Quartermaster Harbor Benthic Flux Study

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King County

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Quartermaster Harbor Benthic Flux Study

Prepared for:

U.S. EPA West Coast Estuaries Initiative Grant
Quartermaster Harbor Nitrogen Management Study

Submitted by:

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Acknowledgements

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Citation

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EXECUTIVE SUMMARY

This report is part of the Quartermaster Harbor Nitrogen Management Study funded in part by a West Coast Estuaries Initiative grant from Region 10 of the U.S. Environmental Protection Agency. The report documents the results of an *in situ* study of nutrient fluxes from sediments in Quartermaster Harbor. Quartermaster Harbor is a shallow estuarine embayment on Vashon-Maury Island in Puget Sound that experiences low dissolved oxygen concentrations during late summer/fall that fall below the applicable state water quality standard. The likely cause of these low oxygen levels is the growth and subsequent die-off of phytoplankton that consume dissolved oxygen in the water column and sediments as they decompose and settle to the bottom.

Field work to measure *in situ* benthic oxygen demand and nutrient flux was conducted on September 1 and 2 of 2010 at five stations in Quartermaster Harbor. The results were similar to the range of results reported by a recent study conducted in four South Puget Sound embayments that used the same equipment and methods. There was a distinct gradient in the results with the greatest sediment oxygen demand and nutrient flux observed at the shallowest location in the inner harbor. Lowest nutrient release was estimated for the two deepest stations in the outer harbor. The flux estimates provided by this study will provide site-specific data for the development and testing of a water quality model of the harbor and also provide data to refine the initial estimate of sediment nutrient loading to the harbor.

Because sediments may provide a long-term reservoir (i.e., internal source) of nitrogen for phytoplankton growth that could delay the response of the harbor to management activities designed to reduce nitrogen loading from terrestrial sources, additional studies of sediment nutrient flux may be warranted. If so, it is recommended that the range of available methods be evaluated to identify a method (or methods) that is the most reliable, repeatable and cost effective. For example, laboratory bench systems have the potential to provide more control over experimental conditions, be logistically more convenient and potentially less expensive while still providing results that are comparable to *in situ* flux chamber or pore water profiling studies.

1.0. INTRODUCTION

In 2008, Region 10 of the United States Environmental Protection Agency (EPA) awarded King County a West Coast Estuaries Initiative (WEI) grant to conduct the Quartermaster Harbor Nitrogen Management Study, which is funded through the end of 2012. The goal of this study is to support the protection and restoration of Quartermaster Harbor–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) and the Washington Department of Ecology (Ecology). This project supports the enhancement of aquatic resource protection in an area threatened by population growth pressures. This report describes the benthic flux study conducted as part of the Quartermaster Harbor Nitrogen Management Study (King County 2009a).

1.1 Project Overview

Dissolved oxygen levels below the Washington State marine water quality standard (Washington Administrative Code 173-201A) have been observed in Quartermaster Harbor over the last five years by King County (Figure 1). Oxygen concentrations are typically lowest in September or October. Dissolved oxygen is essential for fish and other marine life - when levels fall below critical thresholds marine life can become stressed or killed or forced to escape to more oxygenated waters if possible. Low dissolved oxygen levels and the occurrence of nitrate nitrogen in VMI groundwater and streams, combined with the high habitat value of Quartermaster Harbor and ongoing population growth, make this project a high priority for King County.

Quartermaster Harbor was one of 19 areas of Puget Sound judged to be relatively sensitive to anthropogenic nutrient inputs (Rensel Associates and PTI 1991). Nitrogen and phosphorus are essential nutrients for marine plants and phytoplankton. Excess nutrients, nitrogen compounds in particular, can lead to excessive phytoplankton and algae growth which can deplete oxygen concentrations when the algae die and are decomposed by bacteria in the water column and sediments (Figure 2). 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).

The interactions between nitrate, algal biomass and dissolved oxygen in inner Quartermaster Harbor are illustrated in Figure 3. Algal biomass generally peaks during spring and summer, which coincides with a reduction of nitrate concentrations to below the limit of laboratory detection as a result of algal uptake and growth. The minimum oxygen concentrations observed in late summer and fall are associated with the final decline in the summer peaks in algal biomass. These data provide evidence that phytoplankton growth in the harbor is limited by nitrogen and that additional inputs of nitrogen have the potential to fuel additional algal growth, causing even lower oxygen levels when the algae die and are decomposed in the water column and sediments.

A recent study conducted by Ecology to support the development of a water quality model of South Puget Sound found that nutrient fluxes from marine sediments of shallow embayments may be a significant source of nitrogen to marine waters during the critical period of low dissolved oxygen (Roberts et al. 2008). Based on the data provided in Roberts et al. (2008), the marine sediments of Quartermaster Harbor may also be a relatively significant source of nutrients to Quartermaster Harbor during the critical period of low dissolved oxygen (King County 2009a). King County (2009a) recommended conducting a benthic nutrient flux study in Quartermaster Harbor to confirm the rates measured in other shallow embayments of Puget Sound and provide site-specific data for use in the development of the marine water quality model of the harbor.

Generally, the predictive reliability of any particular model is based on the ability of the model to accurately reproduce specific observations under a variety of conditions (National Research Council 2007). In the case of a water quality model that includes water column and sediment interactions, reliable predictions (or specifications) of benthic nutrient and dissolved oxygen fluxes are critical (DiToro 2001). The ongoing marine monitoring program, including monthly water column sampling and high frequency sampling at fixed moorings described in the Quartermaster Harbor Nitrogen Management Study QAPP (King County 2009a) will provide spatial and temporal nutrient and dissolved oxygen profiles in the harbor for model calibration and testing. Demonstrating the ability of the water quality model to accurately reproduce these observations will provide measures with which to evaluate the reliability of the calibrated model. However, site specific observations of benthic fluxes will provide data that can be used to test the ability of the model to simulate sediment diagenetic processes and associated fluxes of nutrients and dissolved oxygen or to specify these measured fluxes as inputs to the model.

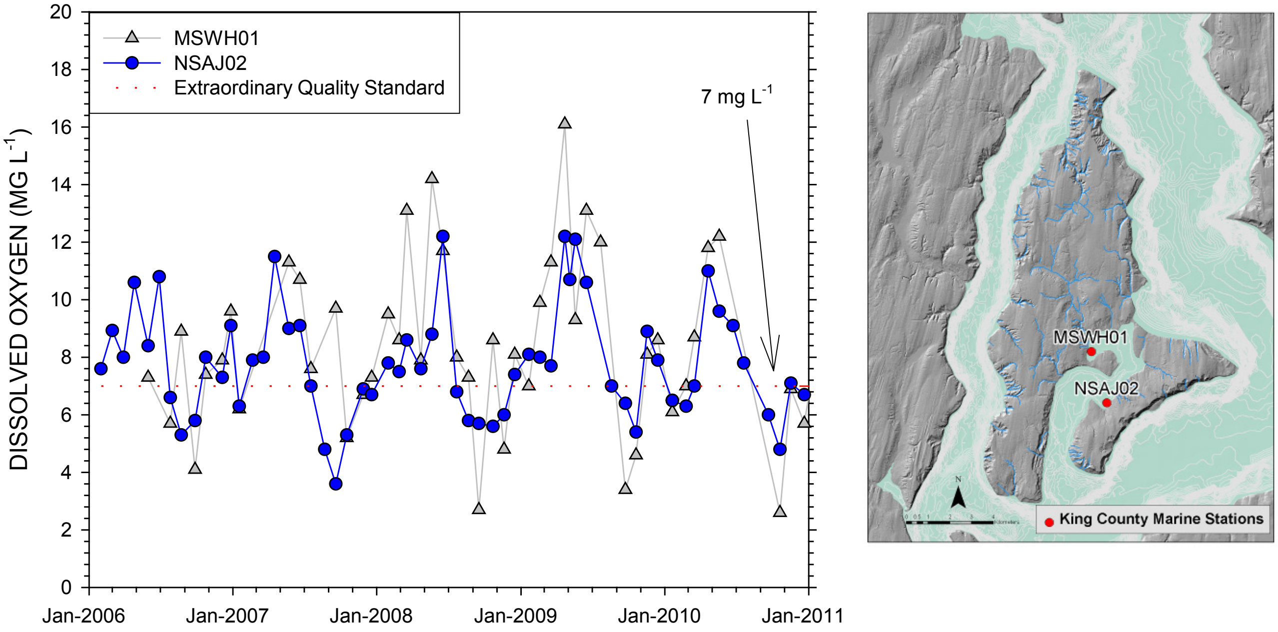

Figure 1. Monthly dissolved oxygen concentrations measured in bottom waters of Quartermaster Harbor by King County.

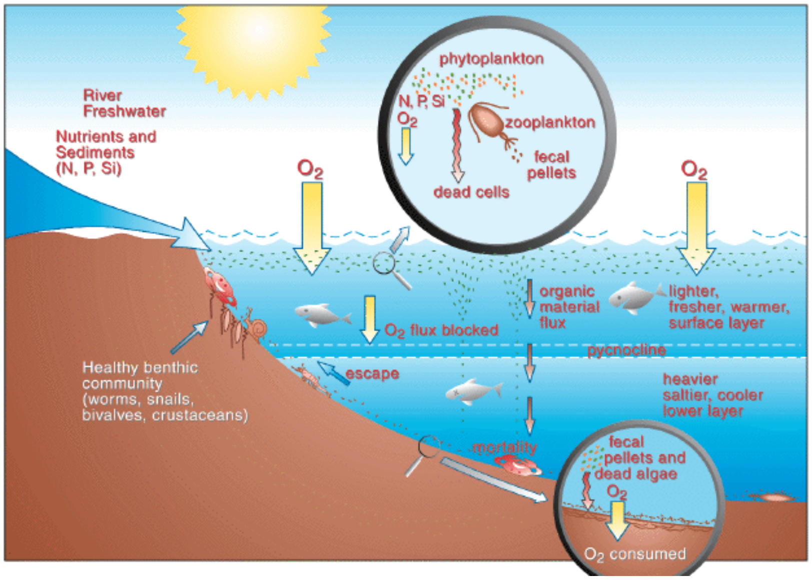

Figure 2. Conceptual diagram of marine nutrient-oxygen dynamics (Source: Downing JA, et al. Gulf of Mexico hypoxia: land and sea interactions.

Note: Task force report no. 134. Ames, IA: Council for Agricultural Science and Technology, 1999 (http://www.ehponline.org/docs/2000/108-3/focusfig2B.GIF)

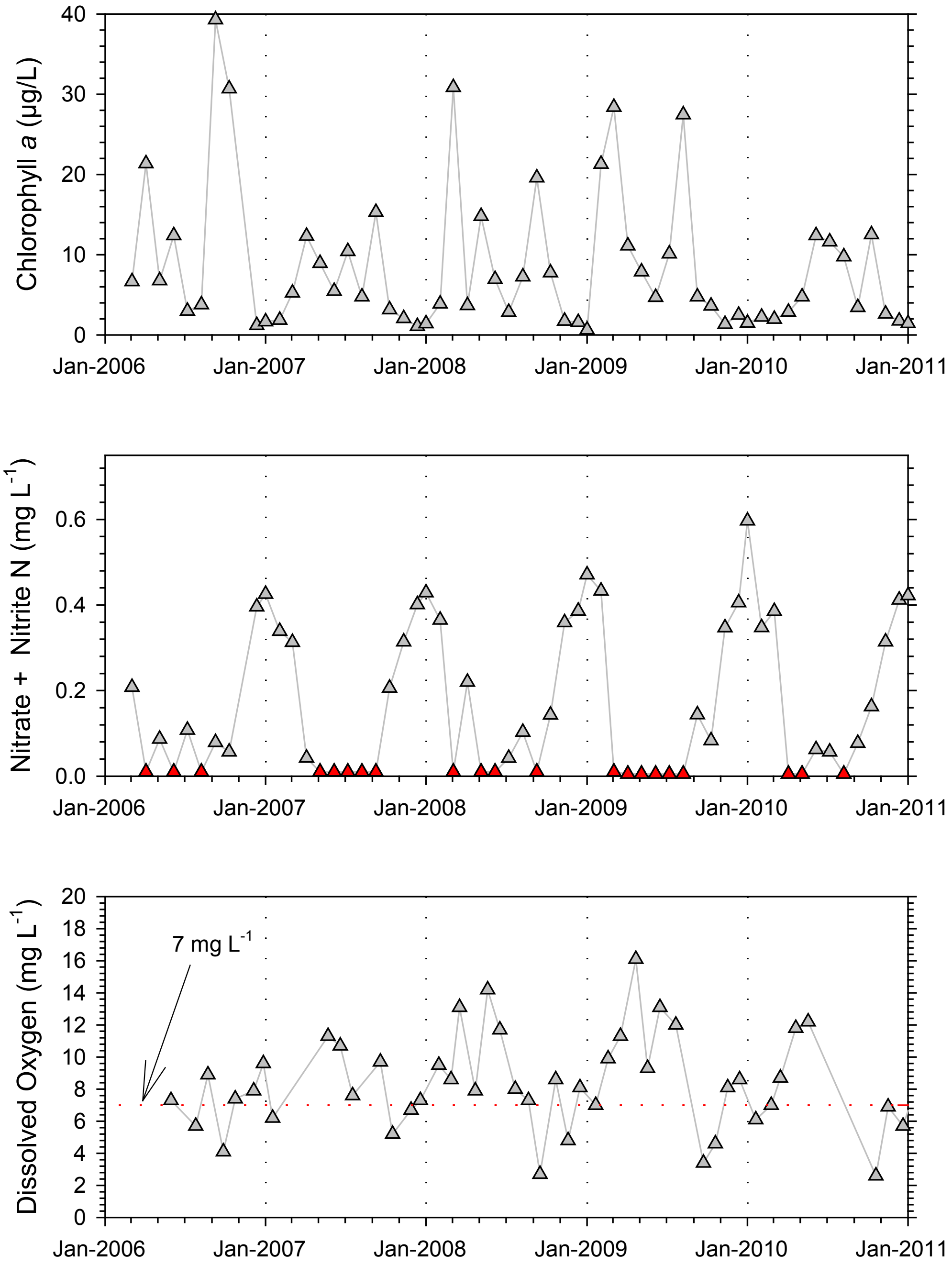

Figure 3. Monthly concentrations of surface water algal biomass (based on measurements of chlorophyll a), surface concentrations of nitrate nitrogen, and bottom water dissolved oxygen concentrations at Stations MSWH01 in Inner Quartermaster Harbor.

Note: Red triangles in the center panel represent nitrate concentrations that were below the laboratory detection limit of 0.02 mg/L. The state standard for dissolved oxygen is shown as a dashed red line in the bottom panel.

1.2 Study Area

Quartermaster Harbor, located between Vashon and Maury Islands in Puget Sound, is sheltered from the wind and waves and receives runoff from about 40 percent of Vashon-Maury Island (Figure 4). It is a shallow, embayment that comprises approximately 12.1 km^2 (3,000 acres) of water surface area in an inner and outer harbor. Inner Quartermaster Harbor 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 Quartermaster Harbor is shallow, with a greatest depth of about 5 to 6 meters and very little tidal flushing. Outer Quartermaster Harbor water depths range from about 11 to 46 meters with rapid tidal flushing. The subtidal sediments are generally dominated by silt and clay, although some shallow areas, especially in the outer harbor, are dominated by sand (University of Washington 1976, Long et al. 2002, King County 2009b, Schatz et al. 2009).

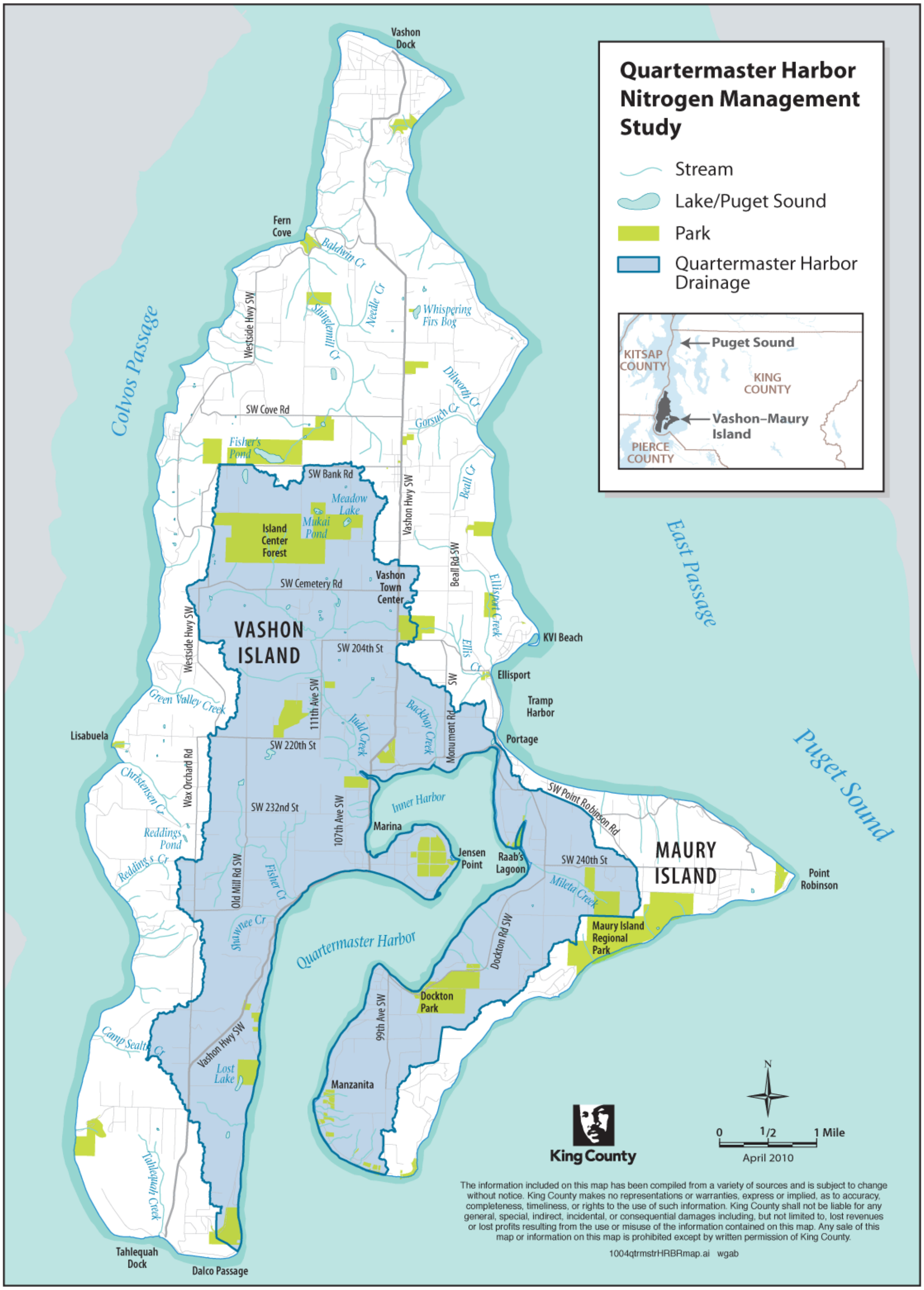

Figure 4. **Map of Vashon-Maury Island highlighting the drainage area to Quartermaster Harbor.**

1.3 Background

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. Previous studies of the marine sediments of the harbor include:

- Sediment characterization conducted as part of a comprehensive study of Quartermaster Harbor in the early 1970s (University of Washington 1976)
- Chemical, physical, and biological analyses of three samples from the outer harbor as part of a larger Southern Puget Sound sediment contaminant study conducted in 1999 (Long et al 2002)
- A sample collected from the inner harbor analyzed for chemical and physical parameters in 2007 (King County 2009b)
- A survey of 24 sediment locations dispersed throughout the harbor in 2007-2008 focused on identifying the distribution of cysts of *Alexandrium catenella*, a toxin producing marine dinoflagellate (Schatz et al. 2009)

Based on these sources of information, the inner harbor sediments have relatively higher organic carbon content, typically greater than 5 percent total organic carbon (TOC) and consist of very fine muds. The outer harbor sediments generally become less organic (typically less than 2 percent TOC) and coarsen to sands at the harbor entrance. The marine biological component of the University of Washington (1976) study included a map that indicated that subtidal sediments were primarily mud-like, while some shallow areas along the shoreline, especially in the outer harbor were primarily sandy. This pattern of TOC and grain size is generally confirmed by the more recent data generated in the other three studies identified above (Figure 5).

Although no benthic nutrient flux measurements have previously been made in Quartermaster Harbor, as noted above, Ecology recently conducted a benthic nutrient flux study in four shallow embayments of South Puget Sound (Figure 6). Benthic flux chambers were deployed in three discrete sampling events at three depths (5, 15, and 25 m) in four South Puget Sound inlets (Budd, Carr, Case, and Eld) during September and October 2007 (Roberts et al. 2008). A range of benthic flux rates and an average rate for all sampling events were reported. The sample results are summarized along with an average of estimates from other published sources in Table 1.

The estimated dissolved inorganic nitrogen (DIN – the sum of ammonia and nitrate+nitrite nitrogen) benthic flux based on studies conducted in South Puget Sound (Roberts et al. 2008) indicates a contribution in late summer from Quartermaster Harbor sediments that could be almost 20 times higher than the largest external source (tributary streams). In general, streamflow and stream DIN concentrations are lowest during late summer, so the relative contributions from the other external sources are likely to be relatively more significant than indicated in this annual summary. Estimated soluble reactive phosphorus (SRP) input from benthic nutrient release from harbor sediments during late summer is estimated based on the South Puget Sound data to also be potentially much larger than all other external sources – over two orders of magnitude higher. The estimated benthic flux of silica also suggests that sediments could be a significant source of this nutrient during late summer – potentially over an order of magnitude higher than the contribution from streams. The reader is referred to King County

(2010a) for details regarding the methods and assumptions used to develop the loading estimates discussed above.

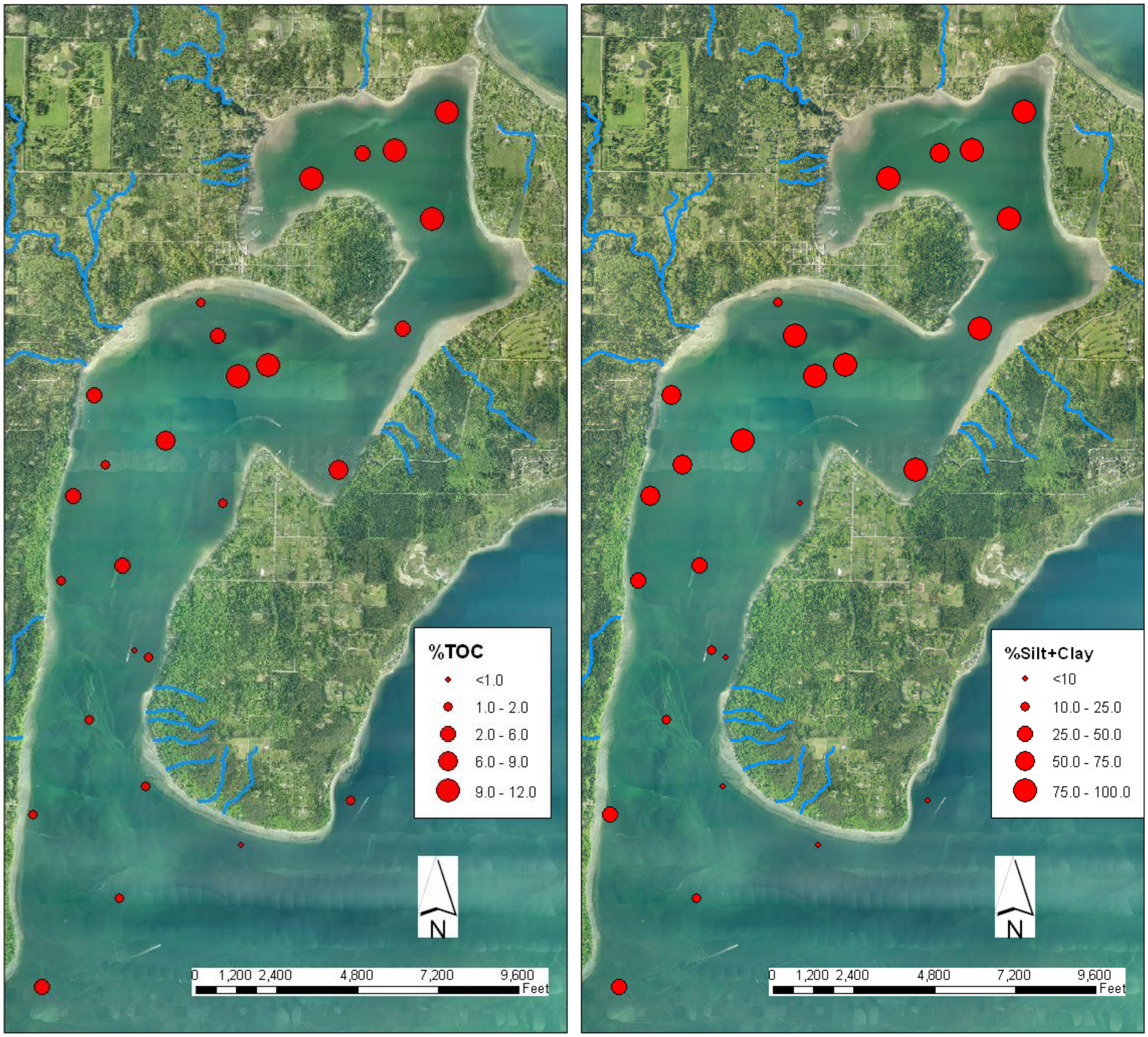

Figure 5. Map of Quartermaster Harbor showing distribution of percent total organic carbon and fine sediment (percent silt+clay).

Sources: *Long et al. (2002), King County (2009b), Schatz et al. (2009)*

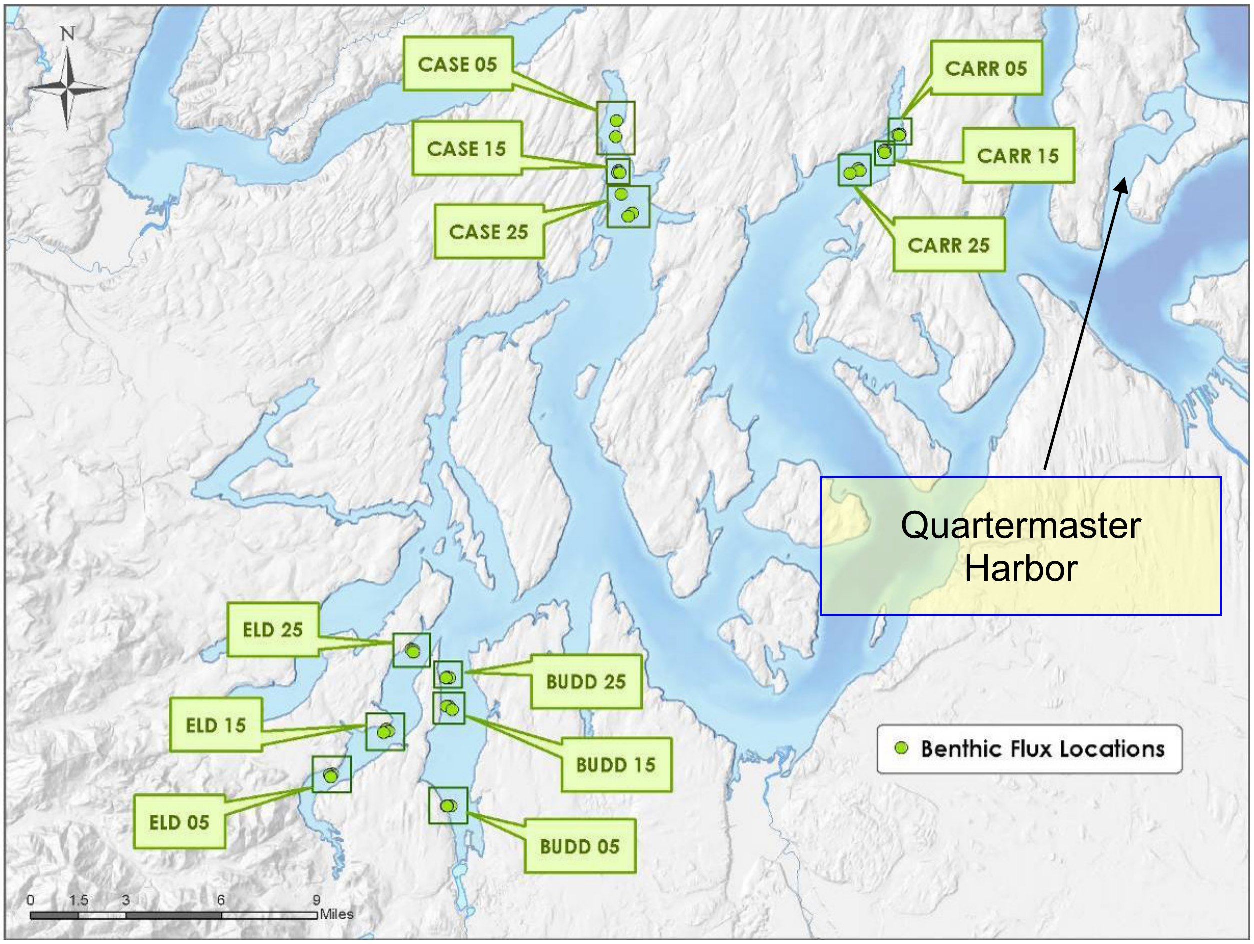

Figure 6. Map showing locations where Ecology conducted benthic nutrient flux studies in 2007 in South Puget Sound.

Source: *Roberts et al. (2008)*

Table 1. Benthic nutrient flux rates measured by Ecology in South Puget Sound embayments and published estuarine/marine benthic nutrient flux data

Constituent	Range	Average	World Flux Database Average [a]
	(g/m^2-day)		
Ammonia Nitrogen	0.002 – 0.153 [b]	0.064 [b]	0.040
Dissolved Inorganic N	0 – 0.13	0.052	0.064
Organic Nitrogen	-0.10 – 0.34	0.038	-
Total Nitrogen	-0.076 – 0.466 [b]	0.085 [b]	-
Orthophosphate Phosphorus	-0.021 – 0.114 [b]	0.024 [b]	0.015
Total Phosphorus	-0.008 – 0.115	0.025	-
Dissolved Silica	-	-	0.200

[a] *World Flux Database – Chesapeake Biological Laboratory (Bailey and Boynton, 2007) as reported in Roberts et al. (2008), with the exception of data for dissolved silica which came from DiToro (2001) who reported a range of 0.050 to 0.300 g Si m^{-2}-day for Chesapeake Bay.*

[b] *Mindy Roberts, personal communication, Environmental Assessment Program, Washington Department of Ecology, Lacey, WA*

1.4 Study Goal

The purpose of this study was to measure benthic fluxes of dissolved oxygen and nutrients *in situ* in Quartermaster Harbor during critical conditions for dissolved oxygen in Quartermaster Harbor for use in water quality model calibration and testing. Benthic sediment fluxes of nutrients are a potentially significant source of nutrients to the harbor in late summer for which no site specific data currently exists. The expected outcomes are local benthic flux estimates from Quartermaster Harbor and increased confidence in water quality model reliability.

1.5 Organization of Report

The report is organized into an introduction (this section), a section briefly describing the methods employed during the study (Methods), and a section summarizing the study results (Results).

A summary of the results and some conclusions are provided in the Summary and Conclusions section. That section also provides some suggestions for additional studies that might help reduce the uncertainty and improve the accuracy of future benthic nutrient flux estimates.

2.0. METHODS

A total of five benthic flux chambers were deployed in Quartermaster Harbor in September 2010. Details of the study design are provided in the Benthic Flux Study Quality Assurance Project Plan (King County 2010b). September was chosen for sampling because this is the general period when maximum flux rates were observed in the Budd Inlet benthic flux study (LOTT, 1998) and it is the period when water column dissolved oxygen concentrations are typically lowest.

The chambers were obtained from Ecology and are the same ones used in the South Puget Sound Benthic Flux Study (Roberts et al. 2008). The chambers were 12x12x36 inch inverted aquaria with a flange fitted around the open end of each chamber (Figure 7). The chambers were divided into two separate sub-chambers to allow for replicated sampling. The divider was constructed to support autonomous monitoring sondes sealed into the divide to sample each sub-chamber. The top of each sub-chamber was equipped with a one-way valve to allow replacement of chamber water with ambient water as water was withdrawn through a separate sampling port. Appropriate lengths of flexible tubing were connected to each sampling port to allow water to be drawn to the surface for sample collection using a peristaltic pump.

The locations where the flux chambers were deployed are shown in Figure 8. Station descriptions and coordinates for each sampling site are summarized in Table 2.

A tethered remotely operated vehicle (ROV) equipped with a video camera was used to document the position of the chamber on the sediment surface and the general character of the bottom near the chamber. Conductivity-temperature-depth (CTD) casts were also conducted at each location, using a calibrated Seabird 19 CTD profiler at the time of deployment to characterize the water column stratification and dissolved oxygen conditions at each location.

The benthic flux chambers remained at each location for approximately 24 hours. Once deployed, sample grabs for Winkler titration of dissolved oxygen and nutrient analysis for nitrogen, phosphorus, and silica compounds were performed initially and repeated four more times during the deployment for a total of five sampling events per chamber. Water samples were collected from each chamber at approximately 2, 4, 8, and 24 hours after initial deployment of the chambers. Nutrient analyses included nitrate+nitrate, ammonia, total nitrogen, soluble reactive phosphorus (SRP also referred to as orthophosphate phosphorus or ORTHOP), total phosphorus, and dissolved silica. Calibrated YSI 6600 V2 EDS sondes were used to autonomously measure dissolved oxygen levels, temperature, salinity, pH, and depth at 15 minute intervals within each benthic flux chamber during the deployment period.

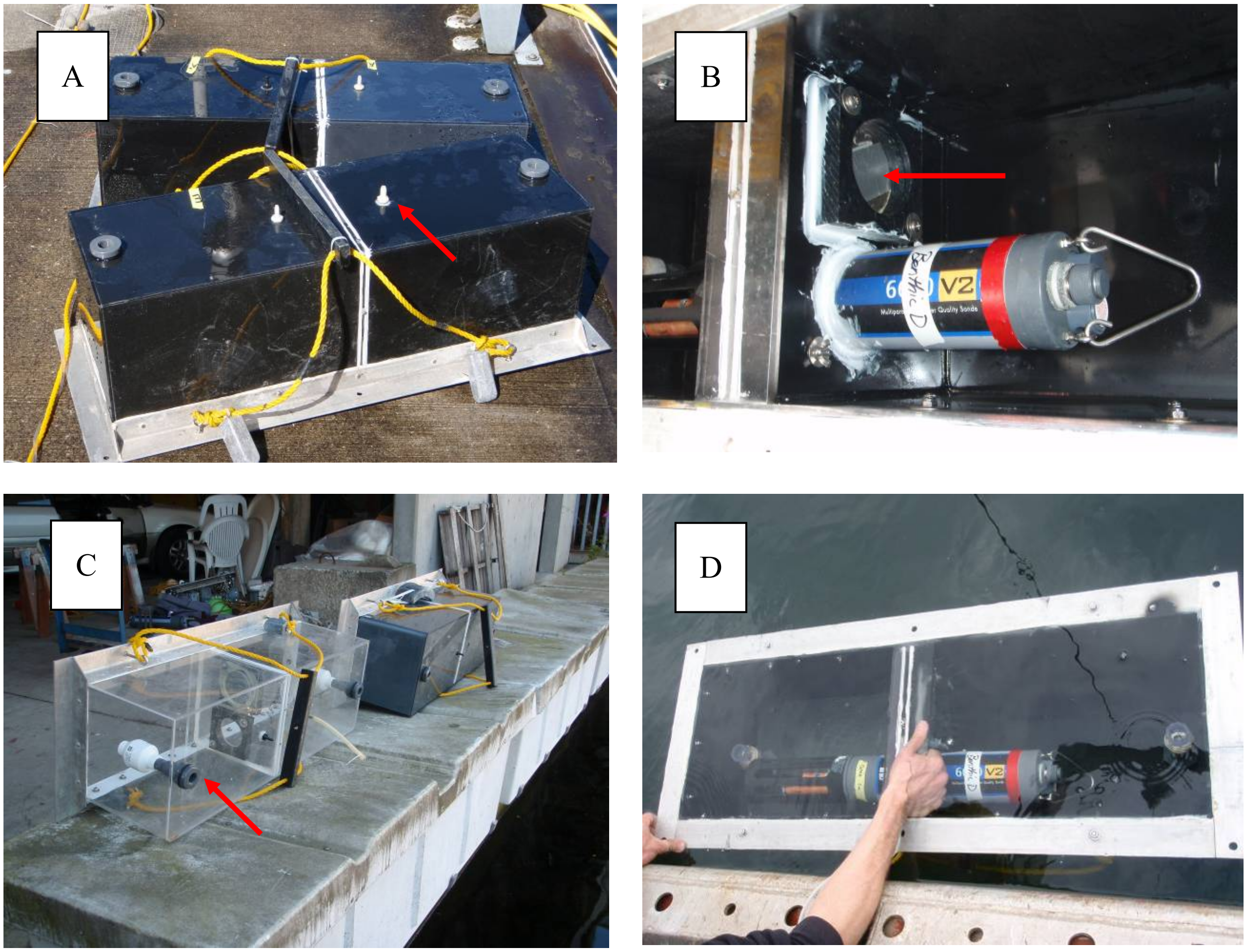

Figure 7. Photographs of the benthic flux chambers used in this study.

A – Painted chambers with harness ready for deployment. Sampling port identified by red arrow.

B – Sonde sealed into chamber. Replicate port for second sonde is sealed with a plexiglass plate.

C – Unpainted and painted chamber being prepared for use in study. Note one-way valve visible through unpainted chamber wall identified with red arrow. Unpainted chamber was subsequently painted for use in this study.

D – Chamber filled with water prior to deployment.

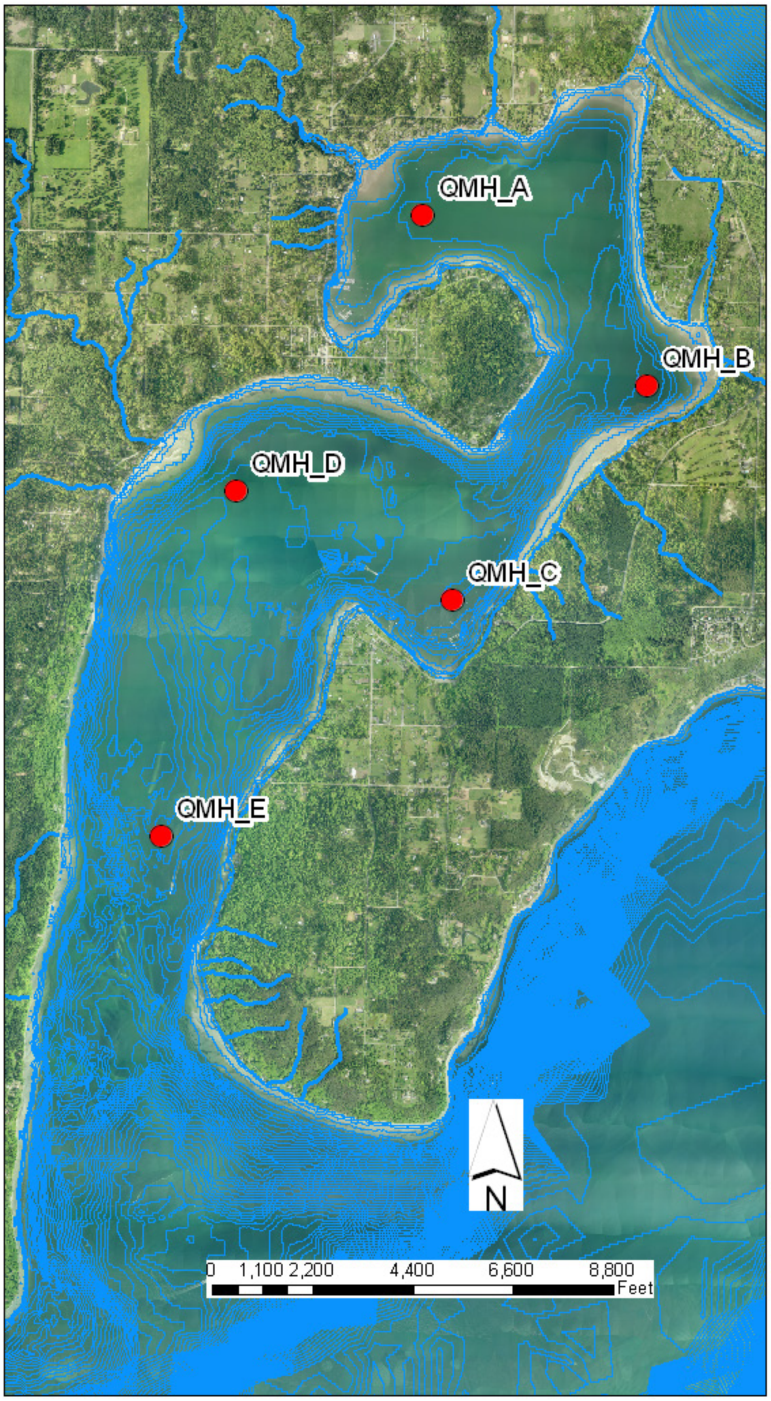

Figure 8. Map showing locations of benthic nutrient flux chambers.

Note: Bathymetric contours (5-ft intervals; NAVD 1988) based on data from Finlayson (2005) are shown to illustrate expected bottom topography at each sampling station.

Table 2. Benthic flux chamber deployment locations.

Station ID	Station Description	Approximate Depth in meters (feet)	Washington State Plan North Coordinates in feet (Easting/Northing)
QMH_A **(replicated chamber)**	Inner harbor near marina	4.0 (13.0)	1238172 / 149372
QMH_B	Inner harbor near Mileta	6.1 (20.0)	1243101 / 145646
QMH_C	Outer harbor near Dockton	7.6 (25.0)	1238818 / 140937
QMH_D	Outer harbor near Fisher Creek	14.0 (46.0)	1234079 / 143328
QMH_E	Outer harbor near Lost Lake Creek	16.8 (55.0)	1232421 / 135788

Note: Approximate depths relative to mean lower low water (MLLW).

One chamber was set up in the inner harbor to utilize both sub-chambers to generate a replicate data set for benthic flux calculations. At each station, the chamber was lowered into the water, initially with the open side up to remove all air bubbles. Once completely submerged, the chamber was inverted and purged of air and lowered to the bottom with the open side down using lines attached to the chamber. Care was taken to gently lower the chamber to the bottom to minimize sediment disturbance. Care was also taken to keep the open ends of the sample collection tubing out of the water.

Once the chamber was in place, inspection by the ROV video camera verified that the chamber flange was adequately seated on the sediment surface. Once the field team was satisfied that the chamber position was acceptable, initial samples were collected using the attached tubing and a battery operated peristaltic pump. To collect a sample, the tubing was attached to the peristaltic pump and purged by 1.5 times the volume of water contained in the tubing to ensure that the sample obtained represented water from the chamber. The amount of water purged from the tubing was measured in a graduated cylinder and discarded. The purge volumes depended on the inner diameter and length of tubing at each deployment location.

Once the initial sample was collected, the pump was disconnected from the sample tubing and the tubing was folded over and clamped to prevent water from entering or leaving the tubing.

The tubing was then secured to a float attached by a line to the chamber so that it could be retrieved in the next sampling round.

Water collected from the chamber for Winkler dissolved oxygen analysis was collected first to minimize oxygen exchange with the atmosphere. Samples were drawn into 300 mL glass sample bottles without turbulence and filled to the rim and immediately fixed with 2 mL manganese chloride followed by 2 mL of alkali-iodide-azide solution. A stopper was placed to ensure that no bubbles were trapped inside the bottle. With a finger on the stopper, the bottle was inverted several times to mix the reagents. The labeled bottle was then placed in a carrying case and the rim of each filled bottle was covered with deionized water.

For unfiltered nutrient samples, water was decanted directly into the sample bottles. For filtered nutrient samples, samples were filtered in the field and the filtrate decanted directly into the appropriate sample container.

3.0. RESULTS

Flux chamber deployment took place on the flood tide on the morning of September 1, 2010 (Figure 9). Winds were generally light during the deployment period (8:00 to 10:40 AM local time) and were generally from the south until early the following morning when stronger winds from the north began and continued through the retrieval period (September 2, 2010 from 8:00 to 10:40 AM local time) (Figure 9).

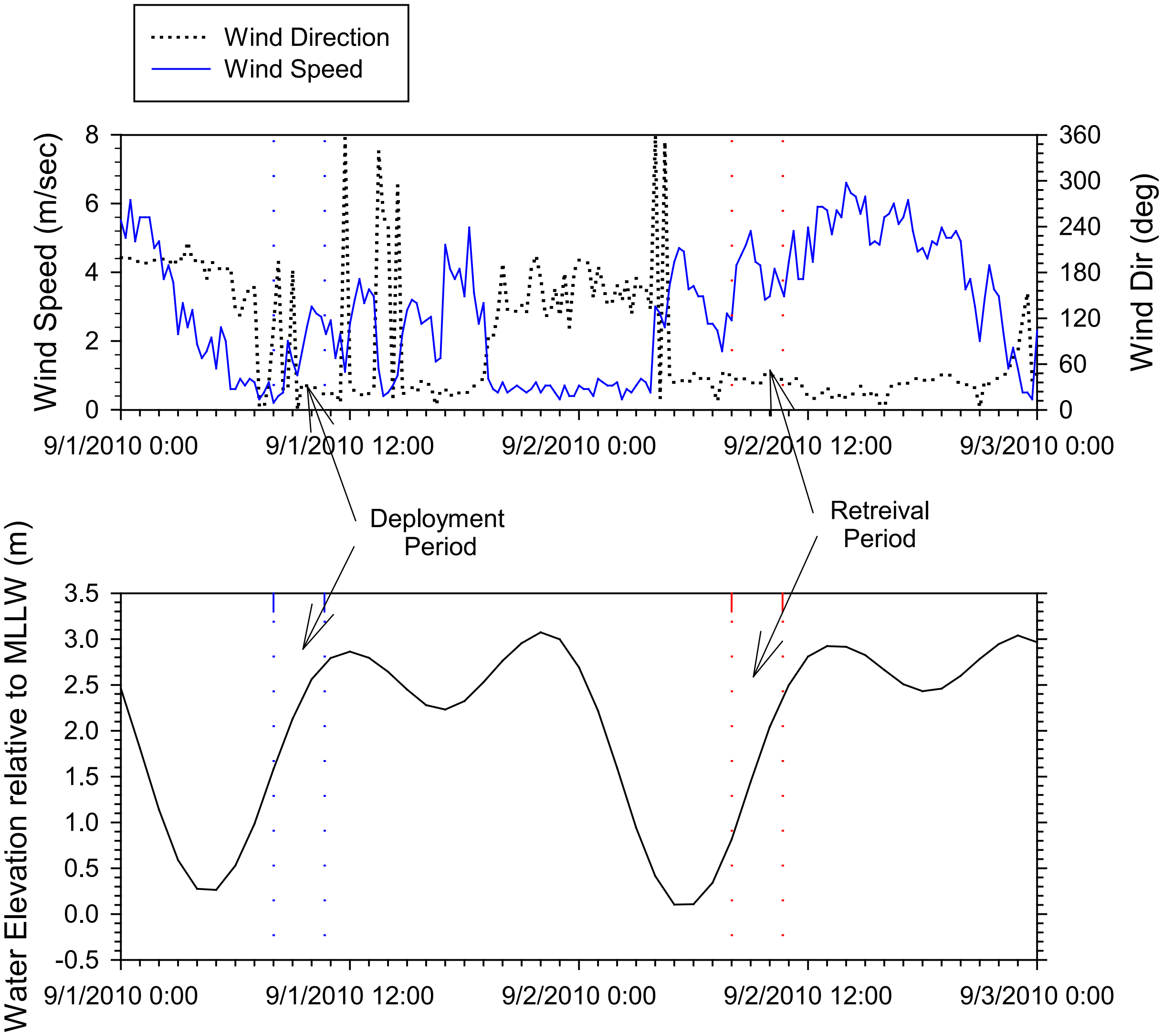

Figure 9. Plot of wind speed and direction (top) and tidal water surface elevation (bottom) during the flux chamber deployment.

Note: Observed tide data from the nearest NOAA PORTS station (Tacoma). Wind speed and direction data from the King County weather station located at the Dockton marina.

Chamber deployment generally went smoothly and inspection using the ROV video camera was useful in verifying whether or not the chambers were properly seated on the bottom. However, visibility at the QMH_D station was so poor that it was not possible to confirm that the chamber was completely seated on the bottom. Poor visibility at this site appeared to be due to a high concentration of *Noctiluca* sp., a nonphotosynthetic heterotrophic and phagotrophic dinoflagellate, which was blooming in the harbor during the study. Inspection of the bottom at QMH_E indicated that the substrate was relatively hard and it is possible that the chamber was not sealed well at this site, although no obvious gaps were seen in the video. All ROV video from the study is available on request.

CTD profiling conducted at each chamber deployment location indicated that bottom water oxygen concentrations in the inner harbor (QMH_A and QMH_B) and at the station in the outer harbor near Dockton (QMH_C) were generally at or above 8 mg/L, while bottom water oxygen concentrations at QMH_D and QMH_E were lower (between 6 and 7 mg/L) (Figure 10). Salinity and temperature profiles were consistent with the patterns of oxygen distribution – the stations with higher bottom DO were not strongly stratified, while profiles at the deeper stations in the outer harbor (QMH_D and QMH_E) indicated some stratification between the surface and bottom (Figure 10).

3.1 Estimated Fluxes

The data from the replicated chamber at QMH_A will be used to illustrate the detailed results and to describe the approaches used to estimate fluxes of DO and nutrients at each site. In general, the data collected in the replicated chambers was very similar (Figure 11). Continuous sonde DO data represented by a solid line in the bottom panel of Figure 11 compared well with the Winkler DO samples (represented by symbols in the bottom panel) collected at the same time as the nutrient grab samples.

Two methods were used to calculate fluxes:

- A rate based on the difference in concentration at the beginning and end of deployment
- A rate based on the slope of a linear regression line based on all of the data collected during deployment

In general, the rates calculated based on these two methods were quite comparable. The results based on the first approach (i.e., beginning and end values) are shown in Table 3. Figures illustrating the data time series for all of the chambers are provided in Appendix A along with the comparison of the flux estimates based on the two calculation methods.

Fluxes were highest at the shallowest inner harbor station (QMH_A) (Table 3). With the exception of dissolved oxygen flux, the lowest fluxes were observed at the deepest stations in the outer harbor (QMH_D and QMH_E). In general, nutrient flux was dominated by net release of dissolved ammonia-N, ORTHOP, and dissolved silica from harbor sediments. Overall, the fluxes estimated for Quartermaster Harbor sediments in September 2010 were within or very nearly within the range of fluxes measured previously by Ecology in South Puget Sound embayments using the same equipment and approach (see Table 3).

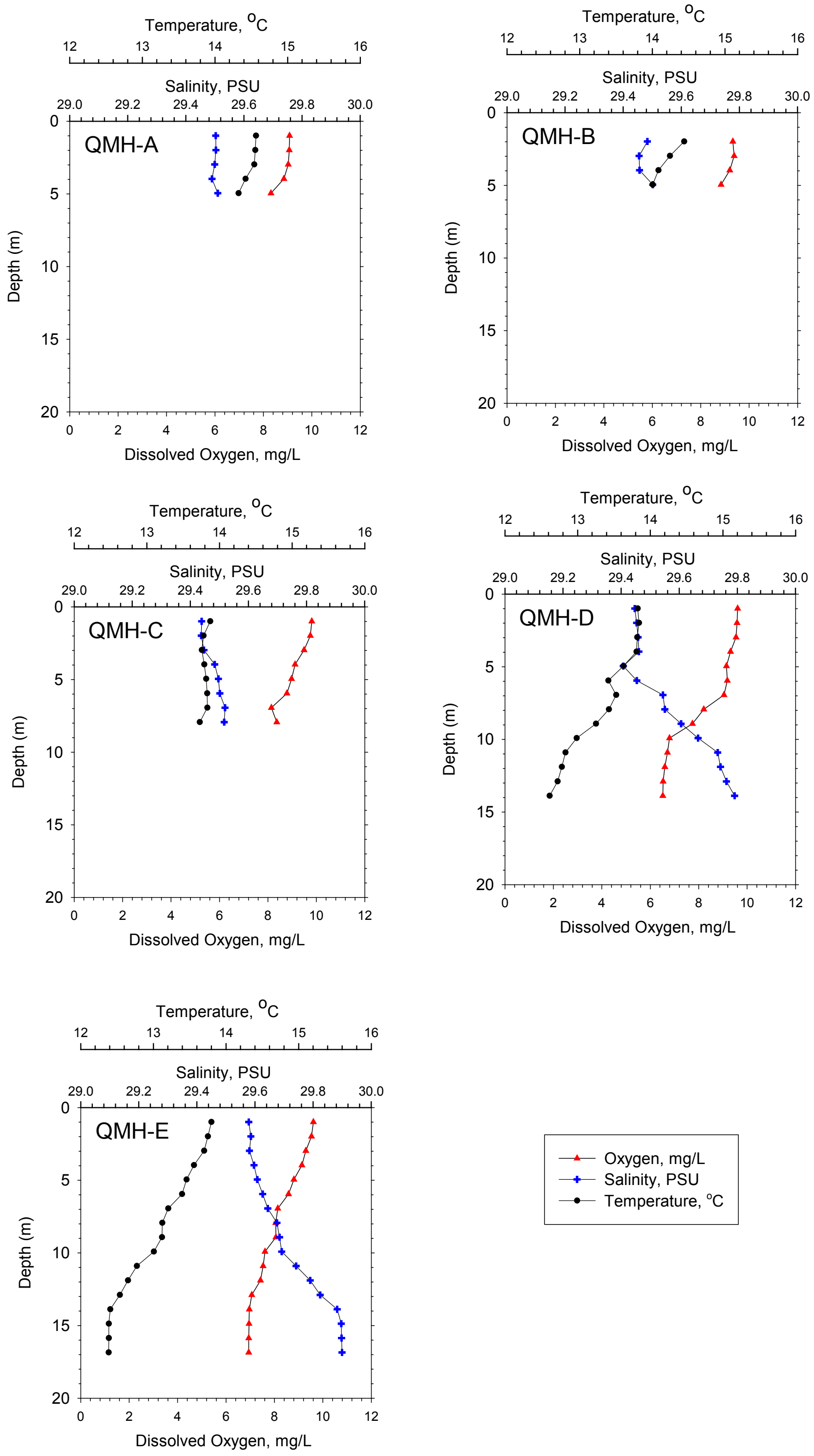

Figure 10. Profile plots of temperature, salinity and dissolved oxygen based on CTD casts made during the deployment of each flux chamber.

Note: Longitudinal contour plots of the CTD data collected at hour 0, 4, and 8 are provided in Appendix B.

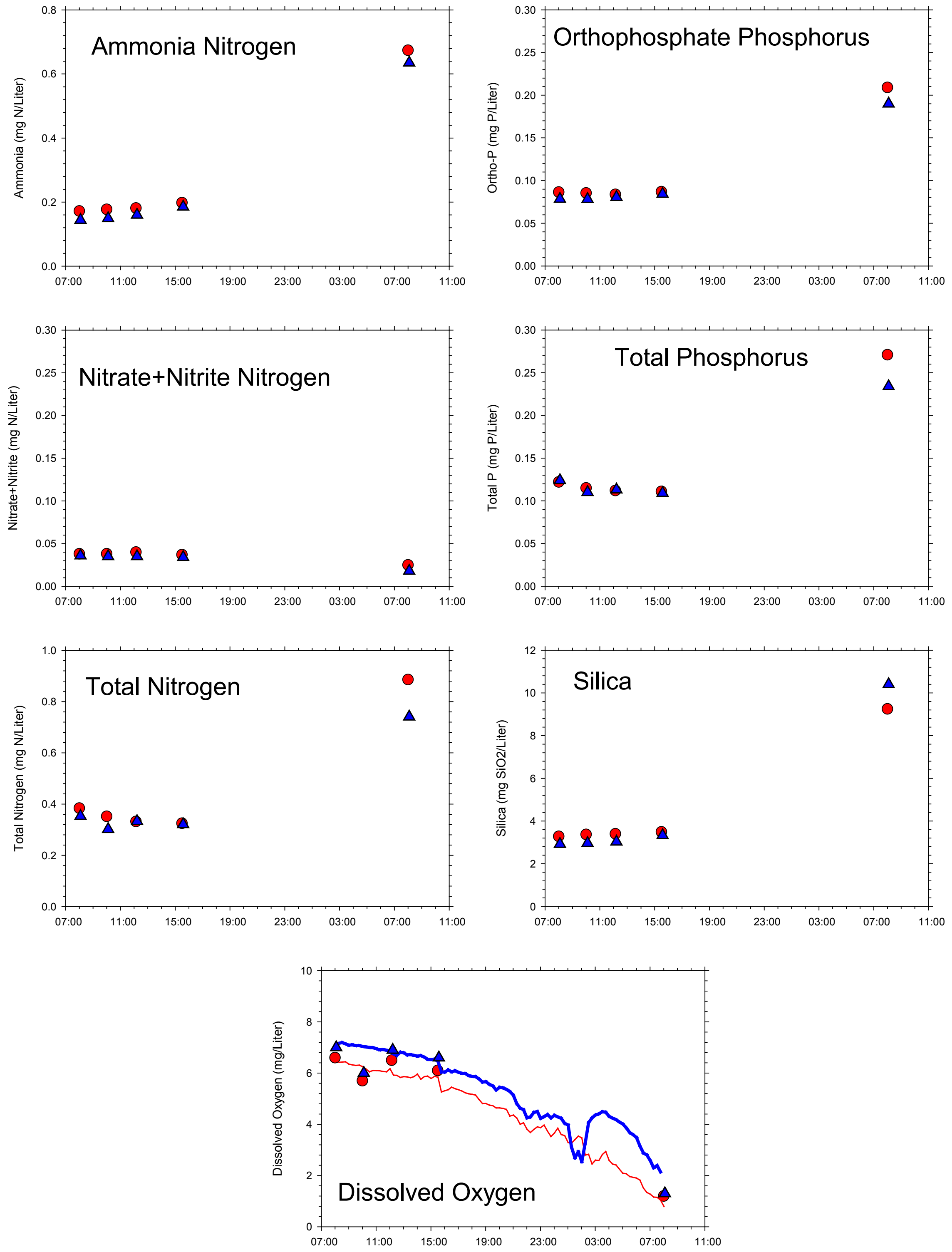

Figure 11. Nutrient and dissolved oxygen data collected from the replicated chamber at QMH_A over the 24 hour study period.

Note: Replicate data differentiated using red and blue lines and red circles and blue triangles.

Table 3. Dissolved oxygen and nutrient flux estimates.

Locator	DO	NH3-N	NO32-N	TN	Ortho-P	TP	DSi
				g m^{-2} day^{-1}			
QMH-A	1.70	0.150	0.000	0.150	0.040	0.040	0.83
	1.73	0.160	-0.010	0.130	0.040	0.040	1.16
QMH-B	0.72	0.06	0.000	0.030	0.010	0.010	0.219
QMH-C	0.64	0.05	0.000	0.010	0.000	0.000	0.079
QMH-D	0.95	0.000	0.010	-0.020	0.000	0.000	0.019
QMH-E	0.16	0.000	-0.010	0.000	0.000	0.000	0.014
South Sound Study[a]	nr	0.064[c]	-0.011[c]	0.085	0.024	0.025	-
	0.00 – 1.7	0.0 – 0.13[d]		-0.07–0.48[c]	-0.02–0.11[c]	-0.008–0.115	-
[b] World Flux Database	1.0	0.040[d]			0.015		0.200

Notes:

DO = Dissolved Oxygen, NH3-N = Ammonia Nitrogen, NO32-N = Nitrate+Nitrite Nitrogen, TN = Total Nitrogen, Ortho-P = Orthophosphate Phosphorus, TP = Total Phosphorus, DSi = Dissolved Silica as silicon (Si).

Negative values indicate net flux into sediments.

"nr" indicates "Not reported."

"-" indicates not measured.

[a] *South Sound Study data reported in Roberts et al. (2008), except as noted in the following footnote.*

[b] *World Flux Database – Chesapeake Biological Laboratory (Bailey and Boynton 2007) as reported in Roberts et al. (2008), with the exception of data for dissolved silica which came from DiToro (2001) who reported a range of 0.050 to 0.300 g Si m^{-2}-day for Chesapeake Bay.*

[c] *Mindy Roberts, personal communication, Environmental Assessment Program, Washington Department of Ecology, Lacey, WA*

[d] Dissolved inorganic nitrogen (DIN) flux, which is the sum of the ammonia and nitrate+nitrite flux.

3.2 Correlation with Sediment Chemistry

Surface sediment samples were collected and analyzed for a variety of physical parameters and chemical constituent, including grain size, total organic carbon, ammonia nitrogen, total nitrogen and total sulfide in November 2010 at ten locations throughout the harbor as part of a separate King County study of harbor sediment quality (King County unpublished data). As a result of coordination between the Quartermaster Harbor Nitrogen Management Study and the King County sediment study, some of the sediment sampling stations were located in the vicinity of the flux chamber deployment locations. Based on comparisons between the estimated dissolved oxygen and nutrient flux rates and sediment quality data, there does not appear to be a strong correlation between sediment texture (based on percent fines), nitrogen, total organic carbon or total sulfide content (Table 4). In general, relatively fine sediment (65 – 77 percent fines) was found in the vicinity of five of the six benthic flux stations – the sediment at the outermost station QMH-E was fairly coarse (18 percent fines) consistent with the ROV observations made during the benthic flux study. A similar pattern was seen for the other sediment variables that have the potential to be predictors of sediment oxygen demand and nutrient flux (i.e., total nitrogen and ammonia, total organic carbon, and total sulfide (see Table 4).

Table 4. Comparison of dissolved oxygen and nutrient flux estimates to surface sediment (0-2 cm) chemistry measured in the vicinity of each benthic flux chamber.

	Sediment Data					Flux Data			
Station	**%Fines**	**%TOC**	**TN**	**NH3-N**	**TS**	**DO**	**DIN**	**Ortho-P**	**DSi**
	%		**mg kg^{-1} dry sediment**			**g m^{-2}-day**			
MSVK01 QMH-A	76	2.8	2,460	14.3	404	1.72	0.15	0.04	0.996
MSXM01 QMH-B	68	2.0	1,970	17.9	717	0.72	0.06	0.01	0.219
NSAJ03 QMH-C	75	2.5	2,280	9.2	935	0.64	0.05	0.0	0.079
MSZF01 QMH-D	75	2.1	2,030	11.5	1,010	0.95	0.01	0.0	0.019
NSCE01 QMH-E	19	0.5	458	5.2	21.7	0.16	-0.01	0.0	0.014

Source of sediment data King County (unpublished)

4.0. SUMMARY AND CONCLUSIONS

Direct estimates of benthic nutrient flux were made in September 2010 in Quartermaster Harbor that were consistent with other recent field-based estimates for South Puget Sound embayments with comparable depth ranges (Roberts et al. 2008). However, one should keep in mind that these estimates are operationally defined[1] (Devol 1987, Miller-Way et al. 1994, Tengberg et al. 1995). Regardless, these estimates provide a reasonable benchmark for the development and testing of a water quality model of the harbor. These estimates can also be used to refine the benthic nutrient flux loading estimates based on the average results of the study conducted in South Puget Sound (King County 2010a). The estimates reported here range from higher to lower than the average sediment flux values, which were applied to the entire bottom area of the harbor to derive the initial benthic nutrient flux estimate (King County 2010a). The estimated nutrient release rate at the two deepest outer harbor stations sampled in this study suggest that sediment nitrogen, phosphorus, and silica release over most of the outer harbor is negligible during the critical low dissolved oxygen period in the harbor. Therefore, a more reasonable estimate of the input of nutrients from sediments to the water column during this period should assume that most of the sediment nutrient release (and sediment oxygen demand) occurs in the inner harbor and the inner-most area of the outer harbor.

Because sediments may provide a long-term reservoir (i.e., internal source) of nitrogen that could delay the response of the harbor to management activities designed to reduce nitrogen loading from terrestrial sources (Boynton and Bailey 2011), additional studies of sediment nutrient flux may be warranted. If so, it is recommended that the range of available methods be evaluated to identify a method (or methods) that is the most reliable, repeatable and cost effective. For example, chemostatic systems have the potential to provide more control over experimental conditions, be logistically more convenient and potentially less expensive while still providing results that are comparable to flux chamber or pore water profiling studies (Miller-Way et al. 1994, Beutel et al. 2008a, Beutel et al. 2008b).

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[1] *Operationally defined* means that the true flux of nutrients and oxygen at the sediment-water interface is not measured because the tools used to measure the fluxes, by necessity, alter the *in situ* conditions under which natural sediment-water interactions occur.

5.0. REFERENCES

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APPENDIX A

Benthic Flux Data Summary

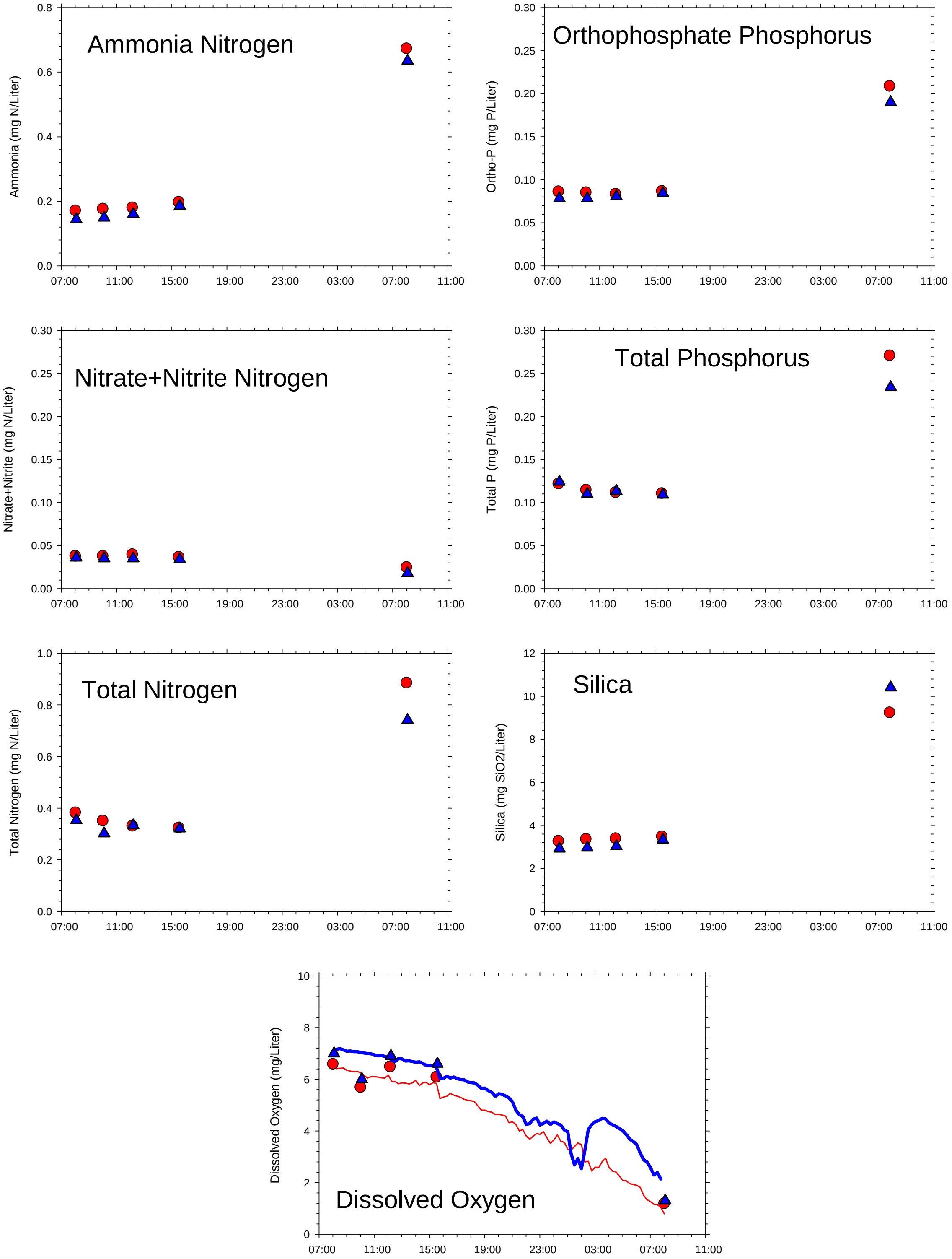


Figure A-1. Nutrient and dissolved oxygen data collected from the replicated chamber at QMH_A.

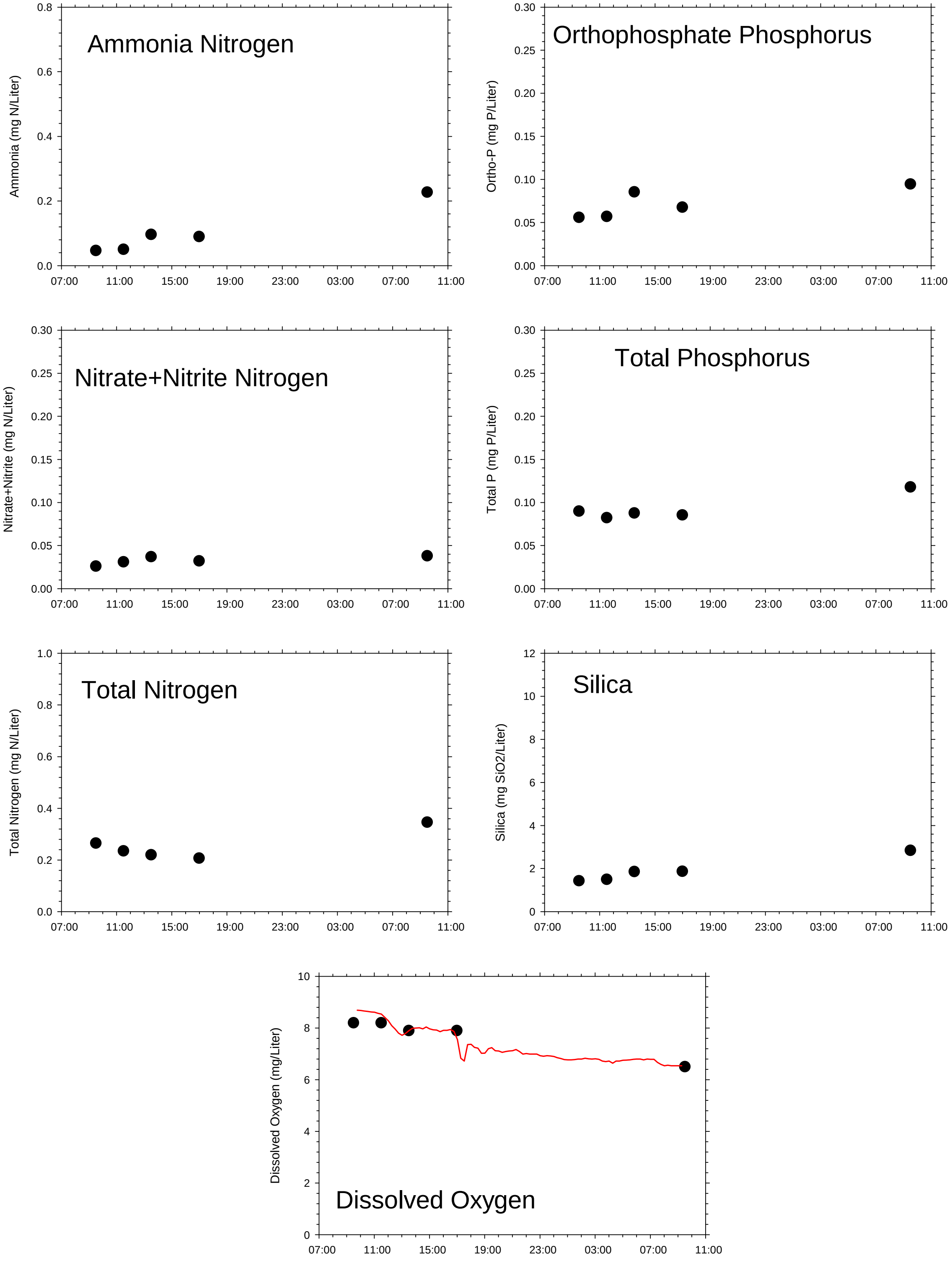


Figure A-2. Nutrient and dissolved oxygen data collected from the replicated chamber at QMH_B.

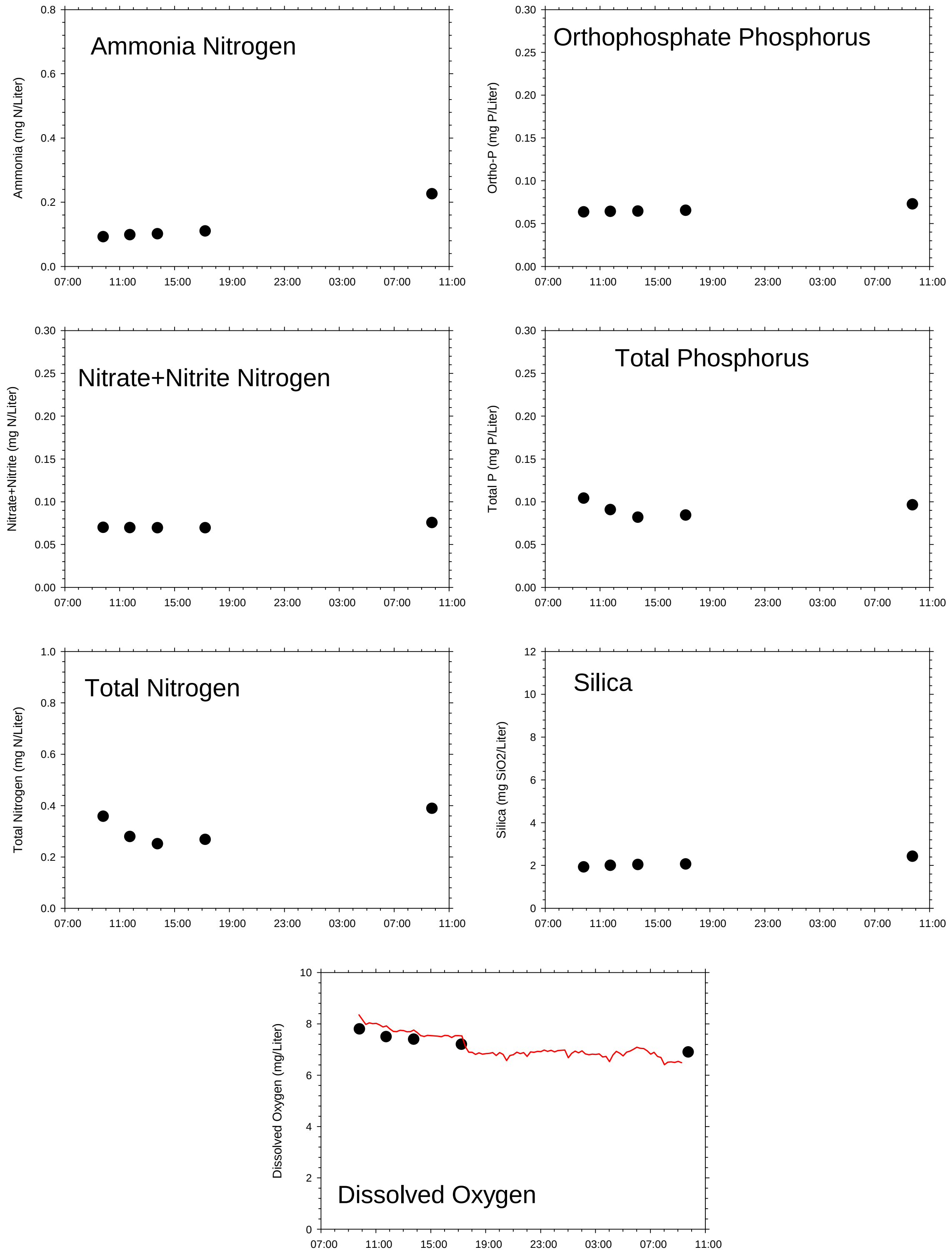


Figure A-3. Nutrient and dissolved oxygen data collected from the replicated chamber at QMH_C.

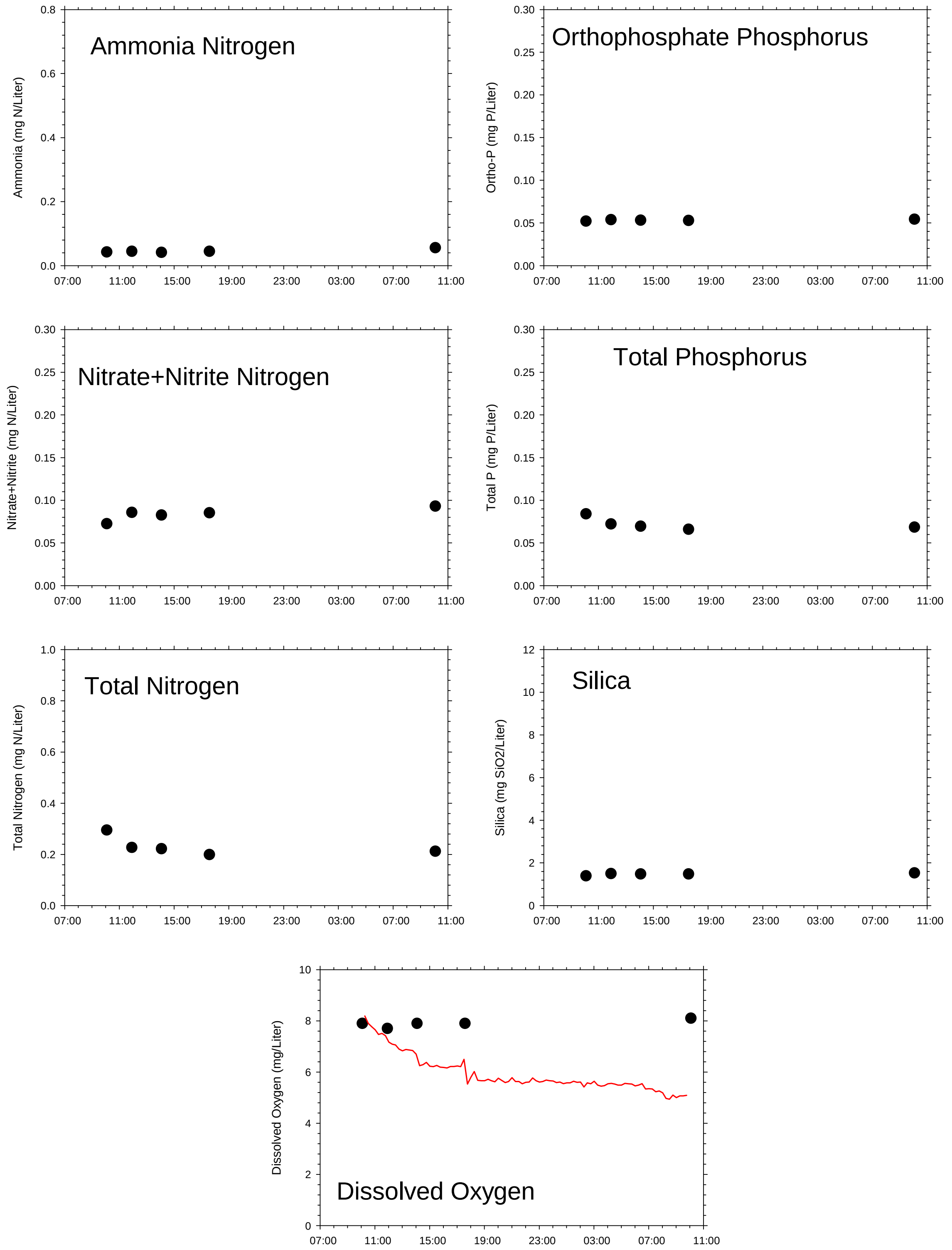


Figure A-4. Nutrient and dissolved oxygen data collected from the replicated chamber at QMH_D.

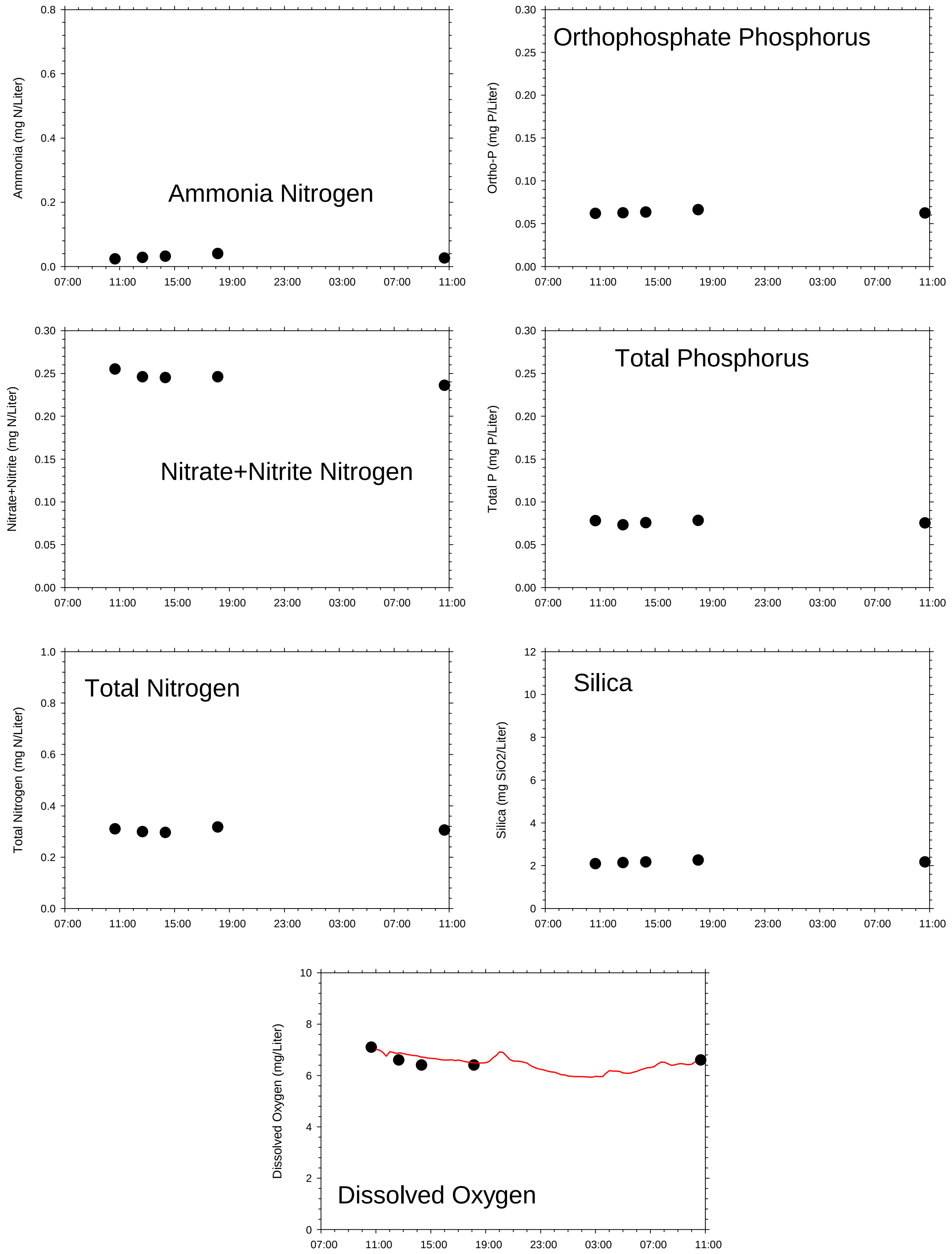


Figure A-5. Nutrient and dissolved oxygen data collected from the replicated chamber at QMH_E.

Table A-1 Dissolved oxygen and nutrient flux estimates (g m^{-2}-day).

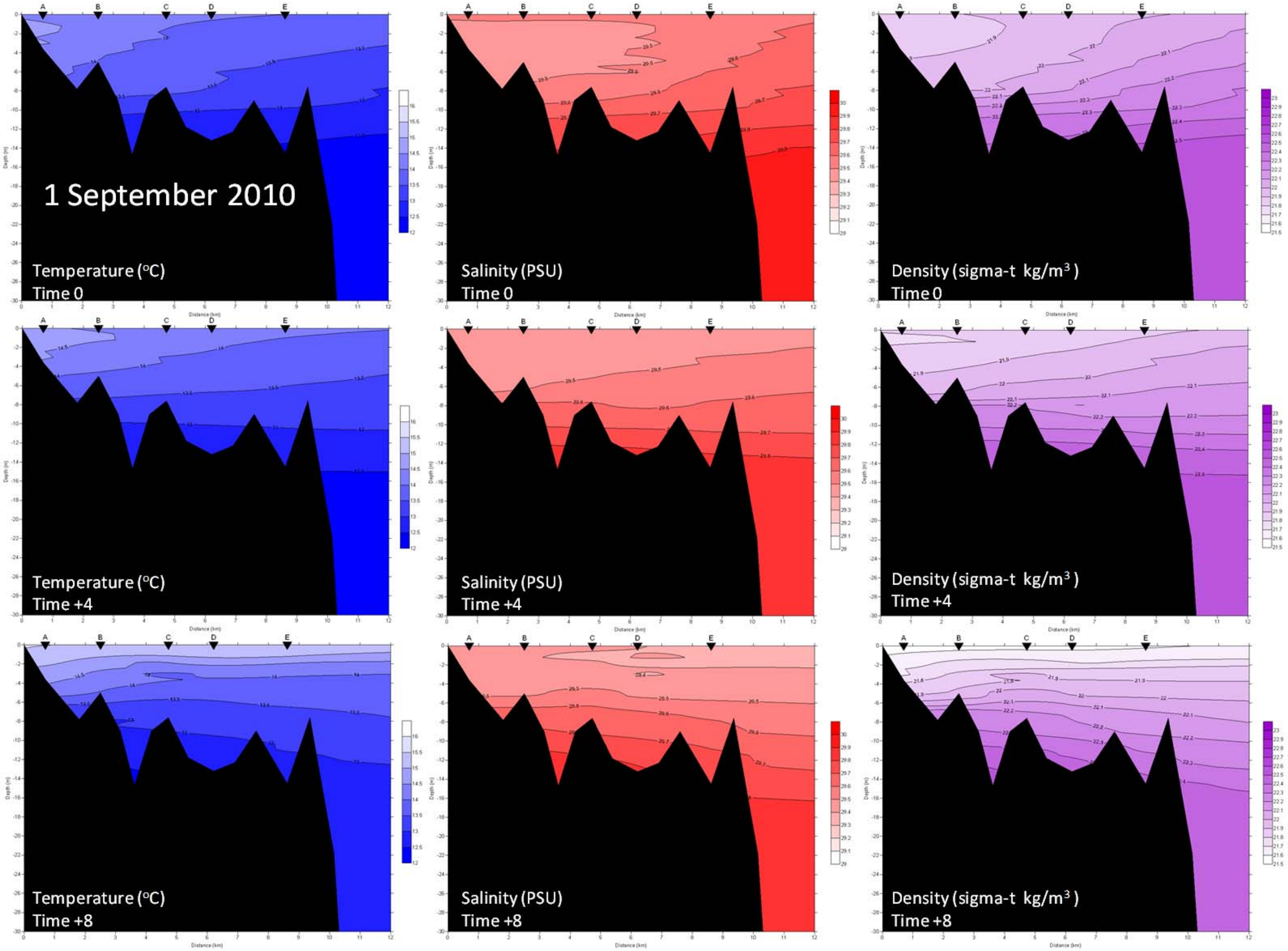
Station	Parameter	Linear Regression	Beginning Value - End Value
QMH-A1	DO	1.63	1.7
	Ammonia-N	0.16	0.15
	Nitrate+Nitrite-N	0.000	0.000
	Total Nitrogen	0.170	0.150
	Organic N	0.010	0.000
	Orthophosphate P	0.040	0.040
	Total Phosphorus	0.050	0.040
	Organic P	0.010	0.010
	Silica (SiO2)	1.880	1.780
QMH-A2	DO	1.62	1.73
	Ammonia-N	0.17	0.16
	Nitrate+Nitrite-N	-0.010	-0.010
	Total Nitrogen	0.150	0.130
	Organic N	-0.020	-0.030
	Orthophosphate P	0.040	0.040
	Total Phosphorus	0.040	0.040
	Organic P	0.000	0.000
	Silica (SiO2)	2.650	2.490
QMH-B	DO	0.67	0.72
	Ammonia-N	0.06	0.06
	Nitrate+Nitrite-N	0.000	0.000
	Total Nitrogen	0.040	0.030
	Organic N	-0.030	-0.040
	Orthophosphate P	0.010	0.010
	Total Phosphorus	0.010	0.010
	Organic P	0.000	0.000
	Silica (SiO2)	0.460	0.470
QMH-C	DO	0.46	0.64
	Ammonia-N	0.05	0.05
	Nitrate+Nitrite-N	0.000	0.000
	Total Nitrogen	0.030	0.010
	Organic N	-0.020	-0.040
	Orthophosphate P	0.000	0.000
	Total Phosphorus	0.000	0.000
	Organic P	0.000	-0.010
	Silica (SiO2)	0.160	0.170
QMH-D	DO	0.65	0.95
	Ammonia-N	0.000	0.000
	Nitrate+Nitrite-N	0.000	0.010
	Total Nitrogen	-0.010	-0.020
	Organic N	-0.020	-0.040
	Orthophosphate P	0.000	0.000
	Total Phosphorus	0.000	0.000
	Organic P	0.000	-0.010
	Silica (SiO2)	0.030	0.040

Table A-1 (Continuted)

Station	Parameter	Linear Regression	Beginning Value - End Value
QMH-E	DO	0.23	0.16
	Ammonia-N	0.000	0.000
	Nitrate+Nitrite-N	0.000	-0.010
	Total Nitrogen	0.000	0.000
	Organic N	0.010	0.000
	Orthophosphate P	0.000	0.000
	Total Phosphorus	0.000	0.000
	Organic P	0.000	0.000
	Silica (SiO2)	0.020	0.030

APPENDIX B

CTD Profiler Summary


1 September 2010
A
B
C
D
E
Temperature (°C)
Time 0
Salinity (PSU)
Time 0
Density (sigma-t kg/m³)
Time 0
Temperature (°C)
Time +4
Salinity (PSU)
Time +4
Density (sigma-t kg/m³)
Time +4
Temperature (°C)
Time +8
Salinity (PSU)
Time +8
Density (sigma-t kg/m³)
Time +8
Depth (m)
Distance (km)
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-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
0
1
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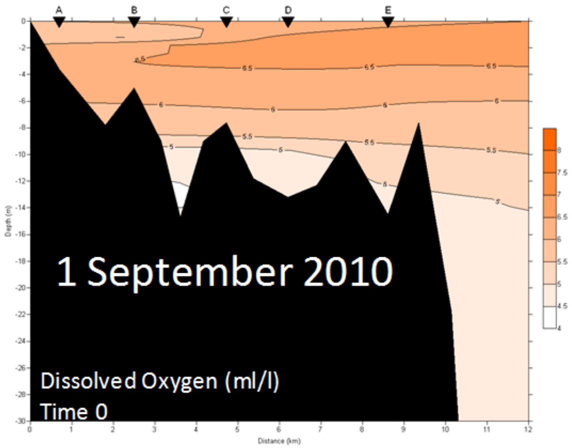
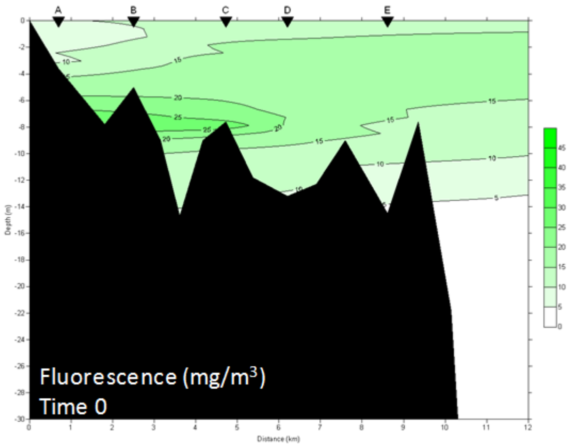
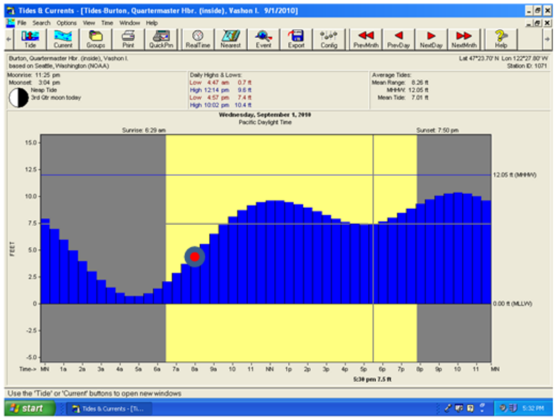
21.5







Tides & Currents - [Tides-Burton, Quartermaster Hbr. (inside), Vashon I. 9/1/2010]

Burton, Quartermaster Hbr. (inside), Vashon I.
based on Seattle, Washington (NOAA)

Lat 47°23.70' N Lon 122°27.80' W
Station ID: 1071

Moonrise: 11:25 pm
Moonset: 3:04 pm
Neap Tide
3rd Qtr moon today

Daily Highs & Lows:

Low	4:47 am	0.7 ft
High	12:14 pm	9.6 ft
Low	4:57 pm	7.4 ft
High	10:02 pm	10.4 ft

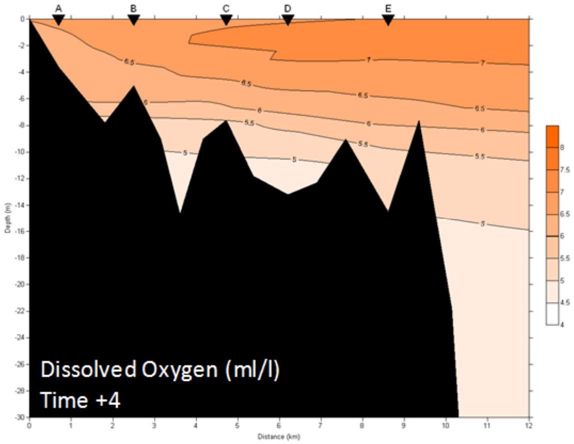
Average Tides:
Mean Range: 8.26 ft
MHHW: 12.05 ft
Mean Tide: 7.01 ft

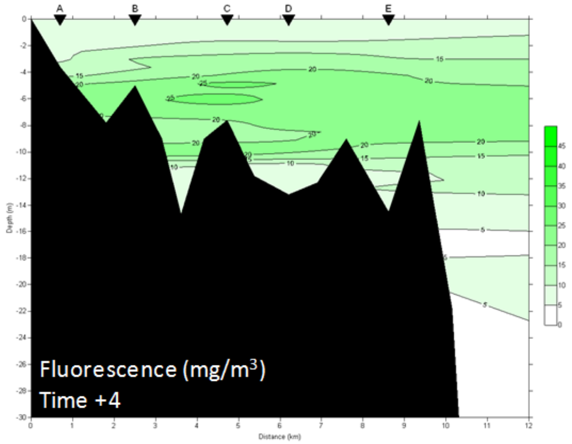
Wednesday, September 1, 2010
Pacific Daylight Time

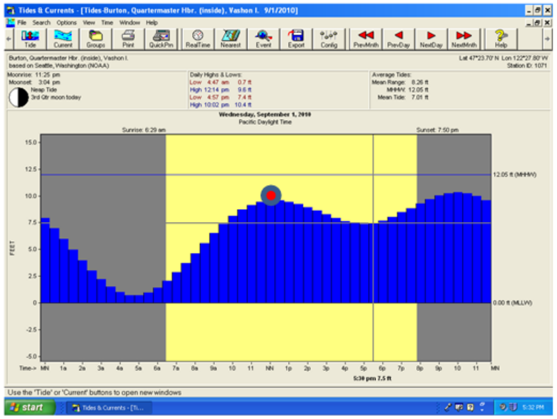
Sunrise: 6:29 am
Sunset: 7:50 pm

5:30 pm 7.5 ft

Use the 'Tide' or 'Current' buttons to open new windows



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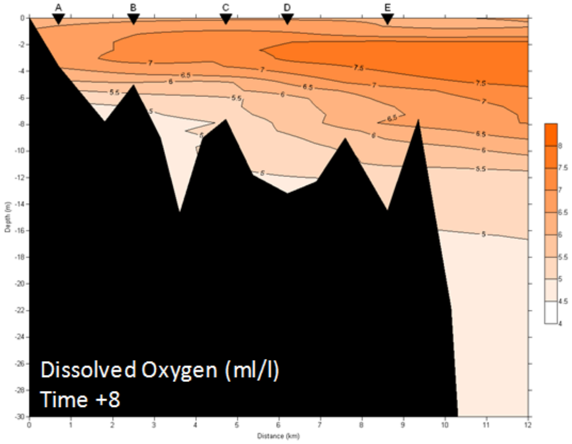

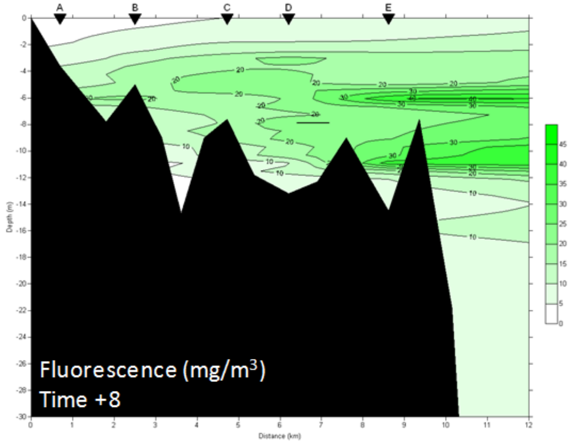

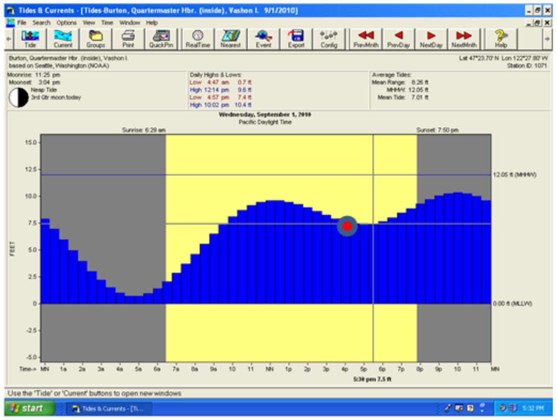
Tides & Currents - [Tides-Burton, Quartermaster Hbr. (inside), Vashon I. 9/1/2010]

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5:30 pm 7.5 ft

Use the 'Tide' or 'Current' buttons to open new windows

Figure B-1. Contour plots showing longitudinal cross sections (inner to outer harbor) of temperature, salinity, density, dissolved oxygen and fluorescence on September 1, 2010 at time of deployment and 4 and 8 hours after deployment.

Note: Tidal elevation during each period also provided.