Quality Assurance Project Plan for Quartermaster Harbor Nitrogen Management Study

**A Targeted Watershed Grant
under the
2008 Puget Sound Initiative**

May 2009

King County

Department of Natural Resources and Parks
Water and Land Resources Division
Science Section
King Street Center, KSC-NR-0600
201 South Jackson Street, Suite 600
Seattle, WA 98104
dnr.metrokc.gov/wlr

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Prepared by

Curtis DeGasperi, Eric Ferguson, and Kim Stark

King County Dept. of Natural Resources and Parks

201 S. Jackson, Suite 600

Seattle, WA 98104

Cheryl Greengrove

University of Washington-Tacoma

Tacoma, Washington

Carol Maloy and Skip Albertson

Washington State Department of Ecology

Marine Monitoring Unit

Olympia, Washington 98504-7710

Prepared for

U.S. Environmental Protection Agency

and

King County Department of Natural Resources and Parks

Initial QAPP–Annual Addendums will be done 2010 □, 2011 □ and 2012 □. See addendums for subsequent signature pages.

Curtis DeGasperi, King County, Project Manager — Date: 06/17/09

Randy Shuman, King County, Science Manager — Date: 6/17/09

Katherine Bourbonais, King County, Laboratory Project Manager — Date: 6/17/09

Cheryl Greengrove, University of Washington - Tacoma, Oceanographer — Date: 10/1/09

Skip Albertson, WA Dept. of Ecology, MMU, Marine Modeler — Date: 8/18/09.

Carol Maloy, WA Dept. of Ecology, Marine Monitoring Unit, Supervisor — Date: 8/18/09

Ginna Grepo-Grove, EPA Region 10 QA Manager — Date: 06/08/09

Ben Cope, EPA Project Monitor — Date: 06/09/09

Tony Fournier, EPA Project Officer — Date: 06/15/09

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ACRONYMS AND ABBREVIATIONS

Following are acronyms and abbreviations used frequently in this document:

BOD	biochemical oxygen demand
CTD	Conductivity, Temperature, and Depth recorder
EAP	Environmental Assessment Program (Ecology)
Ecology	Washington State Department of Ecology
EFDC	Environmental Fluid Dynamics Code
EIM	Environmental Information Management database (Ecology)
MLLW	mean lower low water
Mike-SHE	Integrated hydrological modeling system (Surface and Groundwater)
NPDES	National Pollutant Discharge Elimination System
PSP	Paralytic Shellfish Poisoning
QA	quality assurance
QMH	Quartermaster Harbor, Vashon-Maury Island
RSD	relative standard deviation
TMDL	Total Maximum Daily Load (water cleanup plan)
UWT	University of Washington–Tacoma
VMI	Vashon-Maury Island
WLRD	Water Land Resource Division (King County)
WQP	Water Quality Program (Ecology)
WRE	Water Resource Evaluation Project (King County)

DISTRIBUTION LIST

The following distribution list is all the individuals involved with the implementation of this Study. Annual addendums and revisions will also be distributed.

King County–Department of Natural Resources and Parks, 201 S. Jackson Street, Suite 600, Seattle, WA 98104

Curtis DeGasperi–Project Manger; Surface Water Hydrologist; 206.684.1268; curtis.degasperi@kingcounty.gov

Eric Ferguson–Groundwater Hydrologist; 206.263.5612; eric.ferguson@kingcounty.gov

Kimberle Stark–Marine Biologist; 206.296.8244; kimberle.stark@kingcounty.gov

Laurence Stockton–Policy/Outreach Coordinator; 206.296.1910; laurence.stockton@kingcounty.gov

Katherine Bourbonais - Laboratory Project Manager; 206.684.2382; katherine.bourbonais@kingcounty.gov

University of Washington - Tacoma–Environmental Science, 1900 Commerce Street, Tacoma, WA 98402-3100

Cheryl Greengrove–Oceanographer; 253.692.5658; cgreen@u.washington.edu

Julie Masura–Researcher; 253.692.4317; jmasura@u.washington.edu

Washington State Department of Ecology–Marine Modeling Group, 300 Desmond Drive SE, Lacey, WA 98503

Carol Maloy–Supervisor; 360.407.6675; cfal461@ecy.wa.gov

Skip Albertson - Marine Modeler; 360.407.6676; salb461@ecy.wa.gov

Environmental Protection Agency–Region 10, 1200 Sixth Avenue, Suite 900, Seattle, WA 98101

Ginna Grepo-Grove - QA Manager; 206.553.1632; Grepo-Grove.Gina@epa.gov

Ben Cope - Project Monitor; 206.553.1442; Cope.Ben@epa.gov

Tony Fournier - Project Officer; 206.553.1838; Fournier.Tony@epa.gov

Vashon-Maury Island Groundwater Protection Committee

Michael Laurie, Chair; mlaurie@mindspring.com

Laurie Geissinger, Vice Chair; laurie.geissinger@seattle.gov

Frank Jackson; frank.jackson@centurytel.net

James Dam; eadnjd@comcast.net

John Gerstle; jhgerstle@comcast.net

Phillip McCready; pkmccready@yahoo.com

Jay Becker; jaybecker@aol.com

Donna Klemka croft@centurytel.net

ABSTRACT

We propose to evaluate the role of nitrogen in the risk of lethal, low-level dissolved oxygen events in Quartermaster Harbor (QMH), a sensitive marine embayment of Vashon-Maury Island (VMI) in Puget Sound. The expected outcomes of this study are recommendations for policy changes in the 2012 King County Comprehensive Plan update for nitrogen management on VMI. The similarity of the QMH study area to other rural lands draining to Puget Sound allow for transferring results and knowledge gained to a large part of Puget Sound.

Dissolved oxygen levels in QMH have been recorded near lethal levels over the last three years of monthly monitoring by King County. As a poorly flushed embayment of Puget Sound, QMH has many characteristics similar to Hood Canal, which has experienced multiple, lethal, low-oxygen events. Similarities with Hood Canal include increased upland development and nitrogen loading, high value shellfish fisheries, and high value ecological habitat. Sources of nitrogen will be identified and quantified, and nitrogen impacts on dissolved oxygen in QMH will be modeled. To inform future actions, the degree of improvement in QMH dissolved oxygen will be modeled for various nitrogen management strategies and compared to conceptual costs of each strategy.

1.0. INTRODUCTION

King County was awarded a West Coast Estuaries Initiative (WEI) grant by Region 10 of the U.S. Environmental Protection Agency (EPA) to conduct the Quartermaster Harbor Nitrogen Management Study. The goal of this study is to support the protection and restoration of Quartermaster Harbor (QMH)–a high value, coastal aquatic resource on Vashon-Maury Island (VMI) in Puget Sound. Partners working with King County on this grant-funded study include the University of Washington-Tacoma (UWT), the Washington Department of Ecology (Ecology), and the Tacoma office of the United States Geological Survey (USGS). The WEI grant will also support the enhancement of aquatic resource protection programs in an area threatened by growth pressures. This Quality Assurance Project Plan (QAPP) describes this grant-funded study as currently conceptualized. This document will be updated on an annual basis as the study evolves and more detail regarding specific study aspects are developed.

1.1 Project Need

Near lethal dissolved oxygen levels have been observed in QMH over the last three years of monthly monitoring by King County (Figure 1). Dissolved oxygen is essential for fish and other marine life, which can become stressed or killed or escape to more oxygenated waters if possible. Low dissolved oxygen levels, combined with the high habitat value of QMH, increased frequency of detections of nitrates in VMI groundwater, and ongoing population growth, make this project a high priority for King County. Quartermaster Harbor has many characteristics similar to Hood Canal, and is believed to be at risk of lethal low oxygen events such as those that have occurred in Hood Canal on multiple occasions this past decade.

Quartermaster Harbor was one of 19 areas of Puget Sound judged to be relatively sensitive to anthropogenic nutrient inputs (Rensel Associates and PTI 1991). Excess nutrients, nitrogen compounds in particular, can lead to excessive phytoplankton and algae growth which can then deplete oxygen concentrations when the algae die (Figure 2). Nitrogen and phosphorus are essential nutrients for marine plants and phytoplankton, particularly nitrate as phytoplankton preferentially take up nitrate and other nitrogen compounds. Although phosphorus compounds are important for phytoplankton growth, nitrogen is generally considered to be the limiting nutrient in marine waters of Puget Sound (Rensel Associates and PTI 1991). Eelgrass losses, fish kills, and harmful algal blooms have been attributed to eutrophication and lethal low oxygen events in Hood Canal. There is also evidence to suggest that QMH is a source of *Alexandrium*, a single-celled organism responsible for toxic algal blooms (Greengrove *et al*. 2006). The similarity of this study area to rural lands draining to Puget Sound allows for transferring results and knowledge gained to a large part of Puget Sound.

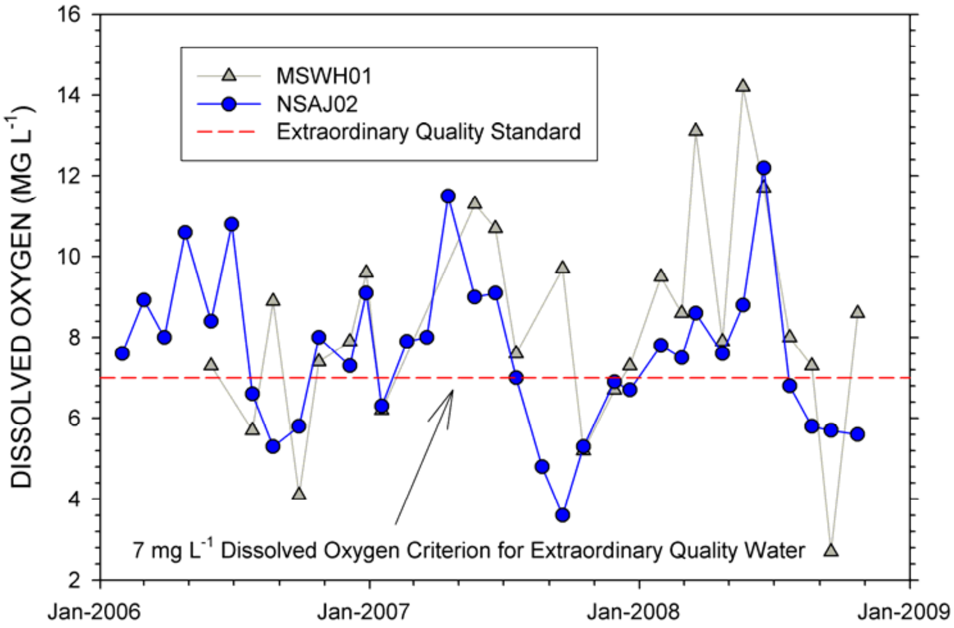

Figure 1. Monthly dissolved oxygen concentrations measured in bottom waters of Quartermaster Harbor by King County. Station MSWH01 is located in the inner harbor near Burton and NSAJ02 is located in the outer harbor near Dockton.

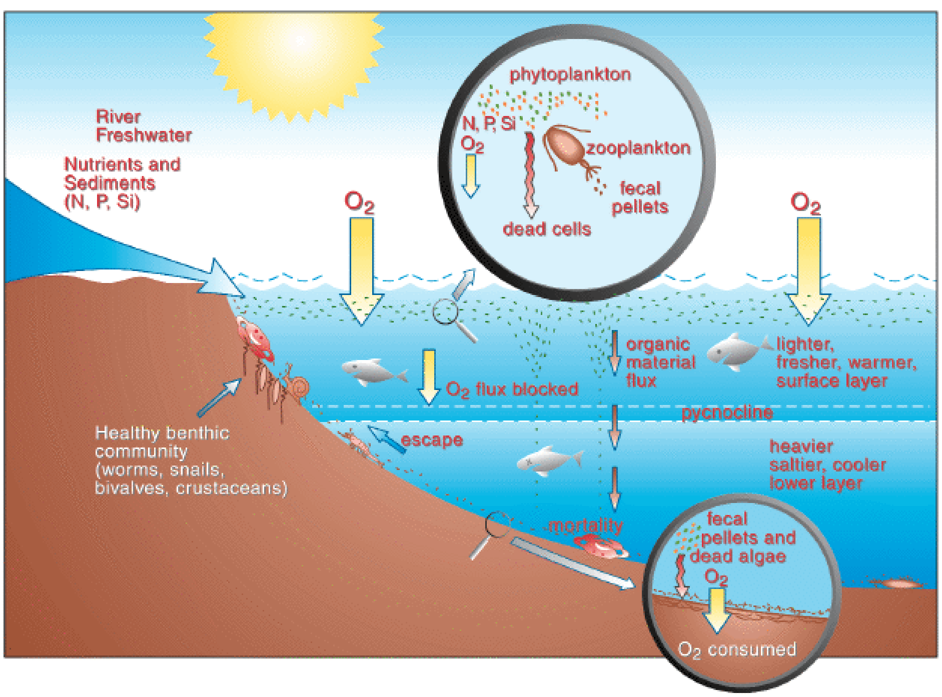

Figure 2. Conceptual diagram of marine nutrient-oxygen dynamics (Source: Downing JA, et al. Gulf of Mexico hypoxia: land and sea interactions. Task force report no. 134. Ames, IA:Council for Agricultural Science and Technology, 1999;5. http://www.ehponline.org/docs/2000/108-3/focusfig2B.GIF)

The King County Vashon-Maury Island Watershed Plan (King County 2005) states that the number of people that the island's water supply can support may be limited by the ability of the island's soils and geologic formations to attenuate nitrate contamination. Onsite septic systems are regarded as a major potential source of nitrate contamination. Other sources of ground-water nitrate contamination may include, but are not limited to, livestock (manure management) and fertilizer use (e.g., residential, agricultural, and golf-course use). Other less direct sources of nitrate include alder trees and other nitrogen-fixing vegetation, decomposing organic matter from logging slash or leaf fall, and atmospheric deposition. The relative contributions of nitrate from these sources are not well known, and this fact hinders efforts to effectively manage nitrogen and sources that contribute to its loading.

Vashon-Maury Island, like many rural coastal areas of Puget Sound, is facing many shoreline related issues. However, this study area is uniquely positioned because of the community involvement, interest and the extent of data available to address many of these issues. The on-going and grant-supported monitoring and modeling efforts within the proposed study area will allow for detailed investigations to be performed, a clear assessment of baseline conditions in QMH, and future scientific and management outcomes to be measured

1.2 Water Quality Standards for Marine Dissolved Oxygen

Under the federal Clean Water Act, every state is required to establish water quality standards that protect, restore, and maintain water quality that supports beneficial uses designated by the state. These standards and beneficial use designations are subject to approval by the EPA. Water quality standards are generally a combination of designated beneficial uses to protect, and numeric or narrative criteria that must be met to maintain or achieve those uses.

Water quality standards for Washington marine waters can be found in the Washington Administrative Code (WAC) 173-201A. The marine waters of Quartermaster Harbor are categorized as *Extraordinary Quality* for use by salmon and other fish for migration, rearing, and spawning; clam, oyster, and mussel rearing and spawning; and crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing and spawning. The numeric criterion for these waters is expressed as the lowest 1-day minimum concentration that should be maintained or exceeded. For *Extraordinary Quality* marine waters the lowest 1-day minimum dissolved oxygen level must not fall below 7.0 mg/L more than once every 10 years on average.

Not all waters are naturally capable of maintaining adequate levels of oxygen (i.e., in the absence of human influence). In recognition of this, the water quality standards provide that when it is determined that the dissolved oxygen is lower than the numeric criterion (or within 0.2 mg/L of the criterion) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the dissolved oxygen of that water body to decrease more than 0.2 mg/L.

Although the interpretation of the standard appears to be fairly straightforward, it is actually rather difficult to determine what the "natural" dissolved oxygen concentration would be (i.e., prior to or without significant human alteration of nutrient inputs). Long-term historical data might provide some indication of pre-settlement oxygen concentrations, but no water quality monitoring stations were established early enough to provide this type of information. Because coastal marine systems do not respond in simple predictable ways to nutrient inputs (Cloern 2001), fairly complex computer models are typically used to assess how sensitive a particular water body is to nutrients inputs.

These computer models can also be used to estimate what water quality conditions might be like in the absence of significant human influence (i.e., under “natural” conditions). This usually requires the development and testing of a model with relatively recent data representing conditions under human influence and then modifying and running the model in ways that represent reductions or removal of human influenced nutrient inputs. If the model is relatively insensitive to reductions in human-derived nutrient sources, then the observed dissolved oxygen conditions are likely due to natural features of the receiving water. Sediment cores from depositional areas could also be sectioned, dated, and analyzed to assess whether trophic conditions in the waterbody have changed dramatically in response to the time history of significant human settlement and development in the upland drainage areas.

1.3 Description of Study Area

Vashon-Maury Island is a 37 square-mile (95.8 square-kilometers) island located in King County in central Puget Sound. Approximately 10,000 people live on VMI and population is expected to grow 23% by 2040 (Puget Sound Regional Council, 2008). Quartermaster Harbor, located between Vashon and Maury Islands, is sheltered from the wind and waves and receives runoff from about 40 percent of VMI (Figure 3). It is a shallow, protected embayment that comprises approximately 12.1 km^2 (3,000 acres) of water surface area in an inner and outer harbor. Inner QMH is especially sheltered and Judd Creek, located in the northwestern portion of the inner harbor, is the largest freshwater input. Transition zones between freshwater surface flows and the marine water within the bay include the estuaries at the mouth of Judd Creek, Fisher Creek, and Raab’s Lagoon along with numerous smaller streams. Inner QMH is shallow, with a greatest depth of about 5 meters and very little tidal flushing. Outer QMH water depths range from about 11-46 meters with rapid tidal flushing. The shoreline around the inner harbor is developed with houses, a marina, a private yacht club, and roads. There are also two public parks located within the harbor area.

The harbor is a regionally significant natural resource area and provides rearing and spawning habitat for herring, surf smelt, sand lance, and salmon (i.e., Chinook, Coho, chum, and cutthroat). It is an important wintering ground for migratory marine birds including western grebes, common loons, surf scoters, black scoters, goldeneyes, mergansers, and ruddy ducks. In all, approximately 60 species of fish, 78 species of birds, several species of marine mammals, and a variety of marine invertebrates inhabit or use Quartermaster Harbor[1]. Quartermaster Harbor currently contains the largest Pacific herring spawning population in this region of Puget Sound

[1] Final Supplemental Environmental Impact Statement: Maury Island Aquatic Reserve. Washington Dept. of Nat. Resources, Aquatic Resources Division, October 29, 2004

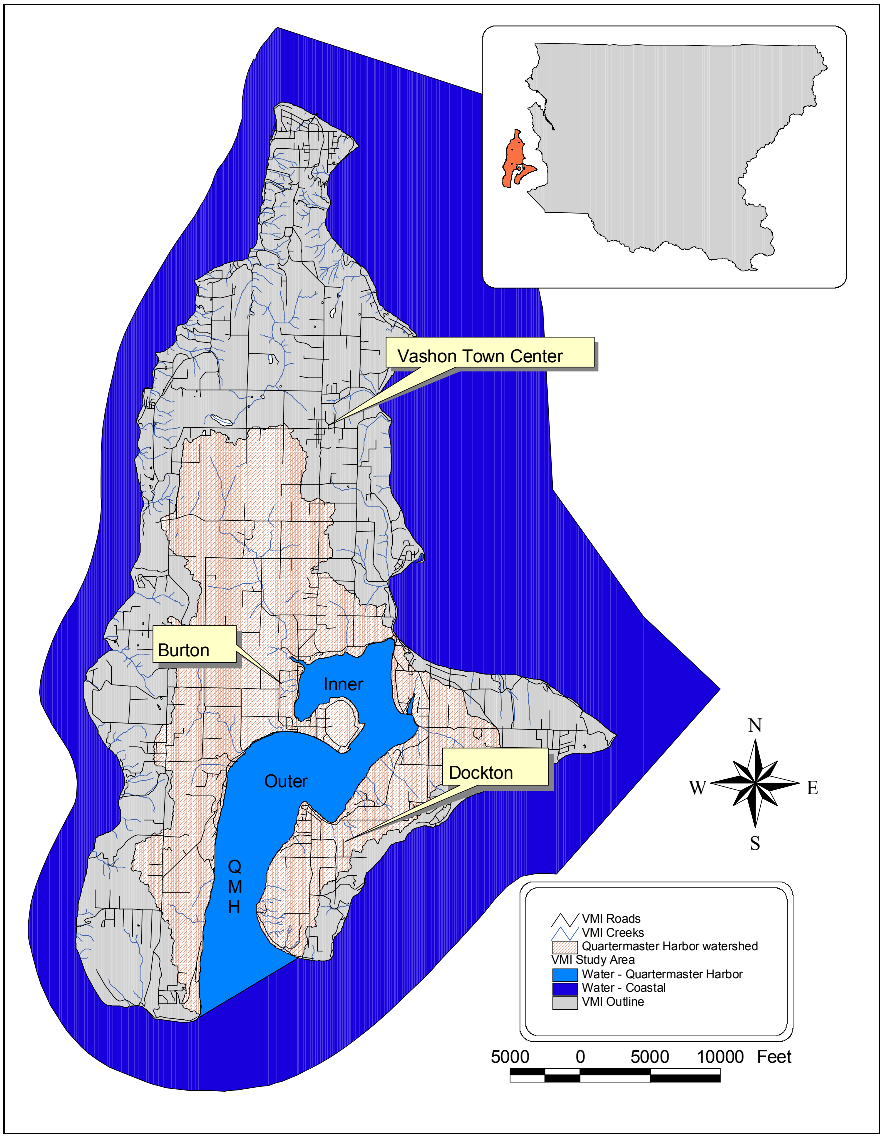

Figure 3. Map of Vashon-Maury Island highlighting the drainage area to Quartermaster Harbor. This cross-hatched area is also the study area for the Quartermaster Harbor Nitrogen Management Study.

and the third largest in all of Puget Sound. The harbor was designated as an Important Bird Area by the National Audubon Society in 2001. Quartermaster Harbor also supports shellfish resources, including geoduck clams.

Chapter 70.118A of the Revised Code of Washington requires the twelve public health jurisdictions bordering Puget Sound to propose a marine recovery area for those land areas where existing on-site sewage disposal systems are a significant factor contributing to concerns associated with:

- Shellfish growing areas that have been threatened or downgraded by the department under chapter 69.30 RCW
- Marine waters that are listed by the department of ecology under section 303(d) of the federal clean water act (33 U.S.C. Sec. 1251 et seq.) for low-dissolved oxygen or fecal coliform
- Marine waters where nitrogen has been identified as a contaminant of concern by the local health officer.

All of VMI is designated as rural zoned land and is outside King County's Growth Management Act (GMA)-designated urban growth boundary. Low-density residential development covers much of the island—typically zoning of one house per five to ten acres. Higher density residential areas are concentrated in Vashon Town Center, Vashon Heights, Burton, Dockton, and along parts of the shoreline (Figure 4). Land cover is predominately forest with other covers being non-forest vegetation and developed land. The residents of VMI are proactive in their interactions with public agencies regarding land-use/cover management, water resources and On-site Septic System (OSS) issues.

Vashon-Maury Island has no external source of drinking water and was designated a Sole Source Aquifer by the EPA in June 1994. In 2004, King County designated 3 categories of Critical Aquifer Recharge Areas (CARAs) for all of VMI. Like much of rural Puget Sound, nearly all the residents in the study area treat domestic wastewater with OSS. A watershed plan for VMI was created by King County in 2005, which identified OSS as a potential threat and listed priority action areas including regular monitoring for nitrates and other potential system contaminants, development of policies for their control, education, and Best Management Practices (BMPs) for OSS operations.

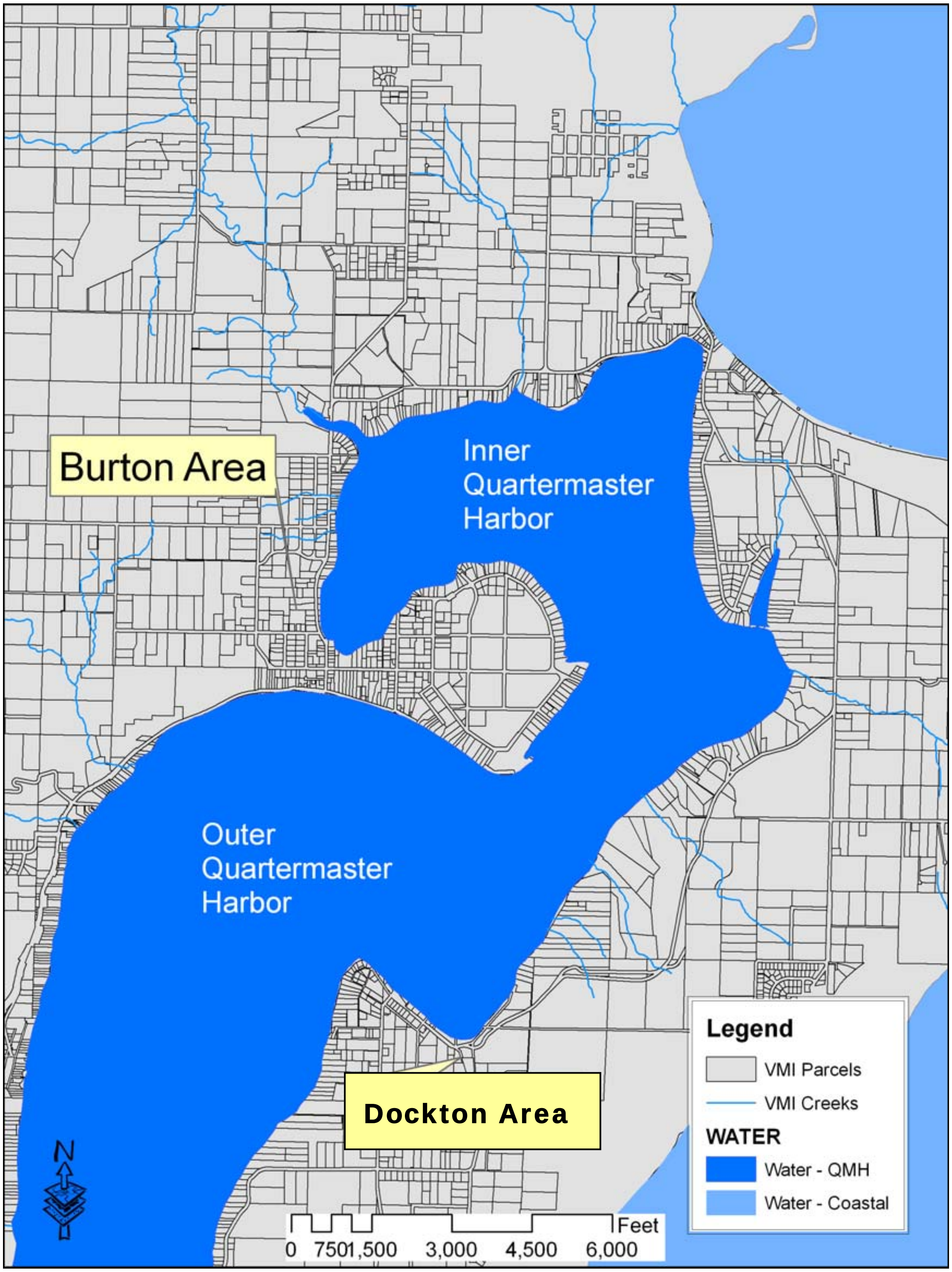

Figure 4. Map of Quartermaster Harbor showing the Burton and Dockton area. This map shows the increased density of development along the shoreline areas of Inner and Outer Quartermaster Harbor.

1.4 Historical Data Review

Quartermaster Harbor and the upland areas draining to the harbor have been the subject of water quality and quantity investigations beginning at least as far back as the early 1970s. These studies are summarized below. However, these summaries are not intended to be exhaustive. The reader is referred to the original sources for more detailed information.

Marine Park Study (University of Washington 1976)

Perhaps the most comprehensive study of QMH was conducted in the early 1970s by the University of Washington for the King County Division of Parks and Recreation (University of Washington, 1976). The study was conducted in response to public concerns over the expansion of overnight recreational boat moorage facilities at Dockton Park in QMH. The study included investigation of historical recreation patterns, land use, and environmental impacts; surficial soils and geology, landslide hazards, drain field performance, and beach forming processes; marine circulation, flushing rates, and water temperatures; marine biological conditions; magnitude and spatial extent of marine fecal contamination; and terrestrial vegetation and wildlife primarily in relation to recreational activities and values.

The University of Washington (1976) harbor circulation study was also published as a graduate study thesis by Turnbeaugh (1976). Based on a combination of physical observations–including drift drogues, velocity, direction, temperature, and salinity measurements–it appeared that the inner harbor had poorer circulation than the outer harbor with poorest circulation observed around the Burton dock and the mouth of Judd Creek.

The University of Washington (1976) terrestrial vegetation studies determined that the vegetation structure of the island changed from primarily coniferous to deciduous hardwoods as the result of logging without active replanting. This shift to deciduous vegetation increased the annual discharge of leaves from canopy and undergrowth. The researchers concluded that this vegetation shift, along with contributions from other sources (e.g., agricultural and residential fertilizers, livestock manure, OSS, and vessel sewage discharges) has resulted in an increase in nutrient discharges into the harbor, potentially overloading the water's nutrient assimilation capacity.

Primarily based on measurements of fecal indicator bacteria, the University of Washington researchers concluded that water quality was degraded most significantly in the inner harbor between the mouth of Judd Creek and the Burton marina and suspected nearshore septic systems as the primary source. Judd Creek was also found to be degraded by fecal pollution and suggested stream-side homes, livestock, poultry, wildlife, and the King County landfill at the headwaters of the creek as potential sources. The University of Washington suggested that water quality of the inner harbor could be maintained or possibly improved by removing septic tank effluent near water areas of high soil permeability by installation of sewer systems. A number of recommendations were made to improve the quality of Judd Creek, but ultimately the UW suggested further study might be necessary to quantify the contributions of various sources and determine the most feasible means of control.

Less attention was given to evaluating the dissolved oxygen condition of the harbor. Five stations were sampled along the harbor axis at three depths (surface, mid-depth, and near bottom) on October 12, 1974. The lowest dissolved oxygen level was found at the inner most station near the bottom (16 m; 3.8 mg/L). Concentrations at all stations and depths were below the *Extraordinary Quality* standard of 7.0 mg/L. However, the University of Washington (1976) cautioned that the natural condition of the harbor was not known and would need to be established in order to speculate on the significance of these values.

Paralytic Shellfish Poison Study (Nishitani *et al.* 1988)

Nishitani *et al*. (1988) reported on a study of paralytic shellfish poisoning (PSP) toxins conducted in Quartermaster Harbor. The focus of the study was on the environmental controls of the growth and accumulation of the toxin producing dinoflagellate *Gonyaulax catenella* and the effects of the dinoflagellate toxins on Puget Sound finfish. The study included measurements of temperature, salinity, Secchi depth, and nutrient concentrations in Quartermaster Harbor. Blooms of *G. catenella* dinoflagellate were observed in the inner harbor in late June of two years under stratified conditions when marine surface water temperatures increased above 13 ^{o}C. Nutrient limitation of *G. catenella* blooms was suspected. Low concentrations of either nitrogen or phosphorus appeared to be a causal factor in bloom decline and suppression of bloom formation. Nishitani *et al*. (1988) speculated that this algal species might have higher relative phosphorus vs. nitrogen requirement than other typical phytoplankton, which would have implications for management of anthropogenic nutrient sources. Recommendations for future monitoring included a suggestion that because of the migratory behavior of these (and other) dinoflagellates, standard water quality sampling techniques (typically grab samples at a few discrete depths) might often miss the greatest density of dinoflagellates. In their study, the highest densities of *G. catenella* were found between 4 and 7 m.

Ulvoid monitoring (Frankenstein 2000)

Frankenstein (2000) identified sites in Puget Sound where ulvoid (a type of marine macroalgae) blooms were occurring and might be considered a growing or ongoing ecological concern. Concerns associated with ulvoid blooms included objectionable odors, detrimental effects on seagrass and macrofauna, and potential for enhancing sediment nutrient recycling into the water column. Quartermaster Harbor was identified as a location where ulvoid blooms might be occurring. Shoreline alteration, failing onsite septic systems, and tributary streams were suggested as potential nutrient sources that could provide fuel for these blooms. Frankenstein (2000) proposed a study to quantify the accumulation of ulvoids and associated environmental conditions at a range of Puget Sound locations to better establish where blooms are occurring and why.

Washington State Department of Ecology

As part of the intergovernmental Puget Sound Assessment and Monitoring Program (PSAMP), Ecology conducts marine water quality monitoring at a number of stations in Puget Sound and along the Pacific coast in Grays Harbor and Willapa Bay. Some stations are monitored every year while some are monitored on a rotating schedule, with a total of about 40 stations monitored each year on a monthly basis. Rotating schedule stations have been located in outer Quartermaster Harbor (QMH001-Burton sampled Oct 1991-Sep 1992 and Oct 1994- Sep 1995) and in the inner harbor (QMH002-Quartermaster Harbor-Inner harbor sampled Nov 1997-Sep 1998, 2001, and 2004). Long term sampling in Puget Sound near Quartermaster Harbor has been conducted at EAP001 (East Passage SW of Three Tree Point) and CMB003 (Commencement

Bay at Browns Point), both sampled approximately monthly since November 1989. Profiles of temperature, salinity, density, dissolved oxygen, light transmission, and pH are measured at 0.5 m intervals at each station. Discrete samples are also collected at various depths for laboratory analysis of fecal coliform bacteria, chlorophyll a, phaeopigment, nitrate, nitrite, ammonium, orthophosphate, and silica. Generally, discrete samples are taken at 0, 10, and 30 meter depths depending on the total depth at a particular station. Secchi disk depth is also recorded at each station.

The locations of these core and rotating stations are shown in Figure 5. A plot of dissolved oxygen concentrations over time at the 10-m depth at the outer (QMH001) and inner (QMH002) stations indicate that concentrations below the 7 mg/L standard have occurred on a regular basis–particularly in the late summer and early fall (Figure 6). Seasonal patterns of Nitrate+Nitrite nitrogen and phytoplankton biomass are consistent with the observed dissolved oxygen data (Figure 7 and Figure 8, respectively)–peak concentration of nitrate in winter followed by an initially large spring bloom and subsequent decline as nitrate becomes depleted.

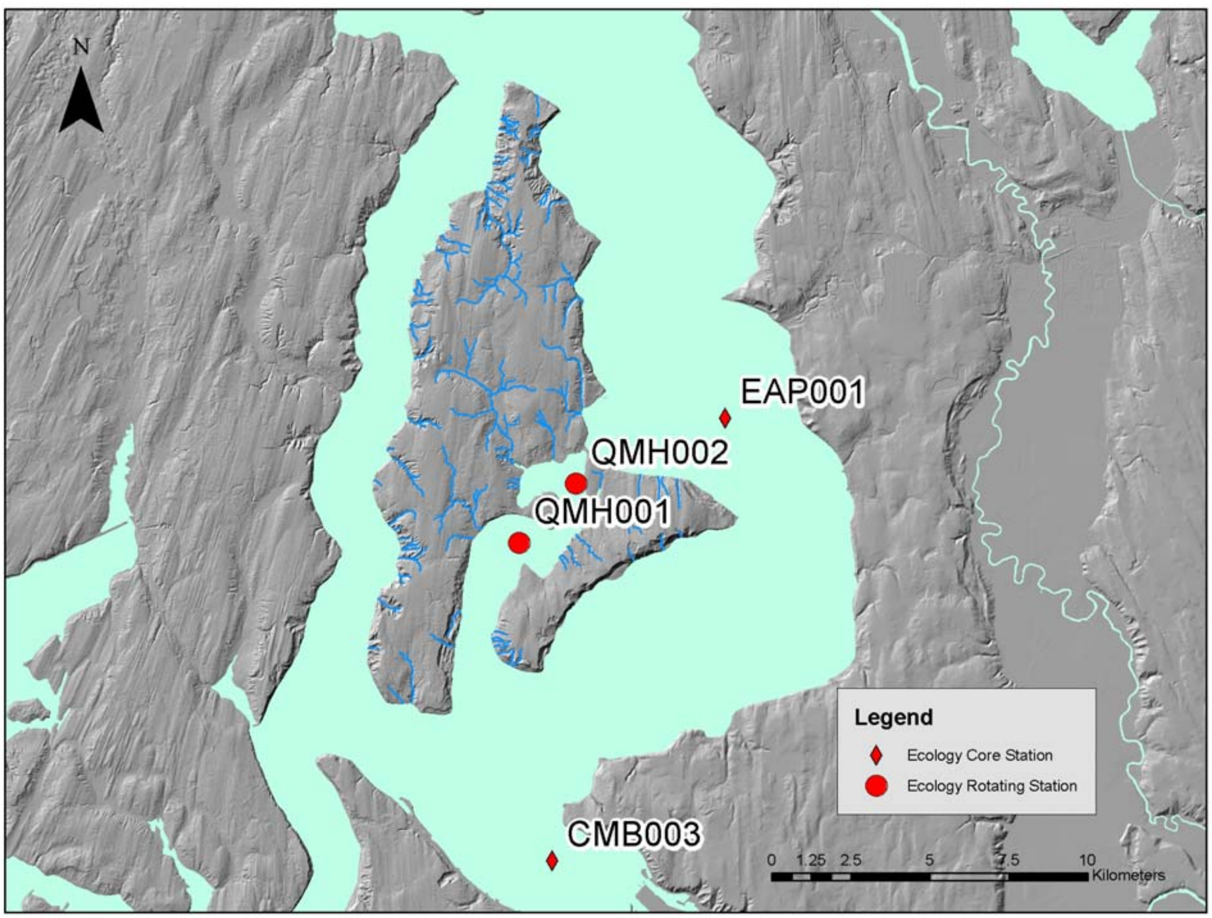

Figure 5. Map showing locations of Ecology marine monitoring locations within and near the vicinity of Quartermaster Harbor.

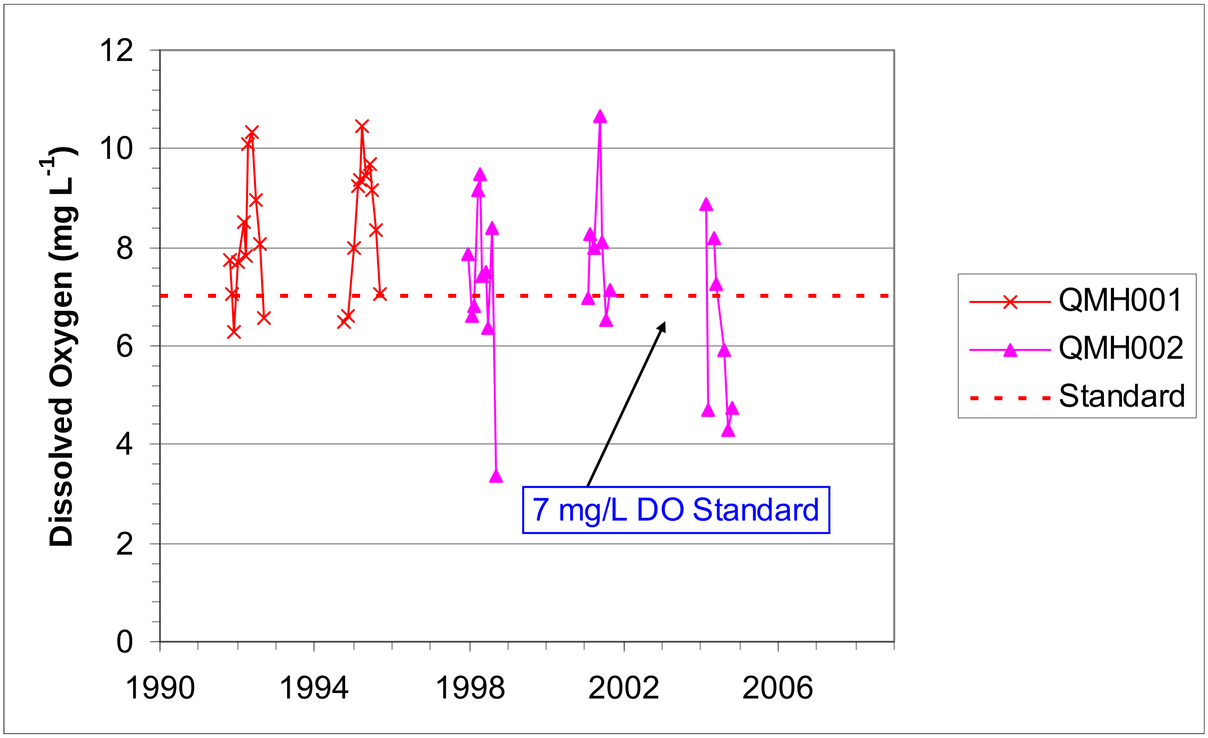

Figure 6. Graph showing the monthly discrete sampling results for dissolved oxygen at the 10-m depth for the two rotating Ecology stations in Quartermaster Harbor.

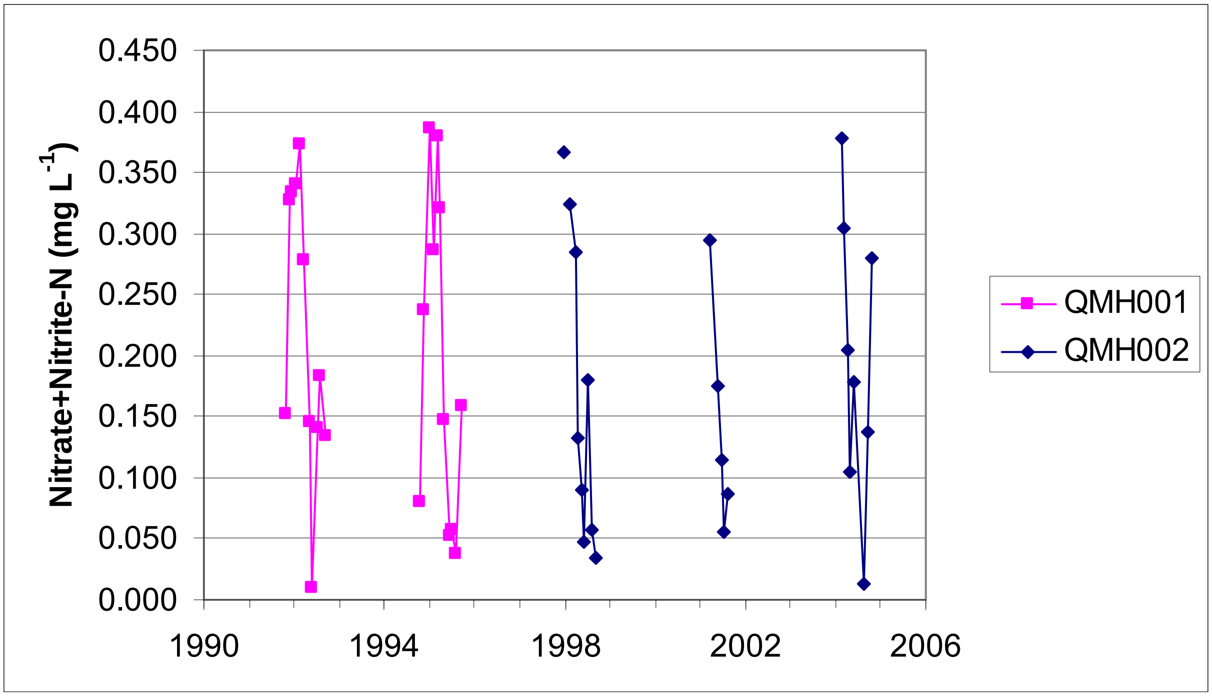

Figure 7. Graph showing the monthly discrete sampling results for Nitrate+Nitrite-N at the 10-m depth for the two rotating Ecology stations in Quartermaster Harbor.

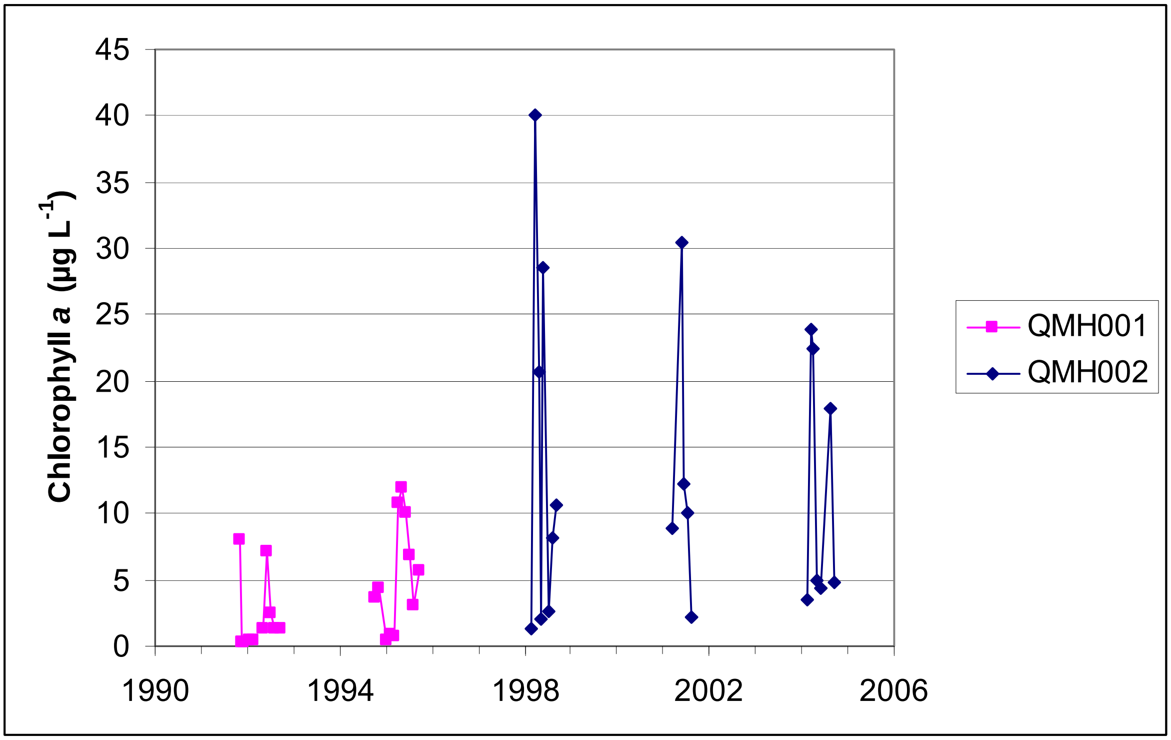

Figure 8. Graph showing the monthly discrete sampling results for chlorophyll *a* (a surrogate measure of phytoplankton biomass) at the 10-m depth for the two rotating Ecology stations in Quartermaster Harbor.

King County Marine Monitoring in Quartermaster Harbor

King County's Water and Land Resources Division's Marine and Sediment Assessment Group supports a comprehensive long-term marine monitoring program that assesses water quality in the Central Puget Sound Basin on behalf of and in coordination with the King County Wastewater Treatment Division (King County, 2006). The marine monitoring program is part of the intergovernmental PSAMP effort, with the county's program focusing primarily on water quality within King County marine waters. In the last five years, sampling has been conducted by King County at four stations relevant to this study. East Passage (Station NSEX01) has been sampled since 2003 to assess physical and biological water column properties within the Central Basin. Beginning in 2006, discrete water column samples have been taken from publicly accessible docks in Quartermaster Harbor–outer harbor near Dockton (Station NSAJ02) and the inner harbor at the Quartermaster Harbor Yacht Club (Station MSWH01). Monthly discrete sampling has been conducted at these stations for fecal indicator bacteria (fecal coliform and Enterococci) and general water quality parameters (i.e., nitrate+nitrite, ammonia, total phosphorus, silica, salinity, temperature, chlorophyll, dissolved oxygen, total suspended solids (TSS), Secchi transparency, and photosynthetically active radiation [PAR]). Beginning in April 2008 through September 2008, semi-quantitative phytoplankton species composition and abundance analysis was conducted at Station MSWH01 bi-monthly during the bloom season. Beginning in April 2009, semi-quantitative phytoplankton species composition and abundance analysis will be conducted at Station NSAJ02 bi-monthly during the bloom season (April through September). General water quality parameters are collected concurrently with the phytoplankton samples.

In addition to discrete samples, water column profiles of temperature, salinity, density, dissolved oxygen, chlorophyll fluorescence, PAR, and turbidity light transmission since December 2005) have also been measured at the East Passage station (NSEX01) since 2003. An intertidal station at Burton Acres Park in the inner harbor has also been sampled monthly since 2006, but these samples are not analyzed for dissolved oxygen, turbidity, TSS, chlorophyll, salinity, Secchi, or PAR.

From December 2007 through December 2008, continuous data collection via a mooring was conducted at Station MSWH01. Dissolved oxygen, salinity, temperature, chlorophyll fluorescence, turbidity, pH, density, and meteorological data were collected every 15 minutes and telemetered to a web-based data server. In January 2008, the mooring was moved to Station NSAJ02 in order to collect data in deeper water than at Station MSWH01 (Figure 9).

The King County marine monitoring data for dissolved oxygen, nitrate+nitrite, and chlorophyll *a* generally corroborate the patterns observed in the Ecology monitoring data–low late summer/fall dissolved oxygen, high winter and low summer nitrate, and maximum phytoplankton biomass in spring through fall (Figure 10 through Figure 12). The data also suggest that higher spring phytoplankton biomass occurs in the inner harbor, although the highest measured chlorophyll *a* concentration at depth was measured at the King County outer harbor station (NSAJ02) in May 2008 (94.4 µg/L).

University of Washington-Tacoma

Work within Quartermaster Harbor grew out of a larger NOAA/ECOHAB study (2004-2008) with researchers from University of Washington-Seattle (UWS) and University of Washington-Tacoma (UWT) investigating the distribution of *Alexandrium catenella* (PSP causing dinoflagellate) cysts in the sediments of Puget Sound. In 2005, marine sediments were sampled, collected via short soutar cores and obtained water property data at 32 stations around Puget Sound and collected longer piston cores from 9 of these locations. In addition, in 2006, more in-depth mapping of cysts in the surface sediments of Dyes Inlet and Quartermaster Harbor was completed and investigated near bottom cyst suspension and transport over tidal cycles near the mouths of both bays using a bottom mounted turbulence meter, CTD, and timed closing bottles. The results from this work in the UWS/UWT–NOAA/ECOHAB study found two orders of magnitude higher concentration of *Alexandrium catenella* (PSP causing organism) cysts in the sediments of Quartermaster Harbor (QMH) than anywhere else in Puget Sound (Horner *et al*., 2008).

University of Washington-Tacoma staff has been collecting data on the biological, chemical, and physical characteristics of Quartermaster Harbor at seven stations since 2006 (Figure 13). Each station has a variety of data collected including Secchi disk, CTD profile, phytoplankton tow and water column samples. Additional data (temperature and salinity) are collected at a mooring in outer QMH at station 54 (Figure 13).

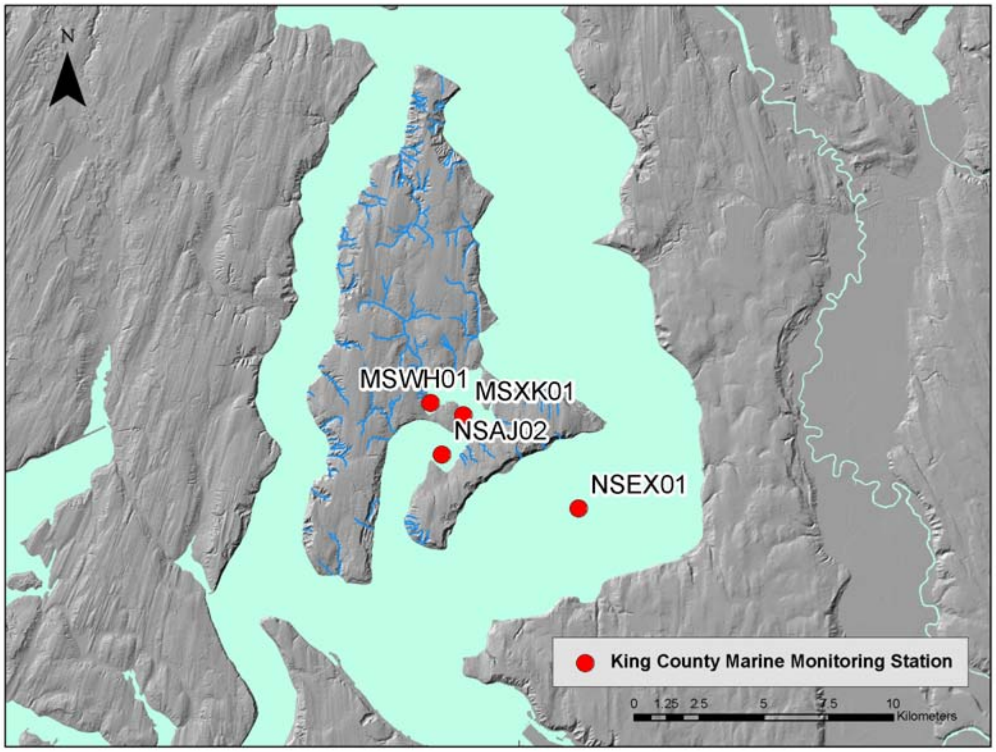

Figure 9. Map showing the King County monthly marine monitoring stations in Quartermaster Harbor and East Passage.

The data collected by UWT generally supports the patterns observed in the Ecology and King County marine monitoring. King County data showing greater chlorophyll *a* concentration in the inner harbor is supported by UWT observations as shown in Figure 14.

King County Vashon-Maury Island Water Resources Evaluation

King County's Water and Land Resources Division has been monitoring groundwater on VMI since 2001. These activities were initiated in support of the development of the Vashon-Maury Island Watershed Plan (King County 2005). In 2004, King County created an island-wide water resources project, the Vashon-Maury Island Water Resource Evaluation (WRE), to assess the status of groundwater on VMI. As part of this project, water quality and water quantity is being monitored at 19 locations throughout the island. The groundwater nitrate concentrations show varying trends (up, down and no change) depending on location (Figure 15 and Figure 16).

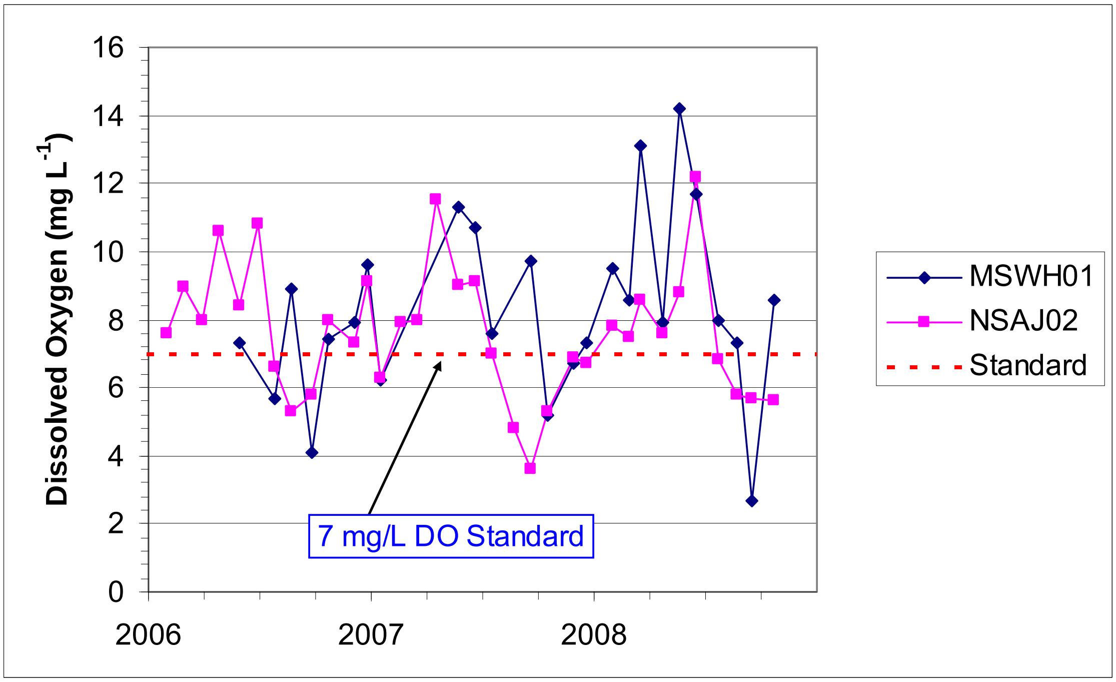

Figure 10. Graph showing the monthly discrete sampling results for dissolved oxygen at the 4 to 9-m depth for the two King County stations in Quartermaster Harbor.

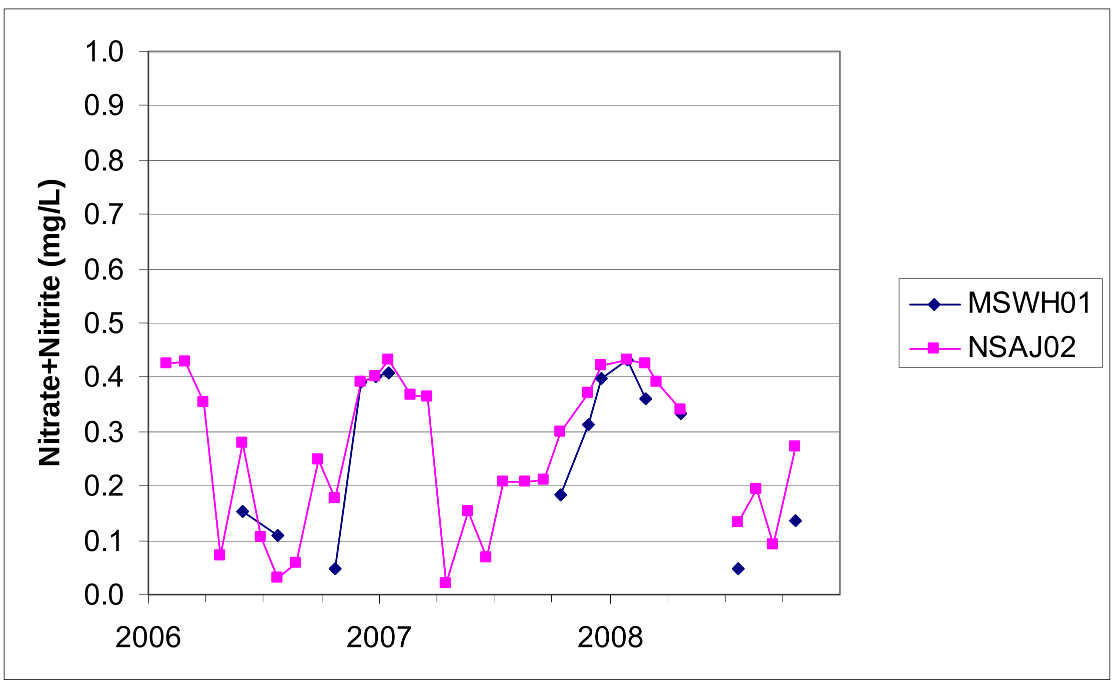

Figure 11. Graph showing the monthly discrete sampling results for Nitrate+Nitrite-N at the 4 to 9-m depth for the two King County stations in Quartermaster Harbor.

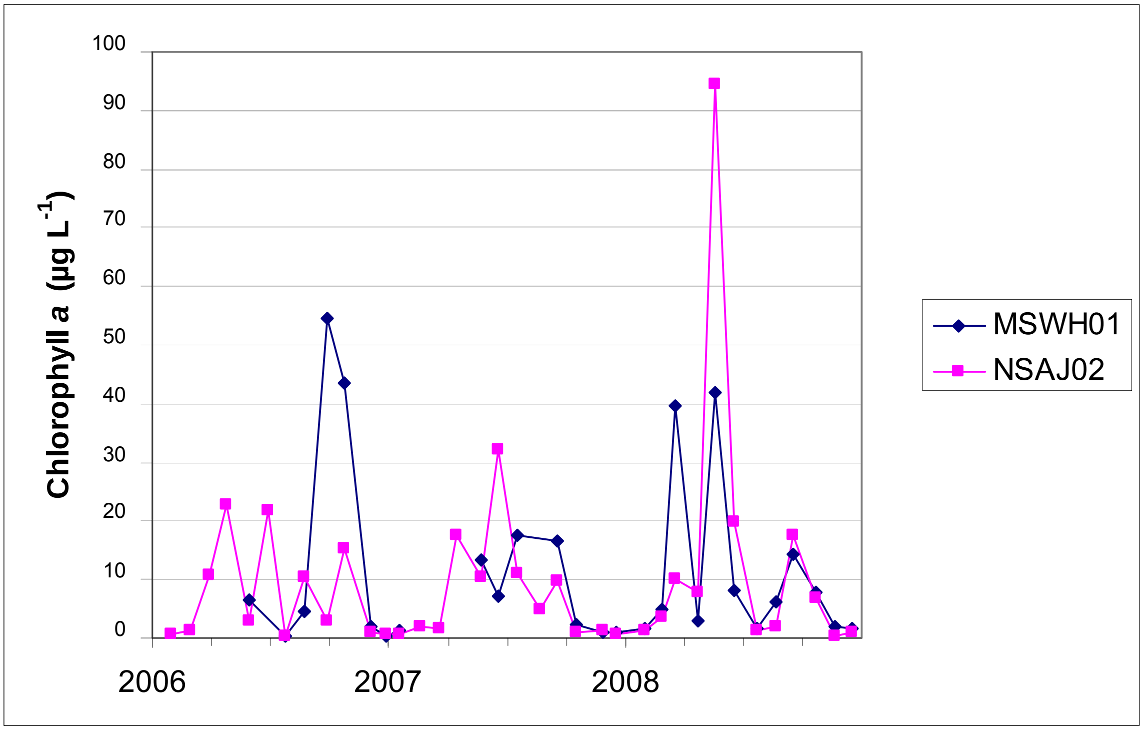

Figure 12. Graph showing the monthly discrete sampling results for chlorophyll *a* (a surrogate measure of phytoplankton biomass) at the 4 to 9-m depth for the two King County stations in Quartermaster Harbor.

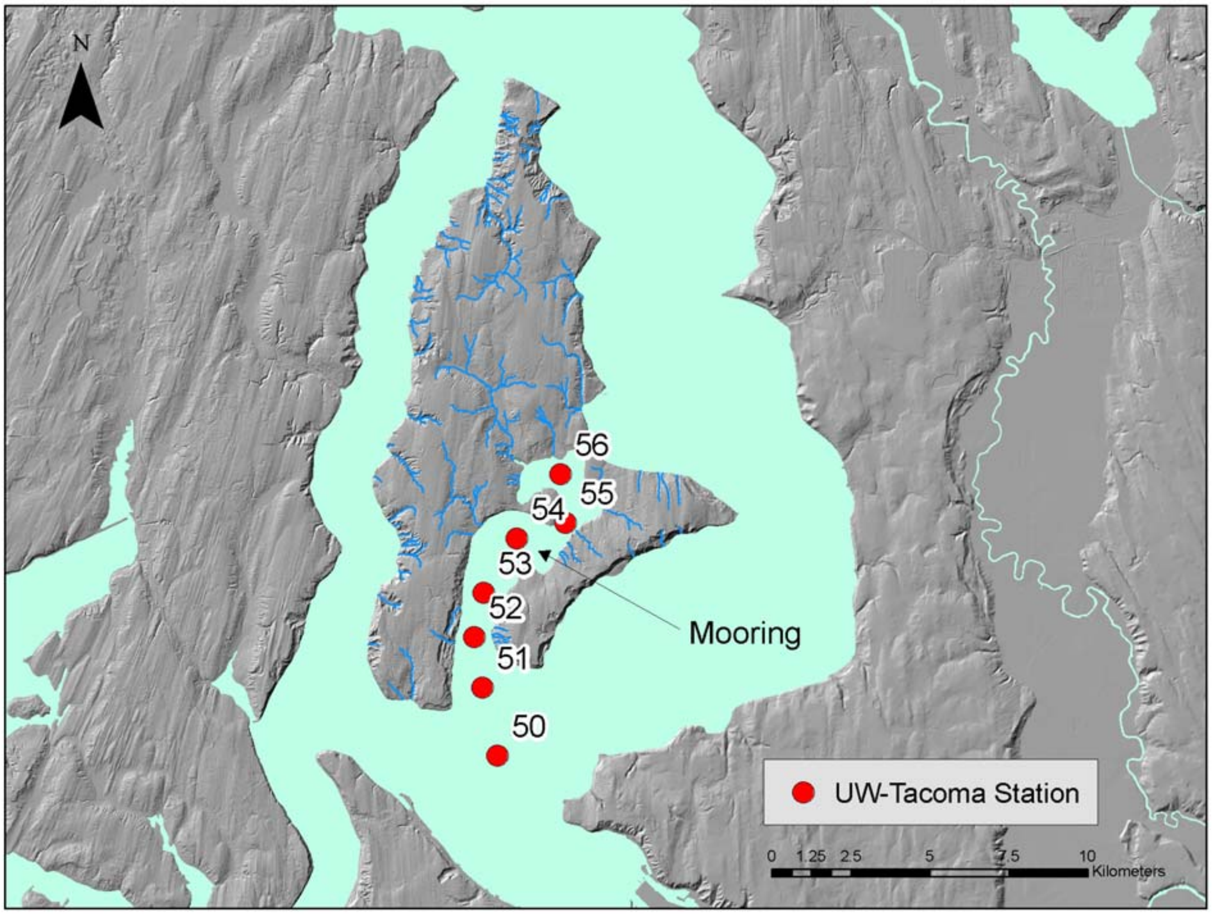

Figure 13. Map showing the University of Washington-Tacoma Quartermaster Harbor monthly marine monitoring stations.

In November 2006, water quality monitoring began at selected stream sites around the island. This initial 14-month assessment has continued due to concerns about high nitrate and fecal coliform bacteria concentrations observed at a few locations during the year (Figure 17, Figure 18 and Figure 19).

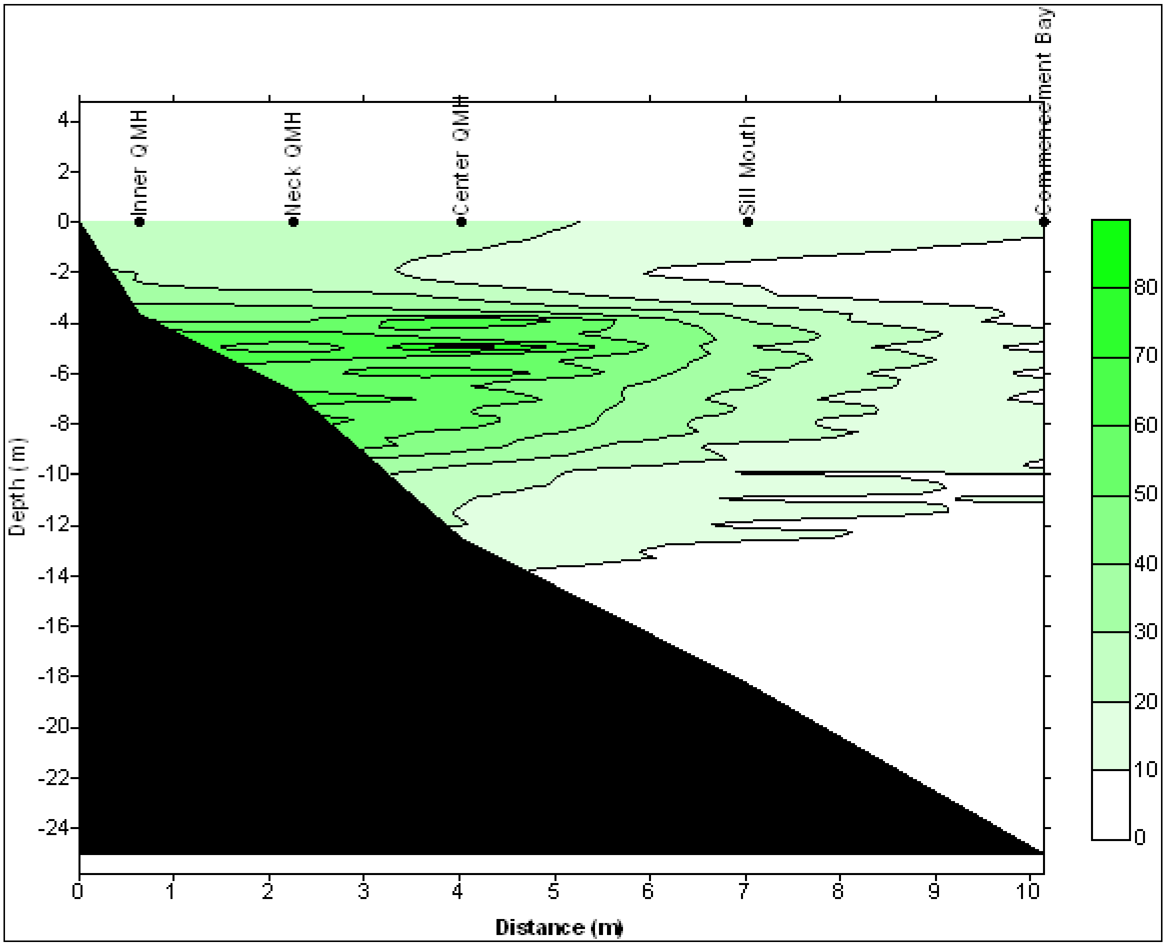

Figure 14. Graph showing chlorophyll a (a surrogate measure of phytoplankton biomass) at all stations within Quartermaster Harbor. Data collected May 5, 2006 by UWT.

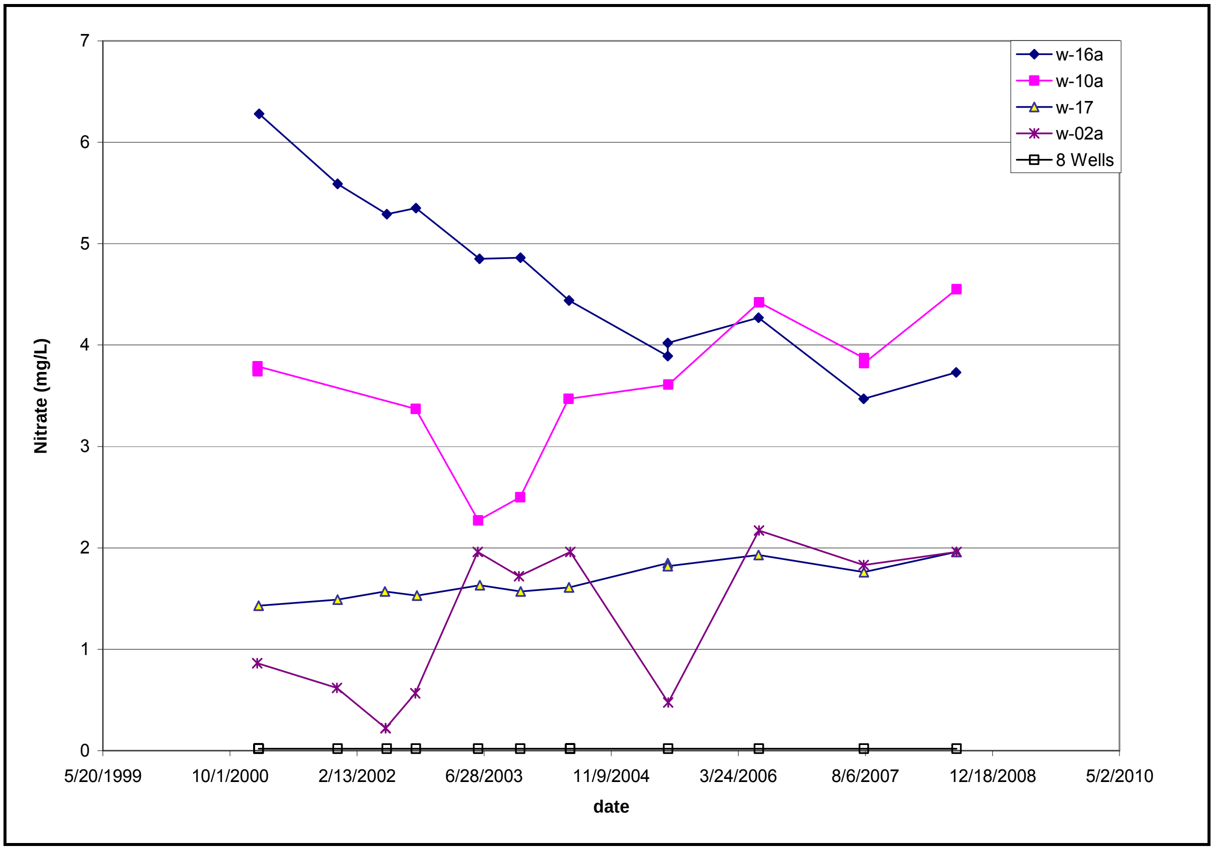

Figure 15. Nitrate + Nitrite water quality data from VMI groundwater long-term sites from 2001 to 2008. The sites sampled are: w-16 & w-17–Green Valley Basin; w-10a–Maury Island; w-02a–North Vashon; Non-detections–8 wells across VMI.

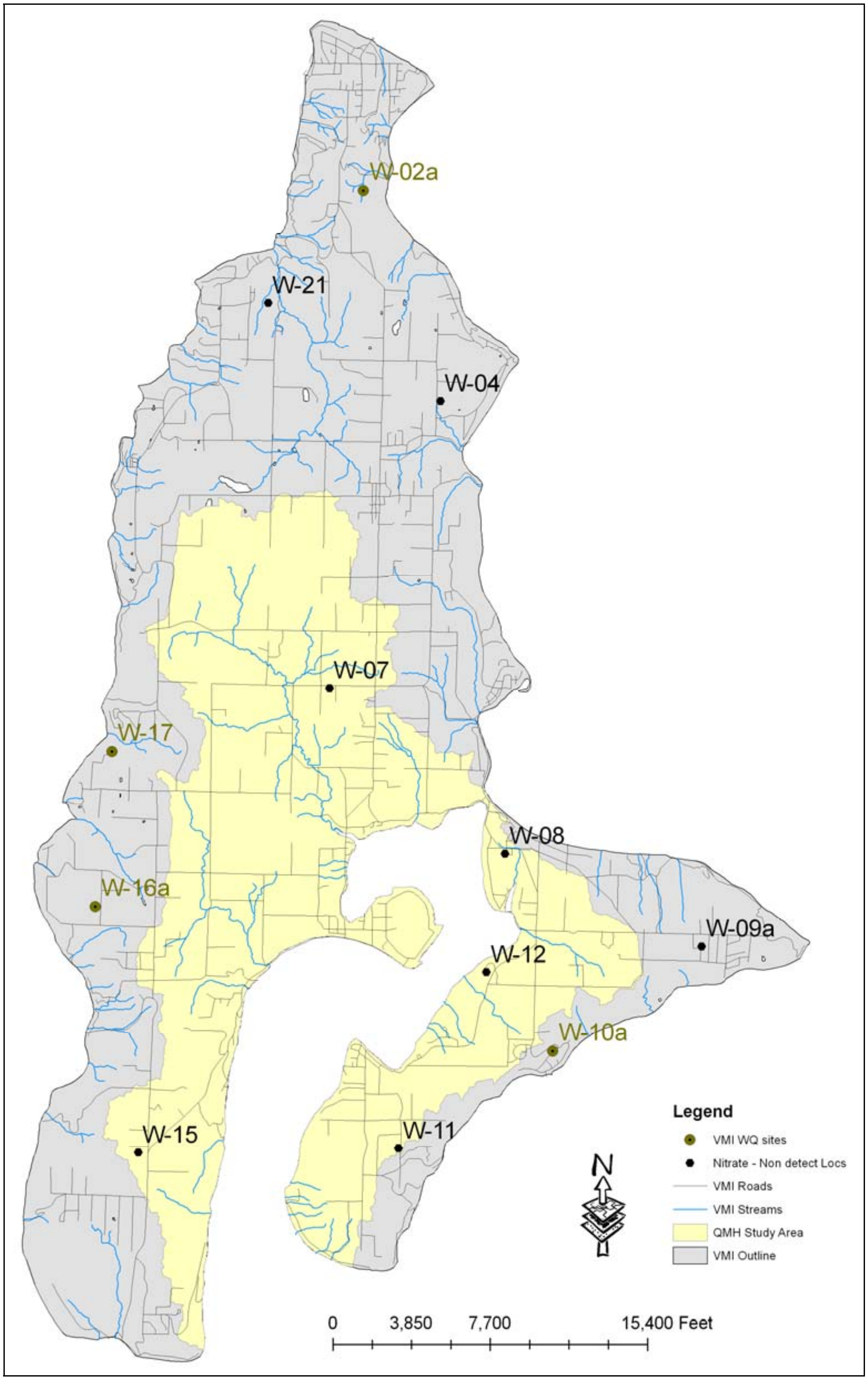

Figure 16. Nitrate + Nitrite water quality locations on VMI as shown in Figure 15. The sites sampled are: w-16 & w-17–Green Valley Basin; w-10a–Maury Island; w-02a–North Vashon; Non-detections–8 wells across VMI.

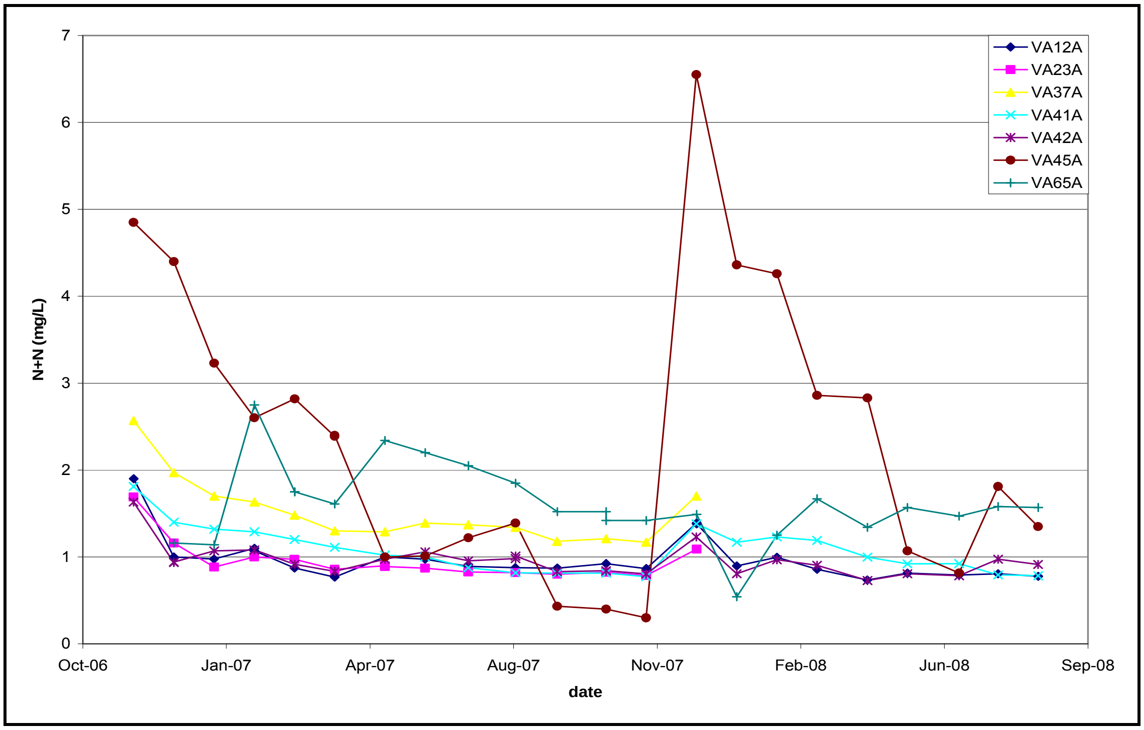

Figure 17. Nitrate + Nitrite water quality data from Vashon-Maury Island Creeks for 2007. The sites sampled are Shingle Mill (VA12A), Christian (VA23A), Tahlequah (VA37A), Fisher (VA41A), Judd (VA42A), Mileta (VA45A), and Gorsuch Creek (VA65A).

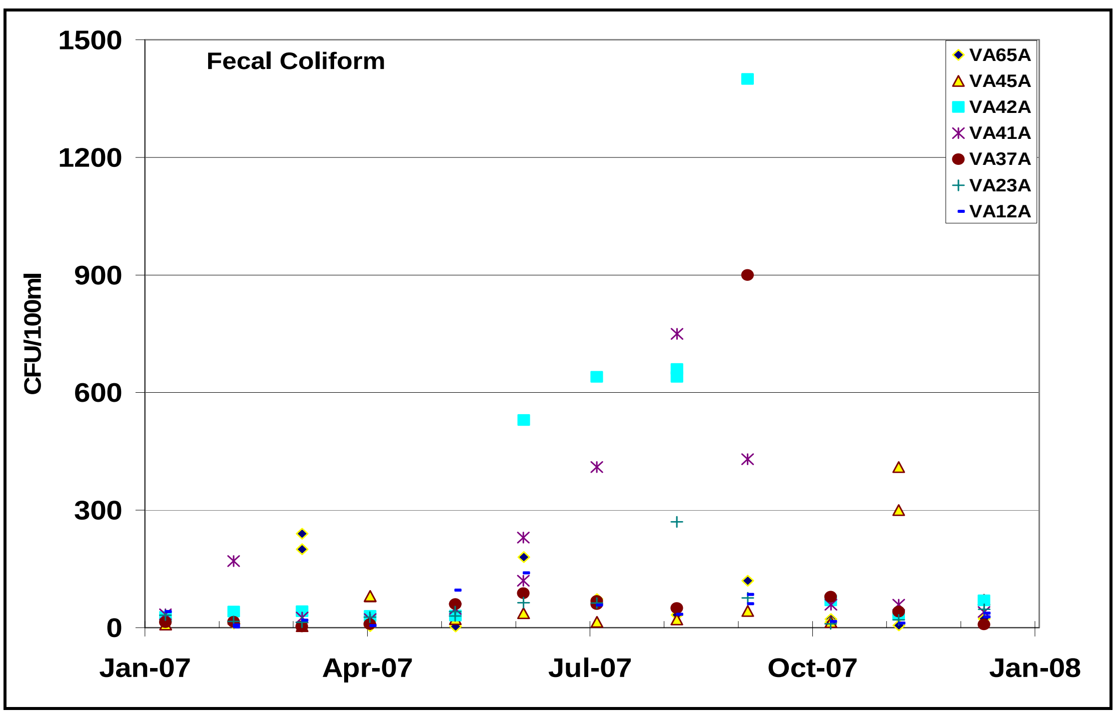

Figure 18. Fecal Coliform data from VMI Stream for 2007. Data collected monthly at 7 stream sites: Shingle Mill (VA12A), Christian (VA23A), Tahlequah (VA37A), Fisher (VA41A), Judd (VA42A), Mileta (VA45A), and Gorsuch Creek (VA65A).

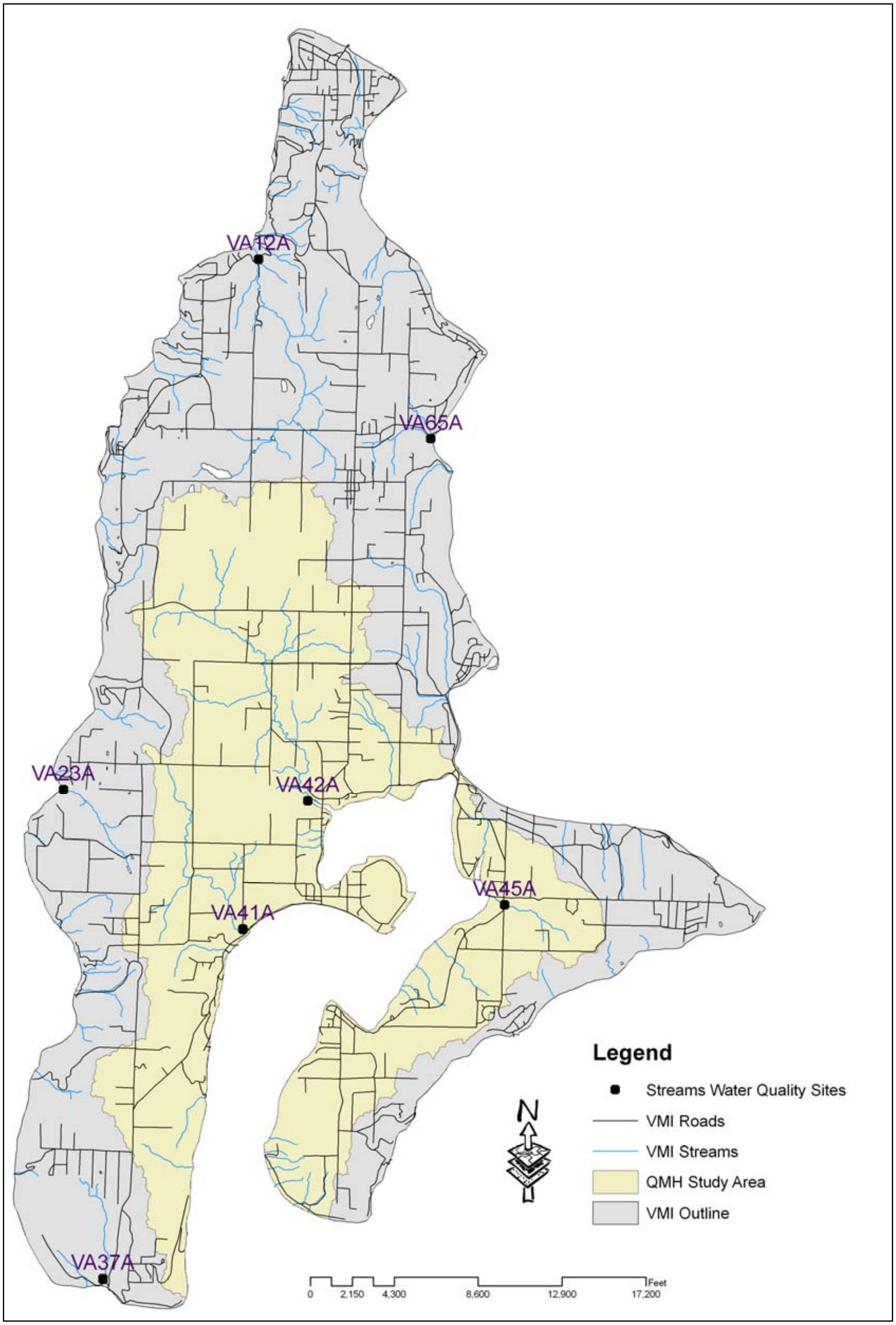

Figure 19. Stream water quality locations on Vashon-Maury Island for results presented in Figure 17 and Figure 18. Data collected monthly at 7 stream sites: Shingle Mill (VA12A), Christian (VA23A), Tahlequah (VA37A), Fisher (VA41A), Judd (VA42A), Mileta (VA45A), and Gorsuch Creek (VA65A).

2.0. PROJECT GOAL AND OBJECTIVES

2.1 Project Goal

The purpose of this study is to determine how nitrogen from a variety of sources affects dissolved oxygen levels in Quartermaster Harbor (QMH). The expected long term outcomes are improved policies in the King County Comprehensive Plan and the implementation of land use management BMPs to reduce nitrogen loading to QMH and the prevention of lethal low level oxygen events in QMH. These outcomes will be useful as a model for other rural areas of Puget Sound.

2.2 Project Objectives

The objectives of the study are:

1. To determine the relative nitrogen loadings to QMH by source type: OSS, livestock (manure), fertilizer, alder forests, and other. Loading from OSS will be further broken down by age (new and those older than 20 years), and by technology (basic or alternatives that remove nitrate). Collect high frequency marine data using buoys in QMH
2. To model these loadings with a surface-subsurface hydrologic model to simulate the time varying loads to a receiving water (marine) model. A stable isotope study will provide data on the source distribution to QMH. These models will be calibrated to data collected in this proposal.
3. To identify Best Management Practices (BMPs) with assistance from regulatory and policy partners that address the land uses with the largest loadings as determined in this proposal.
4. To model the effectiveness of nitrogen management on QMH dissolved oxygen levels, and to compare the level of effectiveness of different management options with conceptual cost estimates.
5. To develop new policies for the 2012 King County Comprehensive Plan update related nitrogen management on VMI, and to recommend management actions for implementing the new policies. Nitrogen management policies and management strategies will be developed collaboratively with Vashon residents the Vashon Community Council and Vashon Groundwater Protection Committee and PHSKC and the King County Departments of Natural Resources and Parks and Development and Environmental Services.

The long term outcomes are improved policies in the King County Comprehensive Plan and the implementation of land use management BMPs to reduce nitrogen loading to QMH and the prevention of lethal low level oxygen events in QMH. These outcomes will be useful as a model for other rural areas of Puget Sound.

2.3 Project Management and Oversight

This project will be managed by King County and includes collaborators from the UW-T, Ecology, and the Groundwater Protection Committee. Funding will be provided by the EPA WEI grant described above. In addition to direct grant support, staff time and resources (primarily in the form of field equipment and laboratory services) are also being provided to match a portion of the grant. The project team plans to meet at least quarterly to communicate progress, problems, and plan future activities. Although no formal technical advisory committee has been formed, work plans and products (including this QAPP) will be reviewed by the project team and technical reviewers assigned by EPA Region 10, primarily the EPA Project Monitor assigned to this grant.

3.0. PROJECT DESIGN

The overall design of the project is as follows:

- Estimate the nitrate load from various potential sources using existing data and published literature values and by preliminary water quality sampling of streams, groundwater, and marine waters.
- Collect field data (ground water, surface and marine water) to describe environmental conditions within Quartermaster Harbor and its catchments area and provide data for the development of a predictive watershed nitrogen loading model and marine dissolved oxygen model.
- Develop a model of the hydrodynamic conditions of groundwater and stream inflows into Quartermaster Harbor including relevant biogeochemical processes.
- Develop a three-dimensional numerical model that describes the hydrodynamics and relevant biogeochemical processes in Quartermaster Harbor.
- Apply these models to evaluate the sensitivity of water quality in Quartermaster Harbor to changes in nutrient inputs.
- Simulating the effects of nitrogen management scenarios on Quartermaster Harbor and recommend policy changes in the 2012 King County Comprehensive Plan update for nitrogen management on Vashon-Maury Island, and to assess management options for implementing the recommended policy changes.

3.1 Project Design Details

The study will be conducted in three phases over the next four years (2009-2012).

Phase 1, January 2009 to December 2009, will estimate the nitrate load from various potential sources using existing data and published literature values. This phase also starts the field collection of water quality data (groundwater, surface and marine water) that will continue through the entire length of the study.

The next phase, Phase 2, will begin in January 2010 and continues to December 2011. During this phase, special sub-studies– OSS evaluations and a stable isotope source tracking assessment will be done. The modeling assessment begins in this phase of the project with the Mike-SHE model assessing the hydrodynamic and biogeochemical conditions of the ground and stream inflows into Quartermaster Harbor. The receiving water model will be developed to describe the hydrodynamics and biogeochemical processes in Quartermaster Harbor. Initial steps of simulating the effects of nitrogen management scenarios will begin in this phase.

Phase 3, January 2012 to December 2012, will focus on linking the nitrogen loadings to Quartermaster Harbor dissolved oxygen levels and by simulating the effects of nitrogen management scenarios. Policy change recommendations for nitrogen management on Vashon-Maury Island, and management options for implementing the recommended policy changes will be completed in this final phase of the project. Any policy changes may be included in the 2012 King County Comprehensive Plan update.

The project will also include an ongoing public outreach and communication component that will include the development of a web portal for project information; press releases to local papers; and presentations to the public through the VMI Community Council, Septic Solutions subcommittee, VMI Groundwater Protection Committee, and public meeting specifically for residents of the study area.

3.1.1 Ongoing Monitoring

The following activities are scheduled to begin in Phase I and continue throughout the four year project:

3.1.1.1 Groundwater

Groundwater is being monitored on an annually basis at 14 locations within the Quartermaster Harbor study area (Figure 20 and Table 1). All groundwater sites will be sampled for nine parameters listed in Table 2. Six field parameters will be collected at the time of sampling (Table 2).

Table 1. Locations of Groundwater water sites. Northing and Easting are in Washington North State Plane Feet (North American Datum 1983-High Accuracy Reference Network).

Well ID	Location type*	Northing	Easting	Well Depth (feet)	Well Elevation (NGVD feet)
W-06	LT	167375.23	1233777.06	169	406
W-07	LT	158016.56	1235401.16	267	260
W-08	LT	149889.53	1244002.63	462	96
W-11	LT	135435.73	1238780.43	423	321
W-12	LT	144080.74	1243087.96	473	110
W-13	LT	149267.62	1232322.97	80	223
W-19	LT	166391.41	1228382.08	173	413
W-65	MW	158570.14	1237393.75	160	325
W-61	MW	158544.96	1237415.33	152	325
W-64	MW	135533.47	1226485.09	244	388
W-70	MW	158547.99	1237379.22	335	325
W-71	MW	163939.60	1235024.82	104	360
W-72	MW	153882.27	1231599.89	135	395
W-73	MW	156745.44	1233520.75	60	128

Note: * Location type: LT–refers to long-term monitoring locations and MW–refers to monitoring well locations.

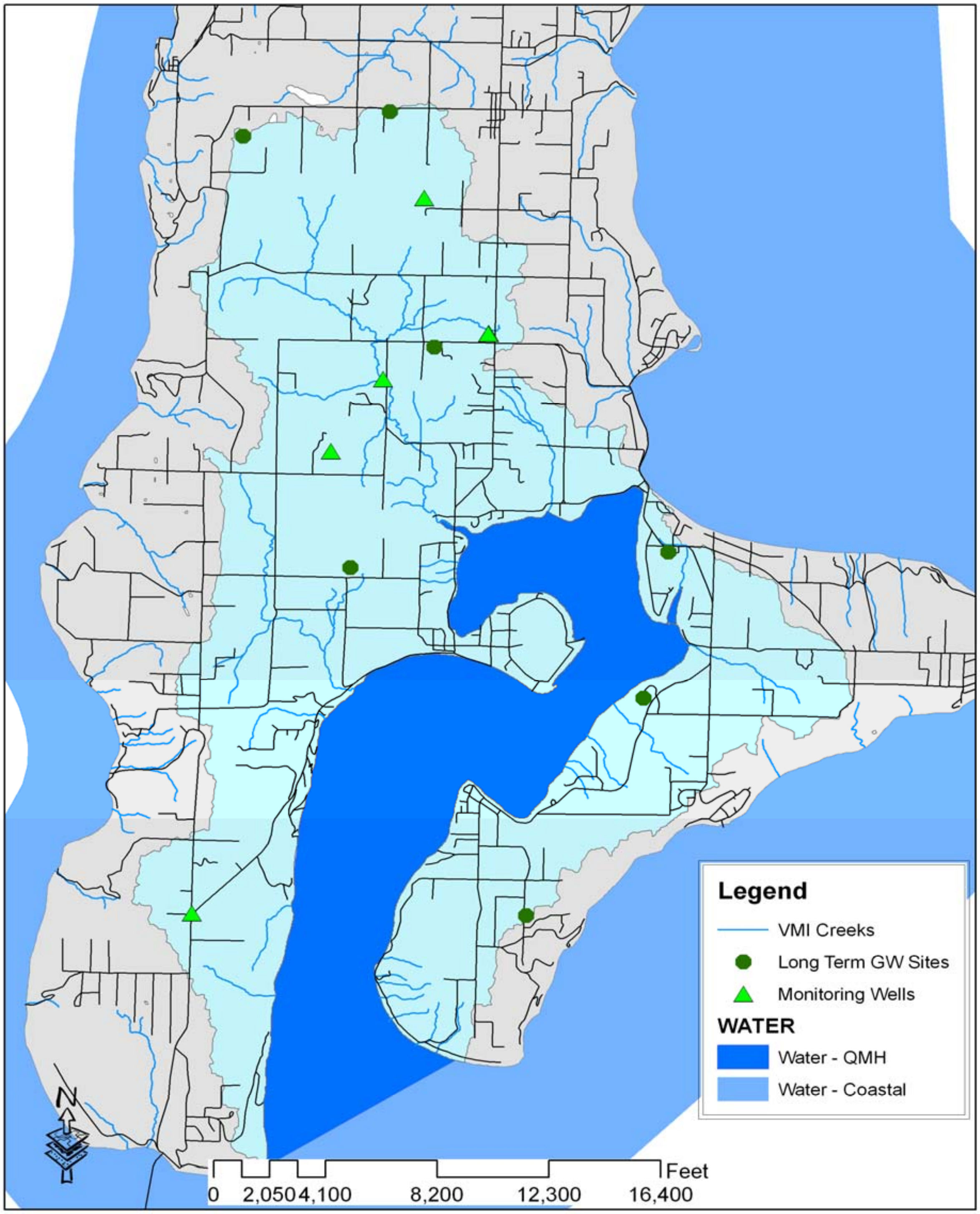

Figure 20. Groundwater sampling locations within the Quartermaster Harbor (QMH) study area. Highlighted area represents the project study area. Sites that are existing wells that have been part of the long term water quality monitoring on Vashon-Maury Island (VMI) are shown as circles. Triangles represent sites of monitoring wells installed by King County. All groundwater sampling sites will be sampled annually.

Table 2. Water Quality Parameter List for Groundwater and Stream sampling locations.

Parameters		Groundwater	Stream
Alkalinity	Laboratory	X	X
Ammonia Nitrogen	Laboratory	X	X
Nitrite + Nitrate Nitrogen	Laboratory	X	X
Total Nitrogen	Laboratory	X	X
Ortho-Phosphate	Laboratory	X	X
Total Phosphorus	Laboratory	X	X
Total Suspended Solids	Laboratory	X	X
Fecal Coliform	Laboratory	—	X
E. Coli	Laboratory	—	X
Dissolved Oxygen	Field	X	X
Temperature	Field	X	X
Specific Conductance	Field	X	X
pH	Field	X	X
ORP	Field	X	—
Turbidity	Field	X	—

"—" refers to parameters not sampled.

3.1.1.2 Streams

Four stream sites will be sampled for water quality parameters on a monthly basis during the length of the project (Figure 21 and Table 3). Two of the largest creeks discharging into Quartermaster Harbor, Judd and Fisher, are being monitored. Mileta Creek on Maury Island is the third creek being monitored. The final creek, Shinglemill–VMI 2^{nd} largest, is being monitored as a reference site. The list of parameters for this sampling is similar to the groundwater locations except for the addition of microbiology and no collection of turbidity and ORP as field parameters (Table 2).

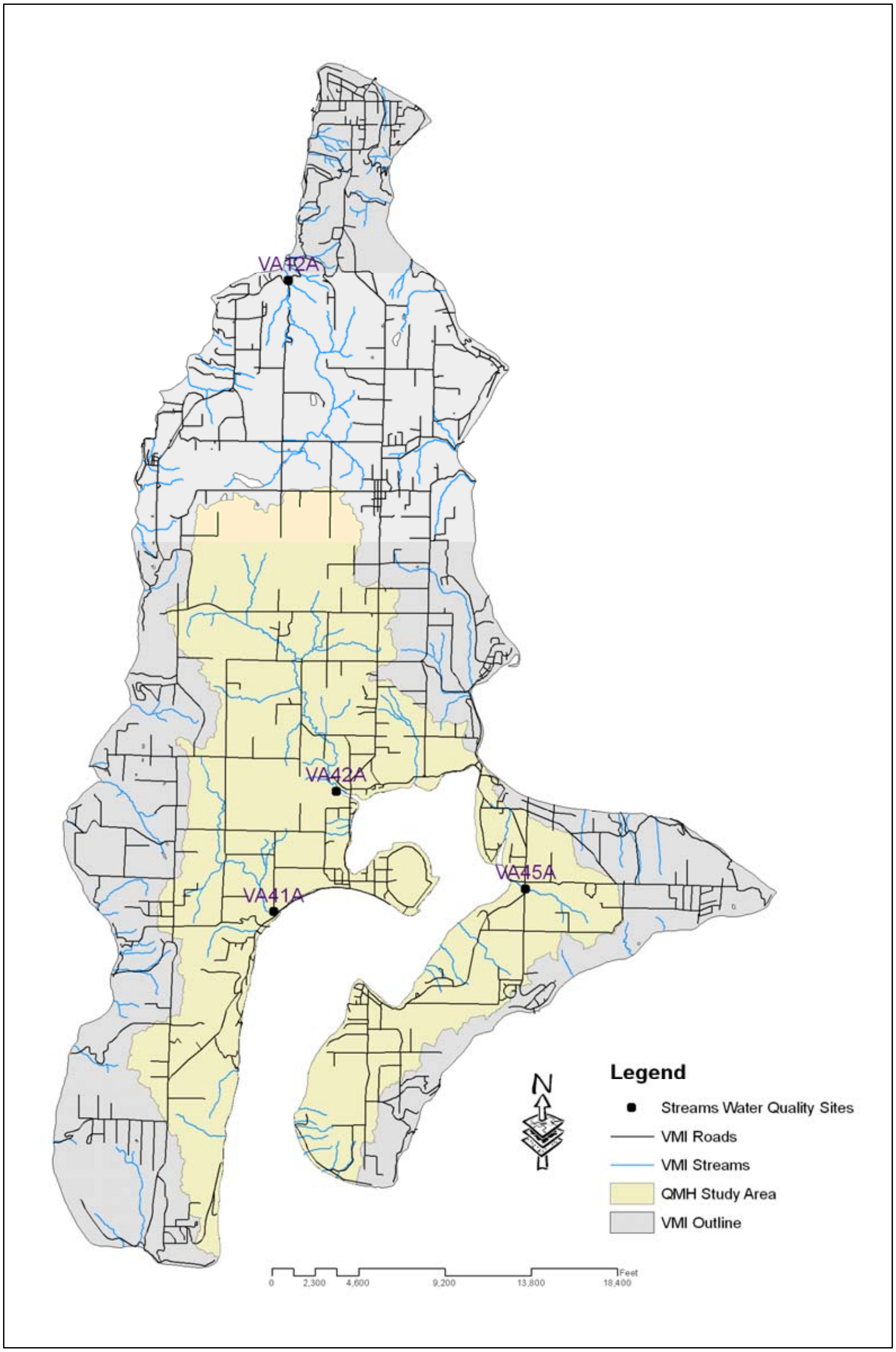

Figure 21. Stream Water Quality sampling locations. The sites are Shinglemill (VA12A), Fisher (VA41A), Judd (VA42A) and Mileta (VA45A) Creeks. These sites will be sampled monthly during the project.

Table 3. Location data for stream sampling locations. Northing and Easting are in Washington State Plane Feet North coordinates. Datum the same as Table 1.

Site Id	Name	Northing	Easting	Elevation (NGVD feet)
VA12a	Shinglemill Creek	178898.5	1232934.2	30
VA41a	Fisher Creek	144481.2	1232132.7	35
VA42a	Judd Creek	151065.0	1235464.2	20
VA45a	Mileta Creek	145730.6	1245564.1	70

Stream flow will also be measured on Vashon-Maury Island as part of the Water Resources Evaluation Project. The data from this activity will be used to help assess the inflows into Quartermaster Harbor and provide flow information for stream loading estimates. The stream flow is being measured continuously (15-minute intervals) at five sites and measured bi-annually at another 22 sites (Figure 22). Continuous stream temperature (15-minute) is an additional parameter that is measured at all of these locations.

3.1.1.3 Marine Water

The marine monitoring will be done by King County and the University of Washington-Tacoma.

King County

King County is monitoring four locations within the Quartermaster Harbor area with 2 different types of sampling techniques (Table 4). A grab sampling method will be done at all four locations, Quartermaster Harbor Yacht Club, Burton Beach, Dockton Park, and the Quartermaster Harbor entrance (Figure 23). These locations will be sampled monthly. Continuous recording sondes will collect data at Dockton Park as well as at a mooring located at the entrance of Quartermaster Harbor (Figure 23). The mooring data will be collected every 15 minutes. The parameter lists for the marine monitoring vary depending on location (Table 4 and Table 5). Location and depth information for these sampling sites are presented in (Table 6).

University of Washington–Tacoma

University of Washington–Tacoma staff will collect CTD profile data and discrete samples approximately monthly at six stations along the main axis of Quartermaster Harbor and at another station located outside of the harbor in the main channel for a total of seven stations (Figure 23). Additional time series data will be collected at a mooring located in the outer Quartermaster Harbor area (Figure 23). The sampling depths of the vessel stations are near surface, near bottom and seasonally at the pycnocline when present. The parameter lists for the marine monitoring vary depending on location (Table 4 and Table 5). Location and depth information for these sampling sites are presented in (Table 6).

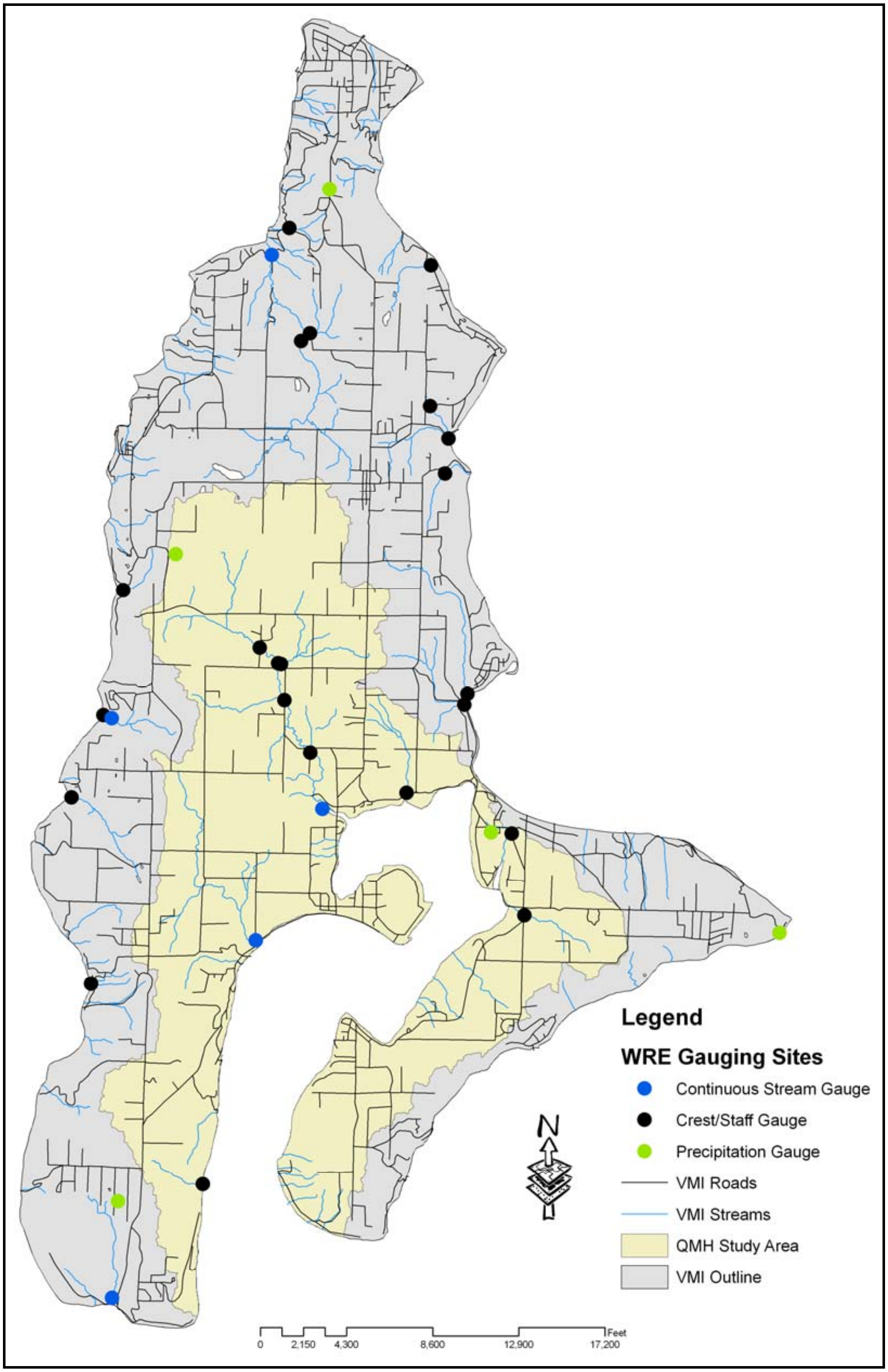

Figure 22. Gauging locations on Vashon-Maury Island as part of the Water Resources Evaluation (WRE) project. This including continuous stream flow, crest/staff stream flow and precipitation sites.

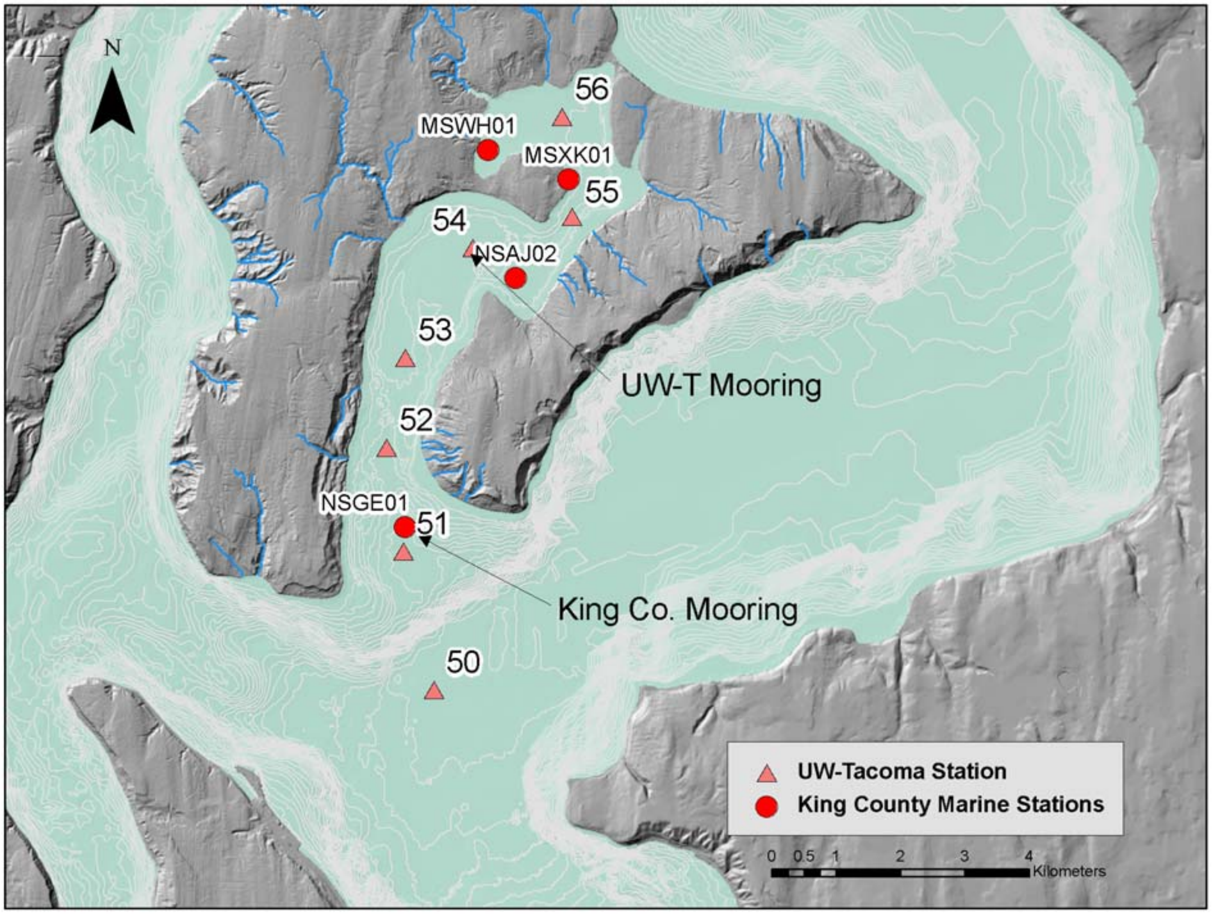

Figure 23. Marine monitoring sites sampled by King County [MSWH01, MSXK01, NSAJ02 and NSGE01] and the University of Washington-Tacoma [Stations 50-56 including the mooring at station 54].

Table 4. Water Quality Parameter List for all Marine Monitoring Sites within Quartermaster Harbor. These locations are being sampled monthly.

Parameters		King County			UWT
		Yacht Club (MSWH01)	Dockton Park (NSAJ02)	Burton Acres Park (MSXK01)	QMH stations (50-56)
Ammonia Nitrogen	Laboratory	x	x	x	x
Nitrite + Nitrate Nitrogen	Laboratory	x	x	x	x
Total Kjeldahl Nitrogen	Laboratory	—	x	x	—
Total Phosphorus	Laboratory	x	x	x	x
Silica	Laboratory	x	x	—	x
Total Suspended Solids	Laboratory	x	x	—	—
Fecal Coliform	Laboratory	x	x	x	—
Enterococcus	Laboratory	x	x	x	—
Salinity	Laboratory	x	x	x	x
Chlorophyll-a	Laboratory	x	x	—	x
Pheophytin-a	Laboratory	x	x	—	—
Dissolved Oxygen	Field	x	x	—	x
Temperature	Field	x	x	x	x
Secchi depth	Field	—	—	—	x

"—" refers to parameters not sampled.

"UWT" refers University of Washington–Tacoma

"QMH" refers to Quartermaster Harbor

Table 5. Parameter List for the Continuous Marine Monitoring Sites. These parameters are recorded every 15 minutes.

Parameters		King County		UWT
		QMH Entrance (NSGE01)	Dockton Park (NSAJ02)	Outer QMH (54)
Chlorophyll	Continuous	x	x	—
Dissolved Oxygen	Continuous	x	x	—
pH	Continuous	x	x	—
Salinity	Continuous	x	x	x
Specific Conductance	Continuous	x	x	—
Temperature	Continuous	x	x	x
Turbidity	Continuous	x	x	—
Nitrate	Continuous	x (surface only)	—	—
Barometric Pressure	Continuous	x	x	—
Meteorological Suite	Continuous	—	x	—
Photosynthetically Active Radiation	Continuous	x	x	—

"—" refers to parameters not sampled.

Table 6. Location and depths of marine monitoring locations for King County (KC) and University of Washington–Tacoma (UWT) locations are listed. Depths are given in meters (m) of mean lower low water (MLLW). Datum the same as Table 1.

Station	Agency	Location	Northing	Easting	Depth
MSWH01	KC	Quartermaster Harbor Yacht Club	147976	1236667	varies[1]
NSAJ02		Dockton Park	141440	1238084	varies[1]
MSXK01		Burton Acres Park	146481	1240772	1
NSGE01		Quartermaster Harbor Entrance + Mooring	128744	1232440	1 & 52
50	UWT	East Passage (near QMH)	120418	1233916	174
51		Quartermaster Harbor Entrance	127486	1232401	53
52		Outer Harbor QMH	132765	1231501	18
53		Outer Harbor QMH	137347	1232480	22
54		Outer Harbor QMH + Mooring	142965	1235921	14
55		Inner/Outer Harbor QMH	144567	1240977	15
56		Inner Harbor QMH	149649	1240480	7

[1]Depths for grab samples at Quartermaster Harbor Yacht Club and Dockton Park are 1 meter below the surface and 1 meter above the bottom (variable with the tide).

3.1.1.4 Meteorological data

Meteorological data will be collected at a variety of sites throughout Vashon-Maury Island including QMH specific activities. Precipitation will be measured on Vashon-Maury Island as part of the Water Resources Evaluation Project at five locations (Figure 22). One site, Vashon Island Landfill, has a meteorological station which measures precipitation, air temperature, wind speed, wind direction, solar radiation, relative humidity, and dew point temperature.

An additional meteorological station will be part of the marine mooring within Quartermaster Harbor at Dockton Park (Figure 23).

3.1.2 Ongoing Public Outreach and Communication

Outreach and communication are key components of this study and exist at every phase of the work. Public meetings transfer knowledge directly to the people whose behavior changes can enhance the watershed and QMH. This strategy takes advantage of the already active and involved Groundwater Protection Committee (GWPC) on the island. The GWPC have regular public meetings that meet on a quarterly basis. An update of QMH Nitrogen Management Study progress will be given by King County staff at every meeting during the study (2009-2012).

At key times during the study, public outreach and communication will become very important to achieving desired outcomes. Initially, the outreach and communication will focus on informing the community of the study, why it is important, what will be done, how to get involved and where to get more information. The OSS special study in Phase II will need additional outreach and communication with the community to get volunteers to participate in the study.

The project objective to develop new policies for the 2012 King County Comprehensive Plan update related nitrogen management on VMI and to recommend management actions for implementing the new policies will reply on public outreach. Nitrogen management policies and management strategies will be developed collaboratively with Vashon residents, the Vashon Community Council, GWPC, Public Health Seattle-King County and the King County Departments of Natural Resources and Parks and Development and Environmental Services.

3.1.3 Phase 1 Loading Estimates

In addition to on-going monitoring, Phase I will focus on assessing and estimating the nitrogen loadings based on published literature and existing data. The sources (anthropogenic and natural) of nitrogen will be assessed from On-site Septic Systems, Fertilizer, Livestock and Alder trees.

The loading estimate from OSS will be estimated by developing a GIS coverage of parcels and using literature values for OSS discharges of nitrogen. It will be assumed that 100% of the nitrogen discharged from properly operating septic system is nitrate.

Loads from residential fertilizer applications will be estimated using county-level fertilizer data from a USGS report (Ruddy *et al*., 2006) and VMI land cover data. This county level data will be compared to island specific information about fertilizer sales data from stores on the island via the Drink Clean–Garden Green campaign that collected annual data.

Estimates from livestock will be made by combining King County data on the number of livestock present on the Island with estimates of the nutrient content of livestock manure (Ruddy *et al*., 2006).

The natural source of nitrogen from alder trees will be estimated by using VMI land cover data (deciduous tree cover) and published literature values to estimate the loadings. Historical land-use and/or aerial photography data may be used to help assess loads from logging activities.

An assessment of existing water quality data within the study area will be done to determine any areas of concern or data gaps that should be address during the study.

3.1.4 Phase 2 Work Elements

Some Phase 2 work elements need additional scoping before specific details can be described. Annual updates to this QAPP will be done to address these items in late 2009 to early 2010. In particular, the stable isotope source tracking study and the OSS study are two work elements that need additional scoping.

Overviews of these Phase 2 studies are as follows:

The stable isotope source tracking study will be designed during Phase 1 to help quantify the relative importance of various sources of nitrogen VMI to QMH. The results of this study will be used to update and refine the nitrate loading estimated in Phase 1. The stable isotope data will be collected at a variety of sources, along flow paths, and in the receiving waters.

The OSS study is proposed to estimate the range of nitrogen loadings from this type of source. The simple approach is to collect water quality data from several different OSS types/configurations. One factor that may be considered is the age of the OSS system. Local and state health department will be solicited during Phase 1 for their input and guidance in scoping and implementation of this study.

3.1.5 Modeling

As described above, modeling is an essential component of the project. Modeling is proposed to evaluate to what extent dissolved oxygen conditions in QMH are due to human-related inputs and changes relative to conditions prior to significant forest clearing and settlement within the drainage to the harbor. Model selection will take place during Phase 1 and model development and calibration work will be initiated in Phase 2.

3.1.5.1 Modeling Approach

In theory, modeling should be an iterative approach that involves initial conceptualization and implementation based on management information needs and available resources followed by testing and model refinement. However, the application of models as an aid in management decision making typically requires a more finite project timeline. Ideally, modeling and management decision making would be a coupled iterative process that allows for additional data collection, model testing, model refinement, and re-evaluation of model results and management decisions based on them.

A relatively finite timeline will be achieved through the following steps:

- Develop new models or select existing models for project application
- Review of model data needs
- Compilation and review of existing data required for model
- Identification of data gaps or additional data needs
- Additional data collection and incorporation of additional data into model
- Selection of periods for model calibration
- Model setup
- Model calibration and testing
- Identification and implementation of possible model refinements
- Final testing and calibration of individual models
- Integration of receiving water model with watershed model

A brief description of each of these steps that is relevant to the development of the QMH models is provided below. Phase 3 steps involved in application of individual models or integrated models to water quality management decision making are not addressed in the current plan.

3.1.5.2 Model Selection

The most important criteria for selecting the modeling framework for this project include:

1. The framework uses state-of-the-art algorithms and solution techniques that are appropriate for the intended application.
2. Biogeochemical modules are integrated with the hydrodynamic and transport modules and include important kinetic processes that are known to be necessary for simulation of nitrogen fate and transport and dissolved oxygen dynamics in rural watersheds and enclosed embayments of Puget Sound.
3. Peer review of model theory and past applications has occurred.
4. Technical documentation is available.
5. Active development of the framework is ongoing and technical support is available.

In addition to these key criteria, other considerations that would be beneficial include the following:

- Successful past applications in the Puget Sound region have occurred.
- Program source code is available for review as part of program documentation.
- Graphical user interface (GUI) utilities that facilitate model setup, execution, and input and output management and analysis.

A variety of models and modeling frameworks have been applied in the Puget Sound region. Perhaps the most notable recent effort to develop an integrated watershed-receiving water modeling framework is the coupling of the Distributed Hydrology-Soil-Vegetation Model (DHSVM) with the Rutgers Ocean Modeling System (ROMS) to evaluate the impact of watershed nitrogen loadings on Hood Canal dissolved oxygen levels. Additional examples reviewed by Albertson *et al.* (2007) identified marine receiving water model applications such as the Environmental Fluid Dynamics Code (EFDC) application to South Puget Sound, the Generalized Longitudinal Lateral and Vertical Hydrodynamic and Transport (GLLVHT) model application to Budd Inlet, and the application of the Princeton Ocean Model (POM) to Puget Sound. Albertson *et al* (2007) compared two of the models identified above to a third model (Generalized Environmental Modeling System for Surface Waters or GEMSS) and concluded that GEMSS was the preferred model for application to Phase 2 of the South Puget Sound Water Quality Study, primarily due to the inclusion of the diel vertical migration of dinoflagellates which is considered to play an important role in dissolved oxygen dynamics in South Puget Sound.

Other modeling frameworks that have been applied locally include coupling of Hydrologic Simulation Program-Fortran (HSPF) watershed models with the Curvilinear Hydrodynamics in -3-Dimensions (CH3D) as part of the Sinclair and Dyes Inlet modeling study (Johnston *et al*.

2003). King County has also developed HSPF watershed models coupled to vertical 2-dimensional river (CE-QUAL-W2) and 3-dimensional lake (CH3D and CE-QUAL-ICM) hydrodynamic and water quality models (King County 2007). There are also other efforts underway to couple a 3-dimensional hydrodynamic model of Puget Sound (FVCOM) to the CE-QUAL-ICM water quality model–U.S. EPA, Pacific Northwest National Laboratory (PNNL), Ecology (Sackmann, 2009). Parallel to this effort is a project that plans to couple a simple box model of Puget Sound circulation to the Water Quality Analysis Simulation Program version 7 (WASP7). There is also an effort underway lead by Dr. Parker MacCready, UW Oceanography, to develop a ROMS-based model of Puget Sound.

HSPF is not an explicitly integrated surface-groundwater model and therefore may not be appropriate for this project. However, it could be argued that it may be unreasonable to expect the development and calibration of an integrated surface-groundwater model of the QMH drainage basin given the expected level of data that will be available for explicitly quantifying nutrient sources and biogeochemical processes in soil, groundwater, and in surface streams during this 2-year project. Note that with the exception of the Hood Canal modeling effort, no other project is attempting to mechanistically model watershed nutrient fate and transport. If such a model is considered to be feasible given time, budget, and data constraints; one possibility could be the development of a water quality component for the VMI Mike-SHE model (King County work currently in progress). Development and application of the DHSVM model currently being developed for the Hood Canal project might be another possibility.

We propose a model selection process that will identify the best model based on project specific criteria that include considerations of the time and resources available for this project and the current understanding of management needs. The selection of models that will be developed in Phase 2 will be documented in a separate Modeling Quality Assurance Project Plan that will include discussion of:

- Model data needs and identification of data gaps
- Any additional proposed data collection and method of incorporation into the model(s)
- Specific data and time periods to be selected for model calibration and testing
- Process of model set up
- Model testing and calibration procedures
- Identification and implementation of model refinements
- Final testing and calibration of individual models
- Integration of receiving water model with watershed model(s)
- Development and implementation of modeling scenarios

3.1.6 Phase 3 Work Elements

Phase 3 work will take place in the final year of the project (January 2012 to December 2012). During this phase, watershed and receiving water model development will be completed and the models will be used to evaluate the effects of various nitrogen management scenarios on QMH dissolved oxygen levels. Phase 3 also includes the development of conceptual cost estimates for various nitrogen management BMPs and a comparison of these costs to effectiveness of improving QMH dissolved oxygen levels. Relevant data will also be transferred to STORET or WQX for long-term archival storage and use following last data collection and before end of project. A final project report will also be prepared that communicates project outputs and outcomes. Phase 3 will also involve interaction with the Vashon Community Council, VMI Groundwater Protection Committee, and King County departments (PHSKC and DDES) to incorporate findings into nitrogen loading targets for QMH, policy change recommendations for nutrient management on VMI in the next (2012) update of the King County Comprehensive Plan.

3.2 Additional Project Activities

The following are activities that would be additions to the existing study. However, implementation of these activities will require additional funding or time commitments from collaborators or other potential partners.

Current Meter Deployments

Acoustic Doppler Current Profilers (ADCPs) would be used to determine the current vector fields in the channel between inner and outer Quartermaster Harbor. A bottom-mounted ADCP would be deployed for 30 days, and at supplemental sites as needed. Locations would be selected to resolve circulation questions and to provide model input. The first step in verifying that the hydrodynamic model is functioning is a comparison against tidal (water surface) elevations at known or estimated tide gauge stations.

It is unclear in early 2009 whether this activity can be incorporated into existing work (i.e. King County sampling within QMH). Having the data available during the receiving model calibration period will enhance the robustness of the model work.

Pressure Transducers

Two pressure transducers would be deployed simultaneously for a minimum of one month to measure tidal elevation in the inner and outer harbor for the purpose of confirming model tidal response. These tide gauges should be able to resolve the depth of the water column to within 1 (or 10) cm.

Other Activities

The items listed below have been discussed as optional activities. These activities need additional scoping as to the feasibility and timing within the existing study.

- Inter-laboratory Comparison Study
- Salinity Data comparison via SBE SealoggerCTD vs. YSI 6600 sonde
- Primary Productivity
- Marine Benthic Nutrient Flux Measurements
- Marine Macroalgae Biomass
- Assessment of Small Tributary and Marine Outfall Inputs
- Addition of TKN to UW-T program, addition of SRP to King Co. marine program

4.0. QUALITY OBJECTIVES

There are two types of quality objectives that need to be identified: Measurement Quality Objectives (MQOs) and Data Quality Objectives (DQOs). MQOs are "'acceptance criteria' for the quality attributes measured by project data quality indicators. They are quantitative measures of performance…" (USEPA, 2002). MQOs are the targets for precision, bias, and sensitivity against which QC results are compared. Precision is assessed from the results of replicate analyses of samples and standards. Bias is assessed from blanks and check standards and compared to their expected values. Sensitivity is related to the detection and reporting limits for the measurement method used. DQOs are needed in projects where the results are compared to a standard or used to select between two alternative conditions.

4.1 Measurement Quality Objectives

The Measurement Quality Objectives for the field and lab measurements are presented in Table 7. Field crews and the laboratories (King County Environmental Lab and UW Marine Chemistry Laboratory) are responsible for adherence to objectives. King County will be responsible for verifying all MQOs are met.

4.2 Laboratory Data Quality Objectives

The data quality objectives (DQOs) of this study are to collect data of sufficient quantity and quality to meet the study goals. Statistical analysis of data collected for this study will be performed to evaluate whether a sufficient quantity of data has been collected to meet the study goals. Data quality issues of precision, accuracy, bias, representativeness, completeness, comparability, and sensitivity are described below

The study goals are to characterize water concentrations of various constituents at different monitoring locations and depths and to evaluate any differences between sites and depths, either spatially or temporally. Statistical analysis of data that are "undetected"; i.e., laboratory analysis results reported as "<MDL", will use binomial calculations on the probability of a sample with a detectable concentration of the specific constituent and the probability of finding two and three samples in succession with detectable values at a given site or depth. Statistical analysis of data for those constituents that are detected regularly or occasionally will be accomplished through the use of medians and interquartile ranges.

Validation of project data will assess whether the data collected are of sufficient quality to meet the study goals. The data quality components of precision, accuracy, bias, representativeness, completeness and comparability are described in the following sections.

Table 7. Measurement Quality Objectives for field, mooring, and laboratory analyses.

Measurement		Precision (RSD*)	Bias (% deviation from true value	Lowest Value/Range of Interest
pH	field	0.05 SU	N/A	1 to 14 SU
Temperature	field	0.025 °C	0.05 °C	0.1 °C
Dissolved Oxygen	field	10%	5%	0.1 mg/L
Specific Conductance	field	10%	5%	1 µS/cm
Oxidation Reduction Potential (ORP)	field	10%	N/A	1 mV
Turbidity	field	5%	1%	0.01 NTU
Secchi Depth	field	0.5 m	N/A	N/A
Pressure	field	5%	1%	0.1 db
Density	field	10%	5%	0.1 σt
Chlorophyll Fluorescence	field	10%	5%	0.1 FU
Light Transmission	field	10%	5%	0.01%
Chlorophyll a	mooring	10%	N/A	0.1 FU
Dissolved Oxygen	mooring	5%	5%	0.05 mg/L
Nitrate+Nitrite N	mooring	10%	5%	1 mg/L
pH	mooring	0.05 SU	N/A	1 to 14 SU
Salinity	mooring	10%		0.1 psu
Specific Conductance	mooring	10%		10 µS/cm
Temperature	mooring	0.2 °C		0.1 °C
Turbidity	mooring	5%		0.01 NTU
Alkalinity	laboratory	10%	5%	1.0 mg/L
Ammonia Nitrogen	laboratory	20%	5%	0.02 mg/L
Nitrite + Nitrate Nitrogen	laboratory	20%	5%	0.01 mg/L
Total Kjeldahl Nitrogen	laboratory	20%	5%	0.1 mg/L
Total Nitrogen	laboratory	20%	5%	0.05 mg/L
Orthophosphate	laboratory	10%	5%	0.002 mg/L
Total Phosphorus	laboratory	10%	5%	0.005 mg/L
Silica	laboratory	10%	5%	0.05 mg/L
Total Suspended Solids	laboratory	25%	5%	0.5 mg/L
Fecal Coliform	laboratory	NA	NA	1 cfu/100mL
E. Coli	laboratory	NA	NA	1 cfu/100mL
Enterococcus	laboratory	NA	NA	1 cfu/100mL
Turbidity	laboratory	20%	5%	0.5 NTU
Salinity	laboratory	10%	5%	2 PSS
Chlorophyll-a	laboratory	25%	N/A	0.05 µg/L
Pheophytin-a	laboratory	50%	N/A	0.1 µg/L

*RSD (relative standard deviation) is calculated as the ratio of the standard deviation and the mean of several values

NA–Not Applicable.

4.2.1 Precision, Accuracy and Bias

Precision is the agreement of a set of results among themselves and is a measure of the ability to reproduce a result. Accuracy is an estimate of the difference between the true value and the determined mean value. The accuracy of a result is affected by both systematic and random errors. Bias is a measure of the difference, due to a systematic factor, between an analytical result and the true value of an analyte. Precision, accuracy, and bias for analytical chemistry may be evaluated by one or more of the following quality assurance/quality control (QA/QC) procedures:

- Collection and analysis of field replicate samples. Field replicate results should exhibit a relative percent difference less than 150% in order for the evaluation of the spatial and temporal chemical concentrations to be meaningful; and
- Analysis of various laboratory QC samples such as blanks, spikes, and replicates.

4.2.2 Representativeness

Representativeness expresses the degree to which sample data accurately and precisely represent a characteristic of a population, parameter variations at the sampling point or an environmental condition. Water samples will be collected from stations with predetermined coordinates and sampling depths to represent specific site conditions, both compared to other locations and at each location over time.

4.2.3 Completeness

Completeness is defined as the total number of samples analyzed for which acceptable analytical data are generated, compared to the total number of samples submitted for analysis. Sampling at stations with known position coordinates in favorable conditions, along with adherence to standardized sampling and testing protocols will aid in providing a complete set of data for this project. The goal for completeness is 100%. If 100% completeness is not achieved, the project team will evaluate if the data quality objectives can still be met or if additional samples may need to be collected and analyzed.

4.2.4 Comparability

Comparability is a qualitative parameter expressing the confidence with which one data set can be compared with another. This goal is achieved through using standard techniques to collect and analyze representative samples, along with standardized data validation and reporting procedures. By following the guidance of this QAPP, the goal of comparability between sampling events will be achieved. Historical water quality data from the study area may be compared with data generated from this study to enhance data analysis efforts. Previous data will be used if comparable sampling and analytical techniques were employed.

5.0. SAMPLING PROCEDURES

Sampling procedures for groundwater, streams, and marine water are described below.

5.1 Groundwater

The monitoring well locations will collect groundwater samples utilizing dedicated sampling equipment. These procedures are outlined in the Sammamish River Valley (SRV) Groundwater Study Sampling and Analysis Plan, (King County 2003a) except for the usage of dedicated sampling equipment. The long-term (LT) groundwater sites will have their samples collected following the protocols outlined in the Sampling and Analysis Plan for Vashon-Maury Island Groundwater Management Area (King County 2000). All samples will be processed within established holding times and stored refrigerated as necessary (Table 8).

5.2 Streams

Stream sampling in the creeks on Vashon-Maury Island will follow protocols used in the long-term program conducted for the King County Department of Natural Resources and Parks Streams Program as described their SOP/SAP (King County 2002). Field measurements (conductivity, temperature, pH, and dissolved oxygen) will be obtained with a field instrument operated and maintained as described in King County (2002). Samples will be processed within established holding times and stored frozen or refrigerated as necessary (Table 8).

5.3 Marine water

All sampling activities will be conducted to the regionally-accepted guidance found in the Puget Sound Estuary Program's (PSEP) Puget Sound Protocols (PSEP 1997, 1998).

Station Positioning

A precise method of station positioning is important for surveys in which sampling stations will be revisited multiple times. Water column sampling will not only assess spatial differences throughout Quartermaster Harbor but temporal differences at each station as well. In order to assess temporal changes in the water column, the station positioning must be as accurate as possible. Station positioning for the offshore stations will be accomplished using a shipboard Differential Global Positioning System (DGPS). Prior to each sampling event, the prescribed station coordinates will be loaded into a computer. During the sampling, the shipboard navigational system will utilize the differential data transmissions from regional Coast Guard base stations to automatically correct its GPS satellite data. The GPS antenna will be boom-mounted above the sampler descent line to achieve a more accurate coordinate fix above the sampling point. Previous DGPS usage indicates that an average precision of one to two meters can usually be obtained.

Table 8. Sample containers, preservation, and holding times for groundwater and surface water samples.

Analysis	Container	Preservation	Holding Time
Alkalinity	500mL HDPE,CWM	Refrigerate, <6°C	14 days
NH3, NO23, OrthoP	60mL HDPE, CWM	Field filter within 15 minutes and freeze @ -20°C	14 days @ -20°C
Total Phosphorus, Total Nitrogen	250mL HDPE, CWM	Refrigerate, <6°C and freeze within 2 days @ -20°C	28 days @-20°C
Total Suspended Solids	1-Liter HDPE, CWM	Refrigerate, <6°C	7 days
Fecal Coliform	500-ml HDPE, sterile	Refrigerate, <10 °C	24 hours
E. Coli	500-ml HDPE, sterile	Refrigerate, <10 °C	24 hours

Notes:

AWM–Amber wide mouth

CNM–Clear narrow mouth

CWM–Clear wide mouth

HDPE–High density polyethylene

5.3.1 King County

The PSEP protocols are used in the long-term program conducted for the Marine Monitoring Program and are described in King County (2003b).

Non-mooring marine water samples will be obtained with a modified Scott bottle. In situ measurements at non-mooring sites will be made using a Hydrolab and *in situ* measurements at the mooring locations will be collected with YSI 6600 EDS sondes.

Samples at Burton Acres (MSXK01) are collected at approximately knee-depth by inverting sample containers just above the water surface, then sinking the bottle down to approximately 12-inches below the water surface. The bottles are not filled completely in order to allow room for mixing.

All samples will be processed within established holding times and stored frozen or refrigerated as necessary (Table 9).

5.3.2 University of Washington–Tacoma

Secchi disk readings will be made at each station using a Secchi disk with 0.5 meter marks. The disk is lowered vertically in the water until it can no longer be seen with the naked eye. The maximum depth it can be lowered and still be seen is then recorded in meters.

Water column samples are obtained by Niskin bottle being lowered at each station to capture the water samples at various depths. A messenger was sent via a copper weight from the surface

Table 9. Sample Containers, preservation, and holding times for King County marine water samples.

Analysis	Container	Preservation	Holding Time
NH3, NO23	250mL HDPE, CWM	Filter within 1 day and freeze @ -20°C	14 days @ -20°C
Total Kjeldahl Nitrogen	250mL HDPE, CWM	H_2SO_4, refrigerate, <6°C	28 days
Total Phosphorus (collect together with NH3, NO23)	250mL HDPE, CWM	Refrigerate, <6°C and freeze within 2 days @ -20°C	28 days @-20°C
Silica (collect together with NH3, NO23)	250mL HDPE, CWM	Filter within 1 day, refrigerate, <6°C	28 days
Total Suspended Solids	1-Liter HDPE, CWM	Refrigerate, <6°C	7 days
Salinity	125mL HDPE, CNM	Refrigerate, <6°C	28 days
Chlorophyll-a	250mL HDPE, AWM	Refrigerate, <6°C, filter within one day of sample collection	Store filter in acetone, 28 days @ -20°C
Fecal Coliform	500-ml HDPE, sterile	Refrigerate, <10 °C	24 hours
E. Coli	500-ml HDPE, sterile	Refrigerate, <10 °C	24 hours
Enterococcus	500-ml HDPE, sterile	Refrigerate, <10 °C	24 hours

AWM–Amber wide mouth

CNM–Clear narrow mouth

CWM–Clear wide mouth

HDPE–High density polyethylene

that tells the bottle to trip at desired depths. The lids at the ends are snapped shut, capturing a water sample at the determined depths.

Phytoplankton tow samples will be collected using a 20 µm mesh net, horizontal net tow roughly 0.25 meter in diameter was used to collect phytoplankton samples at each station. Samples will be collected using a Niskin bottle, mentioned above in the "Water samples" section.

CTD (Conductivity, Temperature, and Depth recorder) instrument package will be utilized at each station. The device is lowered at each station roughly just a few meters above the bottom of the bay and samples were taken to obtain a depth profile. The CTD is set to collect data at 2

Table 10. Sample Containers, preservation, and holding times for UWT marine water samples.

Analysis	Container	Preservation	Holding Time
NH3, NO2, NO3	60mL HDPE, CNM	Filter within 1 day and freeze @ -20°C	28 days @ -20°C
Total Phosphorus, Total Nitrogen	60mL PP, CNM	Refrigerate, <6°C and freeze within 2 days @ -20°C	28 days @-20°C
Silicate	60mL HDPE, CNM	Filter within 1 day, refrigerate, <6°C	28 days
Chlorophyll-a	60mL HDPE, CNM	Refrigerate, <6°C, filter within one day of sample collection	Store filter in acetone, 28 days @ -20°C

CNM–Clear narrow mouth

HDPE–High density polyethylene

PP– Polypropylene

samples per second while the CTD was lowered at roughly the rate of 1 meter/second to obtain data at approximately ½ meter intervals that will be averaged into 1 meter bins.

All samples will be processed within established holding times and stored frozen or refrigerated as necessary (Table 10).

5.4 Chain-of-Custody

The objective of chain-of-custody (COC) procedures is to allow tracking of the possession and handling of individual samples from the time of field collection through laboratory analysis. Once a sample is collected, it becomes part of the COC process. A sample is "in custody" when: (1) it is in someone's direct possession; (2) it is within visual proximity of that person; (3) it is not in that person's direct possession, but locked up and sealed (e.g., during transport); or (4) it is in a designated secure sample storage area. Field or laboratory staff will complete a COC form, which will accompany each batch of samples as they are transported.

When sample custody is transferred to another individual, samples must be relinquished by the present custodian and received by the new custodian. This will be recorded at the bottom of the COC form where the persons involved will sign, date, and note the time of transfer.

Sampling team members will keep sample coolers in locked vehicles while not in active use or visual range. Samples are hand delivered to the laboratory for analyses.

6.0. MEASUREMENT PROCEDURES

6.1 Groundwater

6.1.1 Field Measurements

During all groundwater sampling events, field parameters–pH, temperature, conductivity, dissolved oxygen, oxidation reduction potential (ORP), and turbidity–will be taken to assess when sampling will occur. All field parameters except turbidity are measured with a QED (MP20) multi parameter probe. The turbidity is measured by a portable device made by the Hach Co. The methods and detections limits for the field measurements are presented in Table 11.

6.1.2 Laboratory Measurements

The groundwater sampling sites within the Quartermaster Harbor study area will be analyzed for the following water quality parameters: alkalinity, ammonia nitrogen, nitrate+nitrite nitrogen, total nitrogen, orthophosphate, total phosphorus, and total suspended solids (Table 2). The methods and detections limits for these parameters are presented in Table 11.

6.2 Streams

6.2.1 Field Measurements

During the collection of stream water samples, field parameters–pH, specific conductance, temperature, and dissolved oxygen–will be taken. These field parameters are measured with a Hydrolab multi parameter probe (KCEL SOP #205). The detection limits of these parameters are provided in Table 11.

6.2.2 Laboratory Measurements

The surface water sampling sites within the Quartermaster Harbor study area will be analyzed for the following water quality parameters: alkalinity, ammonia nitrogen, nitrate + nitrite nitrogen, total nitrogen, orthophosphate, total phosphorus, total suspended solids, fecal coliform and *Escherichia coli* (Table 2). This list of parameters is the same as the groundwater sites except for fecal coliform and *E. coli*. The methods and detections limits for these parameters are presented in Table 11.

6.2.3 Stream Flow Measurements

The stream flow measurements will use a SOP for continuous measurement of discharge developed by King County to meet NPDES monitoring requirements. (**http://green.kingcounty.gov/wlr/waterres/hydrology/NPDES-SOP.doc**). The methods closely follow guidance provided by WDOE (Butkus 2005; http://www.ecy.wa.gov/pubs/0503204.pdf).

Table 11. Water Quality Parameter Method and detection limits for groundwater and stream sampling sites.

Parameters		Method	Detection Limit
Alkalinity	Laboratory	SM 2320-B	1 mg CaCo3/L
Ammonia Nitrogen		SM 4500–NH3-G	0.01 mg/L
Nitrite + Nitrate Nitrogen		SM 4500–NO3-F	0.01 mg/L
Total Nitrogen		SM 4500–N-C	0.05 mg/L
Ortho-Phosphate		SM 4500–P-F	0.002 mg/L
Total Phosphorus		SM 4500–P-B,F	0.005 mg/L
Total Suspended Solids		SM 2540-D	0.5 mg/L
Fecal Coliform		SM 9222D	1 CFU/100ml
E. Coli		SM 9213D	1 CFU/100ml
Dissolved Oxygen	Field	EPA 360.2	0.5 mg/L
Temperature		EPA 170.1	0.1 deg C
Specific Conductance		EPA 120.1	0.5 µmhos/cm
pH		EPA 150.1	0.1
ORP		EPA 150.1 mod.	0.1 mV
Turbidity		EPA 180.1	0.1 NTU

This SOP applies to the collection of continuous discharge data at monitoring sites on streams. It describes equipment and site selection factors, installation, operation, and field measurement techniques. A continuous flow monitoring station is commonly called a stream gauge or gauging station.

Continuous flow monitoring generally involves using electronic equipment to measure and record water level in a stream or other conveyance. A programmable data logger operates a water level sensor and records measured values at time increments. The data logger may process the measured values and signal other devices. A relationship between the water surface elevation and the flow rate (stage-discharge relationship) is developed using various generally accepted techniques. The stage-discharge relationship represents the sum of the various forces that make water move or resist movement, primarily gravity and channel friction. It is expressed as an array or a mathematical function. Continuous stream flow is calculated by using the stage-discharge relationship to match a specific water level with a corresponding rate of flow. In certain situations, equipment that measures water velocity as well as water level can be used to determine flow rate. The automatically calculated flow rate may be adequate for producing flow weighted composite samples, but post processing is usually necessary to produce an accurate flow record and may involve using velocity as an index of flow.

The procedures and tasks involved with a stream gage are designed to accurately measure and record water level and determine the stage-discharge relationship at the site.

6.3 King County Marine water

6.3.1 Field Measurements

During the collection of marine water samples, field parameters temperature, pH, salinity, and dissolved oxygen will be taken. These field parameters are measured with a Hydrolab multi parameter probe (SOP #205). The detection limits of these parameters are provided in Table 12.

6.3.2 Laboratory Measurements

The marine water sampling sites within the Quartermaster Harbor study area will be analyzed for the following water quality parameters: ammonia nitrogen, nitrate + nitrite nitrogen, total Kjeldahl nitrogen, total phosphorus, total suspended solids, silica, salinity, chlorophyll-a, pheophytin-a, fecal coliform and *Enterococcus* (Table 4). The methods and detections limits for these parameters are presented in Table 12.

6.4 UWT Marine Water

6.4.1 Field Measurements

A Seabird 19 CTD will be used to collect profiles of conductivity (calculate Salinity), temperature, pressure (calculate depth), calculate density (sigma-t), DO, fluorescence and transmissivity at each of the 7 UWT sampling stations in conjunction with discrete water sampling (Figure 13).

Secchi disk readings will be made at each station using a Secchi disk with 0.5 meter marks. The disk is lowered vertically in the water until it can no longer be seen with the naked eye. The maximum depth it can be lowered and still be seen is then recorded in meters.

Water column samples are obtained by Niskin bottle being lowered at each station to capture the water samples at various depths. A messenger was sent via a copper weight from the surface that tells the bottle to trip at desired depths. The lids at the ends are snapped shut, capturing a water sample at the determined depths.

Phytoplankton tow samples will be collected using a 20µm mesh net, horizontal net tow roughly ½ meter in diameter was used to collect phytoplankton samples at each station. Samples were collected using a Niskin bottle, mentioned above in the "Water samples" section.

Table 12. Water quality parameter method and detection limits for King County marine monitoring sites.

Parameters		Method	Detection Limit
Ammonia Nitrogen	Laboratory	SM4500-NH3-G	0.01 mg/L
Nitrite + Nitrate Nitrogen	Laboratory	SM4500-N03-F	0.01 mg/L
Total Kjeldahl Nitrogen	Laboratory	EPA 351.2	0.1 mg/L
Total Phosphorus	Laboratory	SM4500-P-B,F	0.005 mg/L
Silica	Laboratory	Whitledge 1981	0.05 mg/L
Total Suspended Solids	Laboratory	SM2540-D	0.5 mg/L
Fecal Coliform	Laboratory	SM9222-D	1 CFU/100ml
Enterococcus	Laboratory	SM9230-C	1 CFU/100ml
Salinity	Laboratory	SM2520-B	2 PSS
Chlorophyll-a	Laboratory	EPA 445.0	0.05 µg/L
Pheophytin-a	Laboratory	EPA 445.0	0.1 µg/L
Dissolved Oxygen	Field Vessel	SBE SealoggerCTD	0.5 mg/L
Temperature	Field Vessel	SBE SealoggerCTD	0.01 deg C
Salinity	Field Vessel	SBE SealoggerCTD	0.01 PSS
Secchi depth	Field Vessel	Secchi disk	NA
Turbidity	Field Vessel	SBE SealoggerCTD	0.5 FTU
Dissolved Oxygen	Field	KC SOP 205v4	0.5 mg/L
Temperature	Field	KC SOP 205v4	0.1 deg C
Chlorophyll	Continuous	SM*	0.1 µg/L
Dissolved Oxygen	Continuous	SM*	0.01 mg/L
pH	Continuous	SM*	0.1
Salinity	Continuous	SM*	0.01 PSS
Specific Conductance	Continuous	SM*	0.1 mS/cm
Temperature	Continuous	SM*	0.01 deg C
Turbidity	Continuous	SM*	0.1 NTU

Nitrate		SM*	0.1 mg/L

"SM*" refers to Standard Methods per YSI performance specification data sheet.

6.4.2 Laboratory Measurements

The water sampling sites within the Quartermaster Harbor study area will be analyzed for the following water quality parameters: for DO, chlorophyll, ammonia, nitrate, nitrite, phosphate, and silicate (Table 4). Note; UWT will also be collecting phytoplankton samples. The methods and detections limits for these parameters are presented in Table 13.

Table 13. Measurement methods and reporting limits for UWT marine data.

Analyte	Analytical Method	Reporting Limit
Dissolved oxygen	Carpenter, 1966	0.01 mg/L
Marine Nitrate	Armstrong et al., 1967	0.15 µM
Marine Nitrite	Armstrong et al., 1967	0.01 µM
Marine Ammonium	Slawyk and MacIsaac, 1972	0.05 µM
Marine Orthophosphate	Bernhardt and Wilhelms, 1967	0.02 µM
Marine Silicate	Armstrong et al., 1967	0.21 µM
Chlorophyll a	EPA, 1977	0.01 mg/L

7.0. QUALITY ASSURANCE AND CONTROL

Quality assurance and control will be provided by project manager oversight, project staff training, and adherence to a combination of laboratory and field standard operating procedures referenced previously.

For measurements involving KCEL-deployed meters, maintenance schedules, calibration schedules, and deployment, instructions will be followed for all meters and sensors. UWT instruments will be calibrated annually. For stream flow, only specially trained and qualified gauging technicians will install, maintain, and extract data from gages. Gauging technicians will maintain and calibrate according to procedures to provide high quality data and gauging technicians or project staff will periodically (about every two weeks at minimum) visit the gauge site to ensure proper working condition. All data are reviewed, rated for accuracy, and approved by a county gauging supervisor before being submitted as a final product.

7.1 Field QC Procedures

Field QC includes proper documentation of field activities and sampling/handling procedures, as described in Sections 5 and 6.

7.1.1 Field QC Samples

Field QC samples will consist of the following:

- One replicate per 20 samples, to be analyzed for the entire suite of laboratory analyses.
- One filtration blank per sampling day, to be analyzed for all filtered parameters (Ammonia, Nitrate+Nitrite and Ortho-Phosphate).
- Field equipment blank for groundwater samples collected by pump, one per sampling day for all lab parameters.

7.1.2 Calibration and Use of Meters

Before use, field equipment must be cleaned and checked for malfunctions. Meters must be calibrated each morning before use in the field, following manufacturers' procedures. Other field equipment will be calibrated at least daily. All field monitoring equipment will be calibrated consistent with manufacturers' procedures using instrument calibration standards prepared according to the manufacture's specifications. In all cases, proper documentation of all calibration procedures must be completed for each sampling event, including calibration methodology (one- or two-point calibration, difference, standard concentration, and expiration date).

Logbooks should be maintained for all field meters. The logbooks must contain the same information as those for permanent laboratory instruments (serial number, name, and model of meter, year purchased, etc.). The books also must contain QC results, maintenance performed by the factory, and calibration notes for each day the equipment is used. Instruments used to measure pH, dissolved oxygen and electrical conductivity should be calibrated at least once each day of sampling. Temperature-measuring devices should be calibrated against a standardized laboratory thermometer at a frequency recommended by the manufacturer. Field instruments used to measure other parameters, e.g., turbidity, should be calibrated in accordance with manufacturer recommendations and documented.

7.1.3 Replicate Samples

Field replicates are used to evaluate consistency of field measurements, sample collection procedures and analytical results from a given sample point. Replicate samples are collected in the field using a matching set of laboratory-supplied bottles and sampling from the selected well, as requested. Each replicate will be sampled after the initial sample has been taken, repeating the process for sample collection. The source where the replicate is collected must be identified on the field sampling data sheet. Once a replicate is collected, it is handled and shipped in the same manner as the rest of the samples. Replicate results will be reported by the laboratory as separate samples.

7.1.4 Field Blanks

Field blanks are used to detect contamination that may be introduced in the field or from the sampling equipment. Field equipment blanks will be prepared in the field by pumping laboratory reagent-quality water through new or pre-cleaned tubing and into the field equipment blank bottles. The well at which the equipment blank is prepared must be identified on the field sampling data sheet. Field blank results will be reported in the laboratory results as separate samples. The field filtration blank for dissolved nutrients will be collected by filtering a portion of lab reagent water through a clean filter into the field filtration bottle.

7.2 Lab QC requirements

In general and at minimum, laboratory QC will consist of the following:

- One matrix spike (MS) per 20 samples
- One matrix spike duplicate (MSD) or lab duplicate (LD) per 20 samples

Method-specific QA/QC samples may include the following, and are discussed as follows:

- Method blanks. A method blank is an aliquot of a clean reference matrix, such as deionized, distilled water for water samples, which is processed through the entire analytical procedure. Method blank results are used to evaluate the levels of contamination that might be associated with the processing and analysis of samples. Method blank results should be "less than the MDL" for all target analytes.

- Matrix spike samples. A matrix spike (MS) is a known concentration of one or more target analytes, introduced into a second aliquot from one analytical sample. The spiked sample is processed through the entire analytical procedure. Analysis of the MS is used as an indicator of sample matrix effect on the recovery of target analytes. Control limits are based on the percent recovery of the spiked compounds.
- Matrix spike duplicate and lab duplicate samples. A matrix spike duplicate (MSD) is a known concentration (same as the MS) of target analytes, which is introduced into a third aliquot of the same analytical sample. The spiked sample is processed through the entire analytical procedure. Analysis of the MSD is used as an indicator of sample matrix effect on the recovery of target analytes as well as method precision. The relative percent difference (RPD) between the MS and MSD results is calculated; however, control limits are not maintained. The RPD for MS/MSD results is, instead, reviewed during the data validation and analysis process to evaluate potential data quality issues arising from questions of analytical precision. A lab duplicate (LD) is a second aliquot removed from one analytical sample, processed through the entire analytical procedure as a separate sample. The RPD between the original sample and the LD is used as an indicator of method precision and sample homogeneity.
- Spiked blank samples. A spiked blank (SB) is an aliquot of clean reference matrix, such as deionized distilled water for water samples, to which a known concentration of one or more target analytes has been added. The spiked aliquot is processed through the entire analytical procedure. SB analysis is used as an indicator of method performance and can be used in conjunction with matrix spike results as an indicator of sample matrix effects. Control limits are based on the percent recovery of the spiked compounds.
- Laboratory control samples.. A laboratory control sample (LCS) is a sample of known analyte concentration(s) that is prepared in the lab from a separate source of analyte(s) relative to the calibration standards. Since the LCS analysis should follow the entire analytical process, it should be stored and prepared following the same procedures as a field sample. Analysis of a LCS is used as an indicator of method accuracy and long-term analytical precision.
- Performance evaluation samples. KCEL participates twice annually in the WP and annually in WS Performance Evaluation programs. PE samples are single-blind samples supplied to the lab through vendors approved by the Washington DOE Lab Accreditation Program.

QC sample results that exceed control limits will be evaluated to determine appropriate corrective actions. Samples will typically be reanalyzed if unacceptable QC results indicate a systematic problem with the overall analysis. Unacceptable QC results caused by a particular sample or matrix will not require reanalysis unless an allowed method modification would improve the results. Analytical results that are outside of QC control limits for some QC sample types will be qualified and flagged according to procedures outlined in Section 7.2.3.

7.2.1 Conventionals QC Parameters

Laboratory QC samples for conventionals analyses and associated control limits are summarized in Table 14. These QC samples will be analyzed at a frequency of one per analytical batch of 20 or fewer samples.

Table 14. Laboratory Conventionals QC Requirements

Analysis	Method Blank	Duplicate RPD (%)	Positive Control % Recovery	Matrix Spike % Recovery
Ammonia as Nitrogen	<MDL	20	85-115	75-125
Nitrate+Nitrite as Nitrogen	<MDL	20	85-115	75-125
Orthophosphate as Phosphorus	<MDL	20	85-115	75-125
Silica as Silicate	<MDL	20	85-115	65-120
Total Nitrogen	<MDL	20	85-115	75-125
Total Phosphorus	<MDL	20	85-115	75-125
Total Suspended Solids (TSS)	<MDL	25	80-120	NA
Alkalinity	NA	10	85-115	NA
Salinity	NA	0.05	99.8-100.2	NA
Chlorophyll-a	<MDL:	25	90-110	NA
Pheophytin-a	<MDL	50	NA	NA
Total Kjeldahl Nitrogen (TKN)	<MDL	20	80-120	70-130

RPD = Relative Percent Difference

7.2.2 Microbiology QC Parameters

Laboratory QC samples for microbiology analyses and associated control limits are summarized in Table 15. These QC samples will be analyzed at a frequency of one per analytical batch, or a minimum of one per 20 analytical samples.

Table 15. Laboratory Microbiology QC Requirements

Analysis	Lab Duplicate	Positive Control	Negative Control	System Control	Pre/Post Filtration Blanks
Fecal coliform	As determined by SM 9020B	*E. coli* (ATCC 25922)	*Enterobacter aerogenes* (ATCC 13048)	No Growth of target organisms	No Growth
E. coli	As determined by SM 9020B	*E. coli* (ATCC 25922)	*Proteus vulgaris* (ATCC 13315)	No Growth of target organisms	No Growth

7.2.3 Laboratory Data Review and Analysis

Data evaluation will include checking holding times, method blank results, surrogate recovery results, field and laboratory duplicate results, completeness, detection limits, laboratory control sample results and COC forms. After the data has been checked, it may be entered into a project database with any assigned data qualifiers. Data evaluation is critical for evaluating how well analytical data meet project DQOs, and is performed, at some level, during several steps in the process of sample collection and analysis.

All analytical data are entered into KCEL's Laboratory Information Management System (LIMS). LIMS may perform additional calculations such as conversion of concentrations measured directly by laboratory instrumentation to final sample results. Automatic calculation of QC results is also performed within LIMS, as well as comparison to acceptance limits.

Laboratory analytical data are reviewed first by the primary analyst and then by a senior peer reviewer prior to entry of the data into LIMS. Analytical data are reviewed for completeness and QC sample data are viewed for compliance with project and method QA/QC requirements. If there are any QC failures at this point, corrective action may be taken or qualifier flags applied to the data.

A laboratory project manager (LPM) will provide the next data review step, at a project level. The LPM will verify the completeness of an entire data set (multiple parameters for a particular sampling event) and report any QC failures or anomalies. An internal King County project data validator may provide a final review of the data to ensure they meet the project DQOs. Data may then be reported in a variety of formats, depending on project needs.

All laboratory analytical data are maintained *in perpetuity* on LIMS. Data may be viewed on-line in LIMS by King County personnel only. Project data may also be downloaded from LIMS into a hard copy format using Microsoft Excel®. Analytical data will be reported on a routine basis in Excel® format along with an accompanying QA/QC review narrative.

Laboratory analytical data may be stored with data qualifier flags indicating QC failures. The flag "B" is used to indicate possible laboratory contamination of a sample and is applied when the parameter of interest is also detected in the laboratory method blank. Sample results that are less than five times the concentration detected in the method blank will be qualified with a "B" flag. Sample results between five and ten times the concentration detected in the method blank will be qualified with a "B3" flag. The flag "SH" is used to indicate a sample handling condition that did not meet method requirements. Handling conditions may include an improper sample container, improper preservation of the sample. The H flag will be applied when there is an exceedance of the method-specific holding time. The flag "J" may be applied to sample data at the discretion of the laboratory analyst, data reviewer, or data analyst, should control limits on one or more QC samples not be met. The flag "J" indicates that sample numerical result should be viewed as *estimated*.

Analytical results from field blanks and field replicates will be reviewed to evaluate their impact on the quality and usability of sample analytical data. Results from field QC samples will not be used to flag sample analytical data but will be taken into consideration during final data review and analysis.

8.0. DATA MANAGEMENT PROCEDURES

Except where noted otherwise, all field data and associated observations will be recorded on standardized field sheets (physical or electronic) as described above (see Sampling Procedures) and entered or transferred into one of several King County databases in a timely manner, generally within one week of collection. King County laboratory and field data will be stored in the King County Laboratory Information Management System. Stream gauging and continuous temperature data will be stored in King County's Hydrologic Information Center database. Additionally, a new database will be developed to store King County marine mooring data. Data collected by UW-T will be transferred in electronic format to King County on a quarterly basis and transferred to a database developed for this project data set.

The Project Manager will provide supervision of all data acquisition and management activities. The Data Management Section will maintain the project database and load data. KCEL staff will provide all data from sondes it deploys. Project staff will enter all other data manually or download from electronic files.

9.0. AUDITS AND REPORTS

As per the EPA's contract requirements, semiannual project reports will be provided to the EPA by the Project Manager. The report will include a description of project activities and status including an overview of data collected, field and data problems encountered and solutions applied, and changes in schedule, measurements, database, and analysis. If needed, the EPA may conduct a Quality System Review on management and technical aspects of the project.

9.1 Annual Addendum of QAPP

This document will be reviewed and updated annually with addendums of new special studies or updates to existing activities. Annual addendums will follow existing approval process with EPA staff, project managers and QA staff. Distribution of annual addendums will be the same as the initial list along with any additional staff as necessary.

10.0. DATA VALIDATION

Data validation is critical in the evaluation of how well analytical and field data meet project DQOs. All analytical data and most field measurements are entered into King County's Laboratory Information Management System (LIMS).

Field data, such as in situ data measurements or recorded environmental observations, are peer reviewed prior to entry into LIMS. Laboratory analytical data are reviewed, first by the primary analyst and then by a peer reviewer, prior to entry of the data into LIMS. Analytical data are peer reviewed for completeness and QC sample data are viewed for compliance with project and method QA/QC requirements.

Quality control results that exceed the acceptance limits will be evaluated to determine appropriate corrective actions. Samples will typically be reanalyzed if the unacceptable QC results indicate a systematic problem with the overall analysis. Unacceptable QC results caused by a particular sample or matrix will not require reanalysis unless an allowed method modification would improve the results.

11.0.DATA ANALYSIS AND USE

Data quality will be evaluated against the objectives set in this document for precision. The data will also be evaluated for obvious errors, such as incorrect units. The sum of dissolved constituents will be compared to the value found for the total constituent. The data will also be evaluated against the objectives set for representativeness and completeness.

The usability of the data will be confirmed by using it in the model and showing relationships between dissolved oxygen, nitrogen, and land use activities/best management practices.

11.1 Existing Data

Not specific quality objectives are being specified for existing data or modeling results at this time. However, data from existing repositories will be used for evaluation and modeling purposes and the following acceptance criteria will be applied:

- *Data Reasonableness* - Data quality of existing data will be evaluated where possible. Best professional judgment will be used to identify erroneous or outlier data and these observations will be removed from the data set.

- *Data Representativeness*–Data will be used that are reasonably complete and representative of the location or time period under consideration. Incomplete data sets will be used if they are considered representative of the conditions during the period of interest. Data from outside the period of interest will be used only if no other data are available. In this case, best professional judgment will be used to determine the utility of the available data.

- *Data Comparability*–Long-term water quality monitoring programs often collect, handle, preserve, and analyze samples using methodologies that evolve over time. Best professional judgment will be used to determine whether/if data sets can be compared. The final project report will detail any caveats or assumptions that were made when using data collected with differing sampling or analysis techniques.

Previous routine data collected by King County and UW-T in Quartermaster Harbor and by King County in Vashon-Maury Island streams and groundwater are the primary existing data that will be used in this study. The list below identifies these studies and additional repositories that contain existing data that will be used in this project. However, additional sources of information may be considered as needed and/or as new sources are identified.

11.1.1 King County Puget Sound Monitoring Data

King County's Marine and Sediment Assessment Group support a comprehensive, long-term marine monitoring program that assesses water quality in Central Puget Sound. Their program consists of offshore water quality, beach water quality, intertidal sediment, algae, and clam monitoring.

URL: http://green.kingcounty.gov/marine/index.htm

11.1.2 King County Vashon-Maury Island Water Resources Evaluation Data

King County's Water Resources Evaluation has collected freshwater surface and groundwater data on Vashon-Maury Island since 2001.

URL: http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/vashon-island/project-documents.aspx

11.1.3 Ecology Marine Waters Monitoring Data

The Department of Ecology has monitored water quality at approximately 40 stations within Puget Sound on a monthly basis since 1975. Some stations have been monitored every year, while some are monitored on a rotating schedule. Ecology stations in Quartermaster Harbor have been monitored on a rotating schedule.

URL: http://www.ecy.wa.gov/programs/eap/mar_wat/mwm_intr.html

Ecology has been conducting a water quality study focused on low DO levels in South Puget Sound. Field surveys occurred from 1994-2007.

URL: http://www.ecy.wa.gov/puget_sound/dissolved_oxygen_study.html

11.2 Reconciliation with User Requirements

This project seeks to identify the sources and quantify the amount of nitrogen entering Quartermaster Harbor from these sources [list]. Furthermore, through modeling and additional special studies, the goal of this project is the development of an understanding of how phytoplankton and oxygen concentrations in the harbor respond to current nitrogen loading. If the study determines that the harbor oxygen concentrations are sensitive to nitrogen loading, various nitrogen management strategies will be evaluated using the developed models. Ultimately, the project goal is to identify feasible strategies for nitrogen management on Vashon-Maury Island and provide recommendations to implement those strategies via policy, regulation or programmatic actions, as input to the update of the 2012 King County Comprehensive Plan.

Reports generated for this project will include identification of any data limitations determined through application of the Data Quality Objectives described in this project plan. This information will be communicated initially through annual project reports and will be mirrored in subsequent project reports that rely on data with known limitations, including, but not limited to, modeling reports and reports containing recommended updates to decision makers that update the King County Comprehensive Plan.

12.0. ORGANIZATION AND SCHEDULE

12.1 Project Staff list and roles

The project involves staff from King County Departments of Natural Resources and Parks (DNRP, including the King County Environmental Lab, KCEL) in collaboration with the UWT Environmental Science program, Washington Dept. of Ecology's Marine Monitoring Unit and the Vashon-Maury Island Groundwater Protection Committee. Detailed roles and responsibilities are:

Core Project Team:

Curtis DeGasperi–King County DNRP - Project Manager - responsible for: (1) supervising project implementation; (2) coordinating and tracking work, budgets and personnel; (3) preparing and presenting presentations and written reports; and team member for all surface water activities. Curtis will also assist with the selection and development of watershed and QMH water quality models.

Eric Ferguson–King County DNRP–Core Team Member–Lead team member for all groundwater related activities; developing and implementing project database and assist project manager as directed in all facets of project implementation. Conduct groundwater monitoring field work and deliver samples to KCEL for laboratory analysis.

Kimberle Stark–King County DNRP–Core Team Member - Lead team member for all marine water related activities.

Laurence Stockton–King County DNRP–Core Team Member–Lead team member in the development of policy and management recommendations and public outreach and communication activities.

Extended Project Team:

King County Environmental Laboratory (KCEL)–Deploy and maintain King County marine moorings and associated meteorological stations and conduct King County monthly marine ambient monitoring at QMH sub-tidal and inter-tidal stations.

King County Environmental Laboratory (KCEL)–Conduct King County monthly stream water quality monitoring on VMI and deliver samples to KCEL for laboratory analysis.

King County DNRP Hydrologic Monitoring Support–Maintain stream gauges and continuous temperature monitoring equipment as well as land-based precipitation and meteorological observation stations on VMI.

Cooperators:

Dr. Cheryl Greengrove–University of Washington -Tacoma–Dr. Greengrove and her staff and students will provide oceanographic instrumentation, scientific expertise, and conduct marine sampling activities in QMH to augment existing data sets and fill data gaps for nutrient and dissolved oxygen for model ground truthing and assist in presenting results at scientific meetings, in reports and papers.

Skip Albertson - Washington Department of Ecology (Ecology) - Ecology staff will assist with model selection and develop model selected to simulate the hydrodynamics of QMH. Skip will also collaborate on the coupling of the modeled hydrodynamics into the model selected and developed to simulate the effects of N-loadings on dissolved oxygen within QMH in current and BMP scenario conditions.

Vashon-Maury Island Groundwater Protection Committee (GWPC)–Committee members will facilitate public outreach on VMI, assist in developing Best Management Practices and policy recommendations.

12.2 Major Activities and Timelines

Table 16 outlines the major project activities and timelines. This project has three major phases as well as ongoing activities that will occur every year of the study. Phase 1 activities scheduled for 2009 is highlighted by the estimation of the nitrate load from various potential sources using existing data and published literature values and by preliminary water quality sampling of streams, groundwater, and marine waters. Additional activities will be focused in completing work elements that outline activities in the next phase. Phase 2 scheduled for 2010-2011 has a variety of activities that build upon the results of Phase 1.

Table 16. Quartermaster Harbor Nitrogen Management Study Activities.

Ongoing activities	Timeline	Organization	Description
Groundwater monitoring	2009 - 2012	King County	Annual water quality monitoring at 14 wells
Surface water monitoring	2009 - 2012	King County	Monthly water quality monitoring at 4 sites
Marine harbor monitoring	2009 - 2012	King County	Monthly water quality monitoring at 2 sites (dock based) and 1 beach site
	2009 - 2010	King County	Continuous monitoring via buoy within Quartermaster harbor
	2009 - 2012	U of Washington - Tacoma	Monthly water quality monitoring at 7 sites (vessel based) and 1 mooring
Annual Water Quality report	2009 - 2012	King County - Lead	Assess water quality using existing and newly collected data for surface, ground and marine waters
Presentations	2009-2012	All	Annual presentations to relevant conferences
Education & Outreach Forum	2009 - 2012	King County - Lead	Develop a forum to involve partners and interested parties in study planning and implementation–includes public meetings, news outlets, and web page development.
Phase 1 activities	**Timeline**	**Organization**	**Description**
Project QAPP document	2009	All	Write and approve an overall Project Quality Assurance Project Plan (QAPP)
Modeling QAPP document	2009	All	Write and approve an Modeling Quality Assurance Project Plan (QAPP) that includes documentation of models selected for use in this study
Nutrient loadings report	2009	King County - Lead	Estimate seasonal and annual loadings of nutrients from various sources based on existing data and published literature information. Report results.
Monitoring plan–OSS Study	2009	King County - Lead	Write a Sampling and Analysis plan for the On-Site Septic system assessment work - Phase 2 work
Monitoring plan–Stable Isotope Study	2009	King County - Lead	Write a Sampling and Analysis plan for the Stable Isotope assessment work - Phase 2 work

Ongoing activities	**Timeline**	**Organization**	**Description**
Phase 2 activities	**Timeline**	**Organization**	**Description**
Phase 1 Progress Report	2009	All	Draft and final report that describes Phase 1 activities, accomplishments, and outstanding issues.
Project QAPP update	2010	King County	Update Project QAPP based on experience and information collected and analyzed during first year of project
Watershed modeling	2010-2011	King County	Develop selected surface-groundwater model of the contributing basins to QMH, assess the loading and transport of nitrate using both existing information and newly collected data;
Marine modeling	2010-2011	Ecology/King County	Develop selected marine hydrodynamic and water quality model of QMH
OSS study	2010-2011	King County	Actively monitor OSS study sites
Stable Isotope sampling	2010-2011	King County	Use stable isotope data collected at sources, flowpaths, and receiving waters to refine the nitrate loading estimated
Phase 3 activities	**Timeline**	**Organization**	**Description**
Nitrogen management scenarios	2012	King County /Ecology	Develop set of nitrogen management scenarios. Estimate effectiveness of various nitrogen management scenarios using models.
Modeling report	2012	King County /Ecology	Write report of modeling work completed as part of QMH Nitrogen management study
Water Quality Report	2012	All	Write report of summarizing/analyzing the water quality component of the QMH Nitrogen management study
OSS study report	2012	King County	Write report on the findings of this special study as a part of the QMH Nitrogen management study
Make policy recommendations	2012	King County	Based on project findings, make recommendations to changes in King County Comprehensive Plan
Submit project data to STORET/WQX	2012	King County	Load project data into STORET or WQX

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