paulson and others (1993) and from cruises conducted by the University of Washington for years 1998-2003. Washington State Department of Ecology (Ecology) samples for nutrients more frequently than the University of Washington, but Ecology's samples are limited to the fresher surface outflowing layer rather than the marine deeper inflowing layer. Flow data into Hood Canal will include the work of Cokelet and others (1990) and Warner and others (2001) as well as recent unpublished work of the University of Washington's School of Oceanography.

Loads of nitrogen compounds entering Hood Canal from direct precipitation will be estimated using available precipitation data and precipitation chemistry data collected by the National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/) and the University of Washington.

Focused Studies.—The design and execution of small-scale studies needed to better quantify nitrogen loading to Hood Canal from various sources and/or source areas will be based on the results of the initial assessment of sources, which may indicate that some of them are too small to warrant further study. The USGS also will consult with other parties involved with Hood Canal before deciding on the scope of the small-scale studies. At this time, it is thought that small-scale studies may be needed to 1) assess how concentrations of nitrogen compounds in ground water vary with land use, 2) refine estimates of the amount of ground water discharging directly to Hood Canal, 3) refine estimates of nitrogen loading to Hood Canal from septic systems, 4) refine estimates of the loads of nitrogen compounds discharged to Hood Canal by rivers and streams, and 5) assess sources of nitrogen compounds in some of the rivers and streams discharging to Hood Canal. The final selection and design of the small-scale studies will be governed by the initial findings, which will rank the importance of various sources of nitrogen compounds, and funding constraints. It is probable that some of the focused studies will not be conducted, or that they may be combined. For example, a synoptic sampling of rivers and streams during base flow will provide additional data needed to compute loads of nitrogen compounds and information to needed assess how concentrations of nitrogen compounds vary with land use. General approaches to focused studies are described in the following paragraphs.

Assess how concentrations of nitrogen compounds in ground water vary with land use.—This task will be accomplished by 1) using available ground-water quality data in the study area, 2) using available ground-water quality data from locations in the Puget Sound Region with similar hydrogeology and land-use characteristics, and 3) sampling of springs and base-flow sampling of small streams, and segments of small streams, if necessary. Because ground water in upper aquifers in the Puget Sound Region is usually oxygenated (Greene, 1997; Inkpen and others, 2000), the concentration of nitrate in water discharged by springs is expected to be representative of local shallow ground water. Nitrate is not conservative in surface water, so surface-water base-flow samples will be used to estimate nitrate concentrations in shallow ground water only if springs cannot be located. Samples collected for this task will be analyzed for filtered ammonia, nitrite plus nitrate, total nitrogen, orthophosphate, and major ions. Some samples will be analyzed to determine the stable-isotope ratios of both the nitrogen and oxygen atoms in the nitrate ion to help identify sources of nitrogen in the samples. The stable-isotope ratio of nitrogen in reduced nitrogen compounds will be determined if concentrations are high enough.

Refine estimates of the amount of ground water discharging directly to Hood Canal

If the initial estimates of nitrogen loading to Hood Canal indicate that nitrogen compounds transported to Hood Canal by direct ground-water discharges are a significant source, this project will evaluate methods of estimating ground-water discharge and employ one or two of the most promising. Possible methods include 1) improve recharge estimates using more detailed soils and climate data than were used to make the initial estimates, 2) using a basic Darcy approach for unconfined aquifers discharging to saltwater (Glover, 1959), and 3) using seepage meters to measure the flux of ground water discharging to Hood Canal in selected locations.

Refine estimates of nitrogen loading to Hood Canal from septic systems The initial estimates of amounts of nitrogen compounds discharged to Hood Canal from septic systems assumes no attenuation of nitrogen (mostly in the form of nitrate) in down-gradient ground water. As mentioned, this assumption is based on previous studies. If the initial ranking of sources indicates that septic systems are potentially a significant source, shallow ground water and shallow ground water discharging to Hood Canal will be sampled. Samples will be collected in locations with high densities of septic systems and for contrast, in locations with no septic systems. Samples will be analyzed for both reduced and oxidized nitrogen compounds, orthophosphate, major ions, and dissolved oxygen. Selected samples will be analyzed to determine the stable-isotope ratios of both the nitrogen and oxygen atoms in the nitrate ion to help identify sources of nitrogen in the samples. The stable-isotope ratio of nitrogen in reduced nitrogen compounds will be determined if concentrations are high enough.

Refine estimates of the loads of nitrogen compounds discharged to Hood Canal by rivers and streams Improved estimates of nitrogen loading from rivers and streams will be obtained by updating previous load calculations by Embrey and Inkpen, 1998, and possibly others, using available new data, and by gaging and sampling rivers and streams during storms and during base flow. Storm samples will be collected from rivers and streams with no available data or from those with data that do not adequately represent stormflows. An analysis will be performed to determine where storm sampling will provide the most valuable information. For example, two storm samples from one river might be of more value in determining annual loads than one sample from each of two rivers. Base-flow samples will provide data needed to refine statistical relations between drainage area characteristics, land use, and nitrogen loads. Base-flow samples also will provide loading data from rivers and streams during the season when concentrations of dissolved oxygen in Hood Canal are at their lowest. Annual loads will not be computed for streams with only base-flow samples. Samples will be analyzed to determine concentrations of suspended sediment, particulate and dissolved total nitrogen and organic carbon, dissolved nitrite plus nitrate, and dissolved ammonia.

Assess sources of nitrogen compounds in some of the rivers and streams discharging to Hood Canal One of the broader goals of the combined effort to address the problem of low dissolved oxygen concentrations in Hood Canal is for local governments and individuals to implement actions to reduce nutrient loading to the canal. Loads of nitrogen compounds from some of the rivers and streams draining areas with mixed land uses may be relatively large, and knowing the sources of nitrogen compounds in these rivers and streams will be important to the design of remedial actions. In addition to the statistical relations between land use and nitrogen loads developed as part of this project, some of the base-flow samples will be analyzed to determine the stable-isotope ratios of oxygen and nitrogen to help identify sources of nitrogen.

Applying the Results of the Focused Studies.—Results of the focused studies will be used to improve initial estimates of nitrogen loading to Hood Canal. The refined loading estimates will provide information on the spatial distribution of loads of nitrogen compounds discharged to Hood Canal and the sources of the nitrogen compounds. These results will help determine the most effective remedial actions.

Timelines and Products.—Because of the constraints of Congressional funding, work on this study must be largely completed by October 2004. A draft report will be completed at that time. All data, including the GIS data, collected and prepared by the study will be made available.

Budget.—The funding available for this project is $346,000.

Category	Cost
Initial estimate of nitrogen loading to Hood Canal	$76,000
Focused studies	$210,000
Revised loading estimate and report	$60,000
Total	$346,000

References.—

Alhajjar, B.J., 1985, Groundwater contamination from septic systems receiving detergents of two types of formulation: Madison, Wisconsin, University of Wisconsin, Ph.D dissertation, 372 p.

Anderson, S.L., Karol Erickson, Newton, J.A., Greg Pelletier, Reynolds, R.A., and Mindy Roberts, 2002, Summary of South Puget Sound Water Quality Study: Washington State Department of Ecology Publication 02-03-020, 4 p.

Bidlake, W.R., and Payne, K.L., 2001, Estimating recharge to ground water from precipitation at the Naval Submarine Base Bangor and vicinity, Kitsap County, Washington: U.S. Geological Survey Water-Resources Investigations Report 01-4110, 33p.

Crawford, C.G., 1991, Estimation of suspended-sediment rating curves and mean suspended-sediment loads: Journal of Hydrology, v. 129, p. 331-348.

Crawford, C.G., 1996, Estimating mean constituent loads in rivers by the rating-curve and flow-duration, rating-curve methods: Bloomington, Indiana, Indiana University, Ph.D. dissertation, 245 p.

Cokelet, E.D., Stewart, R.J., and Ebbesmeyer, C.C., 1990, The annual mean transport in Puget Sound: NOAA Technical Memorandum ERL PMEL-92: 59 p.

Drost, B.W., Ely, D.M., and Lum, W.E., 1999, Conceptual model and numerical simulation of the ground-water-flow system in the unconsolidated sediments of Thurston County, Washington: U.S. Geological Survey Water-Resources Investigations Report 99-4165, 254 p.

Embrey, S.S., and Inkpen, E.L., 1998, Water-quality assessment of the Puget Sound Basin, nutrient transport in rivers, 1980-93; U.S. Geological Water-Resources Investigations Report 97-4270, 30 p.

Frimpter, M.H., Donohue, J.J., and Rapacz, M.V., 1988, A mass-balance model for predicting the effects of land use on groundwater quality in municipal wellhead protection areas: The Cape Cod Aquifer Management Project, Massachusetts, 26 p.

Glover, R.E., 1959, The pattern of freshwater flow in a coastal aquifer. J. Geophysical. Research. v. 64, p. 439-475.

Greene, K.E., 1997, Ambient quality of ground water in the vicinity of Naval Submarine Base Bangor, Kitsap County, Washington, 1995: U.S. Geological Water-Resources Investigations Report 96-4309, 46 p.

Inkpen, E.L., Tesoriero, A.J., Ebbert, J.C., Silva, S.R., and Sandstrom, M.W., 2000, Ground-water quality in the Puget Sound Basin, Washington and British Columbia, 1996-1998: U.S. Geological Water-Resources Investigations Report 00-4100 66 p.

Paulson, A.J., Curl, H.C. Jr, and Feely, R.A., 1993, The biogeochemistry of nutrients and trace metals in Hood Canal, a Puget Sound fjord: Marine Chemistry, v. 43, nos. 1-4, p. 157-173.

Pitz, Charles F., 1999, Estimates of nitrate loading to South Puget Sound by groundwater discharge: Washington State Department of Ecology Report 99-348, 17 p.

Porter, K.S., 1980, An evaluation of sources of nitrogen as causes of ground-water contamination in Nassau County, Long Island: Ground Water, v. 18, no. 6, p. 617-625.

Vaccaro, J.J., Hansen, A.J. Jr, and Jones, M.A., 1998, Hydrogeologic framework of the Puget Sound aquifer system, Washington and British Columbia: U.S. Geological Survey Professional Paper 1424-D, 77 p.

van Heeswijk, Marijke, and Smith, D.T., 2002, Simulation of the ground-water flow system at Naval Submarine Base Bangor and vicinity, Kitsap County, Washington: U.S. Geological Water-Resources Investigations Report 02-4261, 144 p.

Warner, M.J., Mitsuhiro Kawase, and Newton, J.A., 2001, Recent studies of the overturning circulation in Hood Canal: *in* Proceedings of Puget Sound Research February 12-14, 2001, Bellevue, Washington, 9 p.

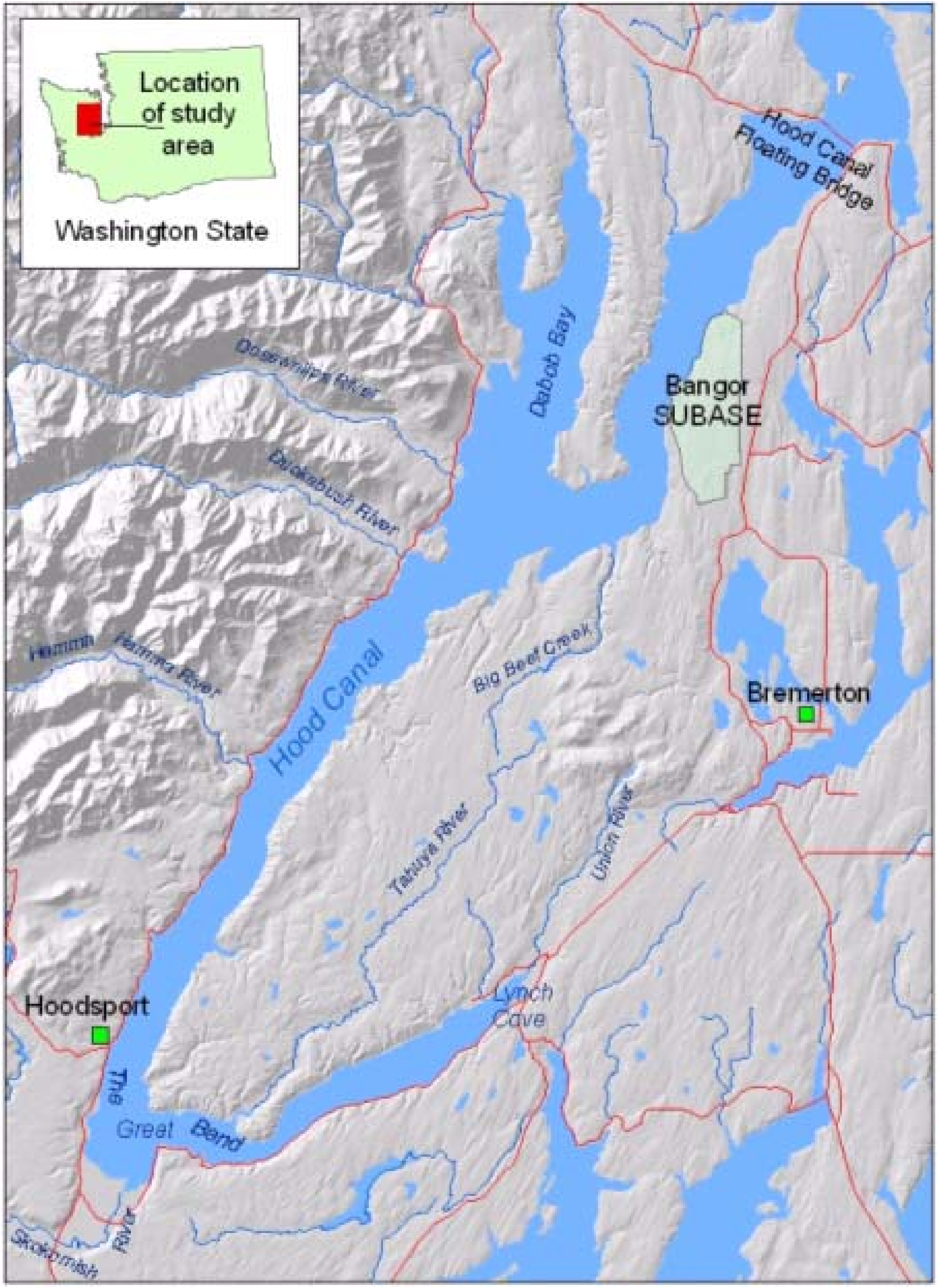

Figure 1. Hood Canal