WATER QUALITY ASSESSMENT REPORT

Freeland Water Quality Improvement Project

Prepared for

Island County Public Works Department

June 2004

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Prepared for

Island County Public Works Department
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Contents

Tables

Figures

Introduction

Island County Public Works Department (PWD) is currently in the planning stages for developing a Comprehensive Drainage Plan (CDP) for the Freeland drainage basin on Whidbey Island (Figure 1). When completed, the CDP will provide a detailed analysis of existing water quality and flooding problems in the Freeland drainage basin and provide recommendations for capital improvement projects and maintenance activities to mitigate these problems. The CDP will also guide future planning activities in the Freeland drainage basin as they relate to stormwater management and flood control.

Island County PWD is also working on two separate drainage improvement projects in the basin: the Freeland park outfall project and Freeland trunk drain project. Under the current design scenario for the Freeland Park outfall project, a new pipeline system will be constructed to divert high stormwater flows from approximately 1,820 feet of an existing ditch that extends from just north of South Main Street in the community of Freeland to an outfall on the shoreline of Holmes Harbor near Stewart Road (Figure 2). The Freeland Park outfall will include a 30-inch storm drain along Myrtle Street and an 24-inch storm drain along Stewart Road. Both pipes will join near the Freeland Park and outfall at a vault between the parking lot and the beach. The anticipated benefit of this new pipeline system will be a reduction in the incidence of flooding in the lowland areas of the Freeland drainage basin along Stewart Road (Figure 2).

The Freeland trunk drain outfall project is in the early stages of planning. The trunk drain carries a perennial Type IV stream underneath the Freeland Plaza which is located on South Main Street (Figure 2). Currently, water from this trunk drain must rise about 6 feet from the invert of the existing trunk drain to get to a surface channel. This project will provide gravity flow from the invert of the existing submerged trunk drain through approximately 320 feet of 12-inch culvert pipe that will daylight downslope to a newly created stream channel. The stream channel will be approximately 20 feet wide, 300 feet long, and be landscaped with native vegetation, terraces and woody debris to provide maximum habitat value on a 5 to 7 percent hillslope. The Freeland trunk drain outfall will include flow conveyance through a 12-inch pipe and stream channel for the first 660 feet of stream north of the Freeland Plaza shopping center.

In order to support planning and permitting efforts related to the Freeland CDP and the two drainage improvement projects described above, Island County PWD is implementing the Freeland water quality improvement project with the overall goal of obtaining data to document aquatic habitat resources and water quality in the Freeland drainage basin. This document summarizes results from water quality monitoring that was conducted from January to November of 2003 in connection with this project. (Aquatic habitat resource investigations for the project were summarized previously in Herrera 2003.) The specific objectives of this water quality assessment report are identified as follows:

- Conduct water quality monitoring to characterize baseline water quality conditions in the Freeland drainage basin.

Figure 1. Vicinity map for the Freeland water quality improvement project in Island County, Washington.

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Figure 2. Water quality monitoring stations, rain gauges, water conveyance systems, and drainage basin boundary for the Freeland water quality improvement project.

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- Identify primary sources of water quality problems in the Freeland drainage basin.
- Quantify water quality impacts on Holmes Harbor for selected parameters.
- Identify the extent of water quality treatment, if any, that is afforded by the existing open-channel ditch system to be affected by the Freeland Park outfall project.

The monitoring data presented in this document are based on sampling procedures, analytical methods, and schedules previously identified in the *Freeland Water Quality Improvement Project Monitoring and Quality Assurance Project Plan* (Herrera 2002). The associated analyses and results in this document are presented sequentially under the following headings:

- Site Description
- Methods
- Results
- Conclusions.

Site Description

The Freeland drainage basin is located on Whidbey Island and covers an area of approximately 695 acres on a low hillside overlooking Holmes Harbor (Figure 2). Runoff in the basin generally flows from south to north via a network of small drainage ditches, stormwater conveyance pipes, and an unnamed stream (water resource inventory area [WRIA] #06-0010). Just south of Stewart Road, most of the runoff from the basin coalesces in several roadside ditches. Two culverts then convey the runoff in these ditches under Stewart Road, where it then travels through an emergent salt marsh for approximately 200 feet.

After traveling through the marsh, flows from the stream and adjacent roadside ditches discharge into Holmes Harbor through a 2-foot-diameter corrugated metal pipe culvert located under the beach berm (see Figure 2). At this location, the outfall into the harbor consists of a concrete culvert with a partially functioning tide gate (Herrera 2002; Sheldon and Associates 2001). During low tide, flows from the Freeland drainage basin discharge into Holmes Harbor without impediment. During high tide, however, saltwater from Holmes Harbor backs up through the tide gate, thereby increasing the hydraulic head in the lower reaches of the channel. When large precipitation events occur coincident with high tides, waters flowing in the roadside ditches along Stewart Road often back up against this hydraulic gradient and subsequently flood the surrounding area. The proposed Freeland Park outfall project described previously would mitigate this flooding problem and potentially improve water quality by reducing erosion in the existing open-channel system and preventing flooding in local drainage areas that are served with on-site septic systems.

Land use in the Freeland drainage basin is characterized by dense commercial and retail areas along the State Route (SR) 525 corridor (Sheldon and Associates, Inc. 2001). The western and eastern regions of the basin contain residential land uses that vary from moderate to low density. The middle to lower portion of the watershed contains low-density residential land use (0.5 to 1.0 houses/acre) and substantial areas of pasture.

Earlier monitoring efforts have shown that water quality in the Freeland drainage basin is generally good (Island County Health Department 1998). However, fecal coliform bacteria concentrations measured in 1997 frequently exceeded the state water quality standard. The source of the fecal coliform bacteria was believed to be failing septic systems located within the basin. High concentrations of fecal coliform bacteria are of particular concern because Holmes Harbor is used for commercial and recreational shellfish harvesting.

Methods

Methods used for this water quality assessment are described briefly herein. These procedures were originally presented in the monitoring and quality assurance plan that was prepared for the project (Herrera 2002). The presentation of this information is organized under the following subsection headings:

- Sampling Locations
- Sampling Schedules
- Sample Collection Procedures
- Monitoring Parameters
- Analytical Procedures
- Data Management Procedures
- Data Analysis Procedures.

Sampling Locations

Water quality monitoring was conducted at four separate stations (Figure 2) within the Freeland drainage basin. The selection of each individual monitoring location was driven by the data needs for each of the stated objectives of the monitoring program. For example, the locations for Stations 1 and 4 were selected to evaluate the relative pollutant contribution from two distinct land use categories within the basin (i.e., low-density residential versus commercial/retail, respectively). Similarly, the locations of Stations 2 and 3 were selected to evaluate the level of water quality treatment that potentially occurs in the open-channel ditch system that will be affected by the Freeland Park outfall project. In its present state, the open-channel ditch system might provide some water quality treatment through biofiltration and sedimentation processes. Table 1 provides a description of the location, purpose, subbasin area, and land use characteristics (based on current zoning information) for each monitoring station identified for this study. Subbasin boundaries for each station are shown in Figure 3. Each monitoring station is also described briefly below:

- **Station 1**: Located at the inlet of an 18-inch acrylonitrile butadiene styrene (ABS) pipe on the southeast corner of the intersection at Highway 525 and Main Street. The station was moved here from its original downstream location on the northeast corner of the intersection because the original site became difficult to sample due to flooded conditions. This station drains 457 acres in the uppermost portion of the Freeland drainage basin and represents approximately 65 percent of the total basin area draining to the outfall at Holmes Harbor. Flow is conveyed to this station via a network of drainage ditches in areas to the south of Highway 525. Based on available zoning information (Fakkema and Kingma, Inc. 2002), land use in the subbasin for Station 1 primarily consists of rural property (63 percent) and low-density residential development (20 percent).

Table 1. Location, purpose, subbasin area, and land use characteristics of monitoring stations identified for the Freeland water quality improvement project.

Station Number	Station Location	Station Purpose	Total Subbasin Area (hectares)	Subbasin Land Use Zoning (percentage [a])					
				Commercial	High/Medium -Density Residential	Low-Density Residential	Mixed Use	Public	Rural
1	Inlet of an 18-inch culvert located on SE corner of intersection at Hwy. 525 and S. Main St.	Basin water quality characterization; pollutant source identification	185	7.3%	0.0%	20.3%	8.5%	1.1%	62.7%
2	Upstream boundary of the open-channel ditch system to be affected by the Freeland Park outfall project.	Basin water quality characterization; pollutant source identification; open-channel ditch water quality treatment evaluation	200	14.3%	0.0%	18.9%	7.9%	1.0%	57.9%
3	Downstream boundary of the open-channel ditch system to be affected the Freeland Park outfall project (i.e., 100 feet upstream of crossing under Stewart Road).	Basin water quality characterization; pollutant source identification; open-channel ditch water quality treatment evaluation	215	15.7%	4.3%	17.6%	7.3%	0.9%	54.1%
4	Outfall of an 12-inch culvert located on NE corner of intersection at E. Layton Rd. and E. Harbor Rd.	Basin water quality characterization; pollutant source identification	42	31.4%	26.6%	34.0%	0.0%	0.0%	8.0%

[a] Subbasin land use zoning data are expressed as percentages of the total subbasin area for each monitoring station. Data source: Fakkema and Kingma, Inc. 2002.

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Figure 3. Water quality monitoring stations and associated subbasins for the Freeland water quality improvement project.

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- **Station 2**: Located at the upstream boundary of the open-channel ditch system to be affected by the Freeland Park outfall project. This station drains 495 acres in the upper and middle regions of the Freeland drainage basin and represents approximately 71 percent of the total basin area draining to the outfall at Holmes Harbor. This station is located directly downstream of Station 1 and receives runoff from the surrounding basin areas via a network of roadside ditches and a piped stormwater conveyance system. Land use in the subbasin for Station 2 consists primarily of rural property (58 percent), low-density residential development (19 percent), and commercial areas (14 percent).

- **Station 3**: Located at the downstream boundary of the open-channel ditch system to be affected by the Freeland Park outfall project (i.e., 100 feet upstream of the crossing under Stewart Road). This station drains 531 acres of the Freeland drainage basin and represents approximately 76 percent of the total basin area draining to the outfall at Holmes Harbor. This station receives flows directly from Station 2 via the open-channel ditch system. Station 3 also receives runoff from land areas directly adjacent to the open-channel ditch system. Land use in the subbasin for Station 3 consists primarily of rural property (54 percent), low-density residential development (18 percent), and commercial areas (16 percent).

- **Station 4**: Located at the outfall of a 12-inch culvert on the northeast corner of the intersection at E. Layton Road and East Harbor Road. This station receives runoff from the northeastern portion of the Freeland drainage basin that drains along East Harbor Road to the tidally influenced ditch system located on the south side of Steward Road. Land use in the 103 acre subbasin for Station 4 is primarily high/medium-density residential development (27 percent), low-density residential development (34 percent), and commercial areas (31 percent).

Sampling Schedule

- Water quality sampling for this study was initiated in January 2003 and concluded in the November of 2003. During this period, one water quality sample was collected from each of the four monitoring stations during eight separate storm events (Table 2). This sampling was targeted at storm events producing at least 0.25 inches of precipitation in a 24-hour period. Actual rainfall totals for sampled storm events were determined based on data from two separate rain gauges within the Freeland drainage basin that are maintained and operated by Fakema and Kingma, Inc. One of these gauges is located at the Freeland Plaza and the other is located on Fish Road (Figure 2).

Table 2. Storm and base flow sampling dates for the Freeland water quality improvement project.

Sampling Dates	
Storm Flow	Base Flow
1/22/2003	1/8/2003
3/12/2003	4/29/2003
4/13/2003	11/5/2003
4/24/2003	
10/20/2003	
11/10/2003	
11/16/2003	
11/18/2003	

In addition to the storm sampling identified above, one water sample was also collected from monitoring Station 1, 2, and 3 during three separate base flow events. Station 4 could not be sampled during base flow events due to a lack of flow. Each base flow sample was collected following a period of at least 3 days of dry weather. This sampling was also targeted to occur in three distinct seasons of the year when water was expected to be present at the monitoring stations (i.e., fall, winter, spring). The actual sampling dates for the base flow events are shown in Table 2.

In addition to the sampling identified above, an automated temperature logger (Hobo® Water Temp Pro) was installed in the ditch running parallel to Stewart Road on the south side of the road, approximately 200 feet downstream of Station 3. Data from this temperature logger were subsequently collected over the period from June 2003 through December 2003 to assess spring and summer temperature extremes in the lower reaches of the open-channel ditch system. The data from this instrumentation will be used to determine if temperature is a limiting factor for fish utilization in this area.

Sample Collection Procedures

The storm and base flow sampling identified for this project was conducted using a modified version of the "clean hands" and "dirty hands" protocol developed by the U.S. Environmental Protection Agency (U.S. EPA) (1996) for low-level detection of metals. The modified version of the protocol allowed sampling to be performed by one field technician as opposed to two. A detailed description of the modified protocol is provided in the Data Quality Assurance Report (see Appendix A).

When implementing this protocol, the sampling location was approached from downstream and, if possible, downwind to prevent contamination of the sample from disturbance of the channel bottom and by the sampler. Each grab sample was collected from the center of the stream or drainage channel by submerging the sample bottle below the water surface to mid-depth. For monitoring stations that are located at the outlet of a pipe, samples were collected from within the pipe or directly downstream of the pipe outlet, depending on access conditions.

Once the bottle had been allowed to fill, the bottle was capped while still submerged so that the sample never came in contact with the air. If sample bottles could not be fully submerged at a particular site due shallow water conditions, a clean wide-mouth bottle was used to scoop water from the stream or drainage channel and subsequently fill the required samples bottles. Immediately after filling, sample bottles were placed in a cooler with ice for transport to the laboratory.

In situ measurements for various field parameters (e.g., pH, dissolved oxygen, temperature, conductivity, and turbidity) were recorded using portable field meters during each sampling event identified for this project. Prior to sampling, the portable field meters were calibrated according to the manufacture's specifications. Actual measurements were then made by submerging the probe from each portable field meter to mid-depth in the center of the stream or drainage channel.

Following sample collection, discharge measurements were made at all monitoring station except Station 1 using a Swoffer Model 2100-13 portable flow meter. Specifically, the water velocity and cross-sectional area of the stream or drainage channel were measured and then converted to an estimate of discharge using protocols established for the Puget Sound region (U.S. EPA 1991). Discharge could not be directly measured at Station 1 because backwater conditions at this location that made water velocity measurements unreliable.

Monitoring Parameters

Grab samples collected during storm and base flow sampling were analyzed for the following parameters:

- Temperature (field measurement)
- pH (field measurement)
- Dissolved oxygen (field measurement)
- Conductivity (field measurement)
- Turbidity (field measurement)
- Hardness
- Total suspended solids
- Fecal coliform bacteria
- Ammonia nitrogen
- Nitrate + nitrite nitrogen
- Total phosphorus
- Total petroleum hydrocarbons (storm samples only)
- Total copper (storm samples only)
- Dissolved copper
- Total zinc (storm samples only)
- Dissolved zinc.

Analytical Procedures

Field measurements of temperature, pH, dissolved oxygen, turbidity, and conductivity were conducted using portable meters operated according to the manufacturer's directions and following standard measurement procedures (APHA, et al. 1992). Separate grab samples were collected at each station for conventional water quality parameters (hardness and TSS), nutrients (ammonia nitrogen, nitrate + nitrite nitrogen, and total phosphorus), fecal coliform bacteria, metals (total copper and zinc, and dissolved copper and zinc), and total petroleum hydrocarbons.

Laboratory analytical procedures followed U.S. EPA approved methods (APHA et al. 1992; U.S. EPA 1983,1984). These methods provide detection limits that are below the state and federal regulatory criteria or guidelines, and enable direct comparison of analytical results with these criteria. Analytical methods and detection limits are presented in Table 3.

Table 3. Methods and detection limits for water quality analyses.

Parameter	Method	Method Number [a]	Detection Limit/Unit
Temperature	Electrode	SM 2550B	0.1°C
pH	Electrometric	SM 4500-H and B	–
Dissolved Oxygen	Electrode	SM 4500-OG	0.1 mg/L
Conductivity	Platinum Electrode	SM 2510B	1 μmhos/cm
Hardness	EDTA Titrimetric	SM 2340C	2 mg/L as CaCO3
Turbidity	Nephelometric	SM 2130B	0.1 NTU
Total Suspended Solids	Gravimetric, 103°C	EPA 160.2	0.50 mg/L
Fecal Coliform Bacteria	Membrane Filter	SM 9222D	2 CFU/100 mL
Ammonia Nitrogen	Automated Phenate	EPA 350.1	0.010 mg/L
Nitrate + Nitrite Nitrogen	Automated Cadmium Reduction	EPA 353.2	0.010 mg/L
Total Phosphorus	Automated Ascorbic Acid	EPA 365.1	0.002 mg/L
Total Petroleum Hydrocarbon	GCFID	NWTPH	0.05 mg/L (diesel) 0.1 mg/L (motor oil)
Copper, Dissolved and Total	GFAA	EPA 220.2	0.001 mg/L
Zinc, Dissolved and Total	ICP	EPA 200.7	0.005 mg/L

[a] SM method numbers are from APHA et al. (1992); EPA method numbers are from U.S. EPA (1983, 1984).
EDTA: ethylenediaminetetracetic acid.
GFAA: graphite furnace atomic absorption.
GCFID: gas chromatograph, flame ionization detector.
ICP: inductively coupled plasma.
mg/L: milligrams per liter.
μmhos/cm: micromhos per centimeter.
$CaCO_3$ calcium carbonate.
NTU nephelometric turbidity units.
CFU colony forming unit.

Samples for parameters requiring filtration (i.e., dissolved copper and zinc) were delivered to the laboratory within 24 hours of their collection. Laboratory personnel immediately filtered and preserved these samples upon their receipt at the laboratory.

The laboratory used for this project (Aquatic Research, Inc.) is certified by the Washington State Department of Ecology (Ecology) and participates in audits and interlaboratory studies by Ecology and U.S. EPA. These performance and system audits have verified the adequacy of the laboratory standard operating procedures, which include preventative maintenance and data reduction procedures.

The laboratory reported the analytical results within 30 days of receipt of the samples. The laboratory provided sample and quality control data in standardized reports that are suitable for evaluating the project data. The reports include a case narrative summarizing any problems encountered in the analyses.

Data Management Procedures

Following each sampling event, all field and laboratory data were reviewed by the quality assurance officer to identify any quality control problems (see Appendix A). Collected data were then compiled in MS Excel™ spreadsheets for data management, analysis, and archiving purposes. These spreadsheets were formatted so as to conform with Ecology's "ten-year" rule. The ten-year rule requires that data documentation be sufficient to allow an individual, not directly familiar with the specific monitoring effort, to understand the purpose of the data set, methods used, results obtained, and quality assurance measures taken, up to 10 years after the data are collected.

Data Evaluation Procedures

Data evaluations used for this water quality assessment were performed to meet the following three objectives: 1) characterize baseline water quality conditions in the Freeland drainage basin, 2) evaluate water quality impacts on Holmes Harbor due to pollutant sources within the basin, and 3) identify the extent of water quality treatment, if any, afforded by the existing open-channel ditch system associated with the Freeland Park outfall project. Separate sections below describe the data evaluation procedures used to meet each of these objectives.

Baseline Water Quality Characterization

As described in the introduction to this document, data from this project are being used to characterize baseline water quality conditions in the Freeland drainage basin. This characterization included the following components: 1) generation of graphical and tabular data summaries; 2) a comparison of the data collected to other regional water quality data; 3) an evaluation of spatial water quality trends in the basin; 4) a comparison of the data collected to state water quality standards; and 5) an analysis of areal loading rates to identify pollutant sources in the basin. The specific data analysis procedures used for each of these components are described in the subsections below.

Generation of Graphical and Tabular Data Summaries

Data collected for this project were used to create tabular data summaries for each monitoring parameter by sampling station. The data were also imported to a data visualization software package (i.e., Statistica™) in order to generate graphical data summaries. The graphical data summaries consist of box plots showing key summary statistics (i.e., median, interquartile range, maximum, and minimum) for each parameter by sampling station. Where nondetect sample values were present in the data, the analytical method detection limit was used in all calculations. Values qualified as "estimates" through the quality assurance review (Appendix A) were also used in all calculations. The graphical data summaries facilitate comparisons of data that were collected during base and storm flow sampling, respectively, as well as comparison to regional water quality data and state water quality standards (see sections below).

Comparison to Regional Water Data

In order to provide a frame of reference for assessing water quality conditions in the Freeland drainage basin, collected data were compared to other regional water quality data (Table 4) that were compiled for this study. These data were obtained from King County (2003) and summarize water quality conditions near the mouths of 27 streams within the Puget Sound lowlands. The period of record for this data spans approximately 10 years (i.e., 1991–2001). Results from this analysis were summarized based on comparisons of the median values from this project to the upper and lower quartiles from the regional stream data (i.e., the 25^{th} and 75^{th} percentiles of the regional stream data). Specifically, anomalous conditions in the Freeland drainage basin were suggested when the median value for a given parameter fell below or above corresponding upper and lower quartiles, respectively, for the regional data.

Spatial Trend Analysis

Spatial trends in the Freeland basin were evaluated by comparing pollutant levels measured at each of the four monitoring stations. Statistical differences in these pollutant levels were assessed using the Friedman test, a nonparametric analogue to the blocked ANOVA (Helsel and Hirsch 1992). A nonparametric test was used because the data generally do not meet the required assumptions (e.g., normality and constant variance) required for a parametric test. A blocked test was used to remove noise or variance in the data that was introduced by sampling over a range of storm sizes. By removing this variance, spatial trends in the data are more easily detected. For parameters where statistical differences were detected using the Friedman test, a follow-up nonparametric multiple comparison test (Zar 1984) was conducted to determine which specific stations were significantly different from others. Statistical significance in all the analyses discussed above was evaluated at an alpha (α) level of 0.05.

Comparison of Data to State Water Quality Standards

In order to assess the level of water quality impairment in the Freeland drainage basin, data were compared to applicable Washington state surface water quality standards (WAC 173 201A). These standards vary depending on the specific designated uses that have been established for the water body in question. Designated uses for all streams in the Freeland drainage basin are as follows:

Table 4. Water quality statistics for stations located near the mouth of selected Puget Sound lowland streams (1991 through 2001).

Aquatic live uses: salmon spawning, noncore rearing, and migration

Water contact uses: primary contact recreation

The associated water quality standards for these designated uses are presented in Table 5. Results from this analysis were summarized based on the percentage of samples from each station that exceeded the applicable standard for a given parameter.

Table 5. Washington State surface water quality standards for the Freeland drainage basin.

Parameter	Standard
Temperature	Shall not exceed 17.5°C as a result of human activities. When natural conditions exceed 17.5°C, no temperature increase will be allowed that will raise the receiving water temperature by greater than 0.3°C. (Water temperature is measured by the 7-day average of the daily maximum temperatures [7-DADMAX].)
pH	Shall be within the range of 6.5 to 8.5 with a human-caused variation within this range of less than 0.5 units.
Dissolved oxygen	Short-term, 1-day minimum value shall exceed 8.0 mg/L.
Turbidity	Shall not exceed 5 NTU over background when background turbidity is 50 NTU or less, or has more than a 10 percent increase in turbidity when the background is more than 50 NTU.
Fecal coliform bacteria	Shall not exceed a geometric mean value of 100 organisms /100 mL, with not more than 10 percent of all samples (or any single sample when less than 10 sample points exist) obtained for calculating the geometric mean value exceeding 200 organisms/100 mL.
Ammonia	Shall not exceed an acute criterion for a 1-hour average concentration or a chronic criterion for a 4-hour average concentration. Acute and chronic criteria vary depending on pH, temperature, and presence/absence of salmonids. Assuming salmonids are present and typical values for temperature (15°C) and pH (7.0), acute and chronic ammonia criteria are 19.7 and 2.1 mg/L, respectively.
Copper, dissolved	Shall not exceed an acute criterion for a 1-hour average concentration or a chronic criterion for a 4-hour average concentration. Acute and chronic criteria vary depending on hardness. At a typical hardness value (100 mg $CaCO_3$/L), acute and chronic dissolved copper criteria are 17.0 and 11.4 µg/L, respectively.
Zinc, dissolved	Shall not exceed an acute criterion for a 1-hour average concentration or a chronic criterion for a 4-hour average concentration. Acute and chronic criteria vary depending on hardness. At a typical hardness value (100 mg $CaCO_3$/L), acute and chronic dissolved zinc criteria are 114 and 105 µg/L, respectively.

Source: WAC 173-201A.
mg/L: milligrams per liter.
µg/L: micrograms per liter.
mL: milliliter.
NTU: nephelometric turbidity unit.
$CaCO_3$: calcium carbonate.

Analysis of Areal Loading Rates

In order to identified subbasins and associated land use activities that are contributing to observed water quality problems within the Freeland drainage, instantaneous areal loading rates for each subbasin associated with a monitoring station were calculated by multiplying the pollutant concentration in a sample by the discharge rate measured at the time of sampling, and the dividing the result by the subbasin area. To facilitate interpretation of these data, an additional unit conversion was performed to express the instantaneous areal loading rates (e.g., mg/second-hectare) as daily areal loading rates (e.g., mg/day-hectare). These data then provided a basis for comparing the pollutant contribution from each of the four subbasins that were evaluated through this study. Subbasins having higher median areal loading rates for a particular pollutant were examined in more detail in an effort to identify a specific land use or activities that may be contributing to the problem. These calculations were performed for the following subset of parameters from this study: total suspended solids, total phosphorus, ammonia, nitrate + nitrite nitrogen, fecal coliform bacteria, total petroleum hydrocarbons, copper (total and dissolved), and zinc (total and dissolved).

As noted earlier, backwater conditions prevented direct measurement of discharge at Station 1. Therefore, areal loading rates for Station 1 were derived based on estimated discharge rates. Station 1 discharge rates were estimated from measured discharge rates for Station 2 that were adjusted in proportion to the subbasin areas of the two stations. According, Station 2 discharge rates were multiplied by 0.92, which is equivalent to the proportion of the two subbasin areas.

Holmes Harbor Water Quality Impact Evaluation

In order to evaluate potential water quality impacts on Holmes Harbor that stem from pollutant sources in the Freeland drainage basin, annual pollutant loads delivered to the harbor were calculated based on the monitoring data collected at Station 2 (Figure 2). These loading calculations were generated using a "rating curve" approach whereby models were developed from measured pollutant concentrations and discharge rates that allow pollutant loads to be predicted as a function of discharge (Helsel and Hirch 1992). Because data transformations are typically required to model this relationship using simple linear regression, a correction for transformation bias (e.g., smearing estimator) was applied to the calculated load estimates. These models were then used to predict pollutant loads for periods when no sampling had taken place. Load estimates for this analysis were derived for the 2003 calendar year using continuous discharge data from a gauging station located at Station 2 (Fakkema and Kingma 2004). (The monitoring and quality assurance plan that was prepared for the project had originally identified Station 3 for this analysis. However, flow data collected at this station proved too unreliable due to tidal influences and other operational problems.)

Loading estimates were generated for the following subset of parameters: total suspended solids, fecal coliform bacteria, ammonia nitrogen, nitrate + nitrite nitrogen, total phosphorus, total petroleum hydrocarbons (motor oil fraction), total and dissolved copper, and total and dissolved zinc. Annual pollutant loads for each of these parameters were subsequently converted to an areal loading rate by dividing the annual load by the subbasin area associated with Station 2. The calculated areal loading rates were subsequently compared to published values from various types of land use in order to quantify the relative impact of stormwater discharges from the Freeland drainage basin on the water quality of Holmes Harbor.

Open-Channel Ditch Treatment Evaluation

As noted earlier, the Freeland trunk drain project would divert high flows of stormwater from approximately 1,820 feet of an existing open-channel ditch that extends from just north of South Main Street in the community of Freeland to an outfall on Holmes Harbor near Stewart Road (Figure 2). High flows from the bypass system will ultimately discharge into Holmes Harbor through a new stormwater outfall that is being constructed as part of a separate project. The anticipated benefit of this new pipeline system will be a reduction in the incidence of flooding in the lowland areas of the Freeland drainage basin along Stewart Road (see Figure 2). However, any existing water quality improvements resulting from biofiltration and sedimentation processes in this open-channel ditch system would thereby be eliminated. Thus, the quality of stormwater delivered to Holmes Harbor could potentially worsen as a result of the Freeland Park outfall project.

In order to investigate the level of water quality treatment, if any, that occurs in the open-channel ditch system, pollutant loads measured at upstream and downstream locations in the ditch (i.e., Stations 2 and 3, respectively) were compared using a one-tailed Wilcoxon signed-rank test. Specifically, this test was used to determine whether loads measured at Station 3 are significantly lower than those at Station 2. The Wilcoxon singed-rank test is a nonparametric analogue to the paired t-test. A paired test was used in this analysis to eliminate noise or variance associated with sampling over a range of storm sizes (Helsel and Hirch 1992). By removing this variance, differences in upstream and downstream concentrations can be more efficiently assessed. Statistical significance in this analysis was evaluated at an alpha (α) level of 0.05. The following subset of parameters was analyzed using this approach: total suspended solids, fecal coliform bacteria, ammonia nitrogen, nitrate + nitrite nitrogen, total phosphorus, total petroleum hydrocarbons (motor oil fraction), total and dissolved copper, and total and dissolved zinc.

Results

This section summarizes the data collected for the Freeland water quality improvement project. This section begins with an evaluation of precipitation totals from the current monitoring period relative to historical precipitation averages, followed by results from the water quality.

Precipitation Results

In order to provide some context for interpreting the water quality data collected in 2003 for the Freeland water quality improvement project, monthly and annual precipitation totals from this period were compiled and compared to historical precipitation totals. Specifically, precipitation data collected over the 12-month period of January through December 2003 were obtained from two rain gauges located within the Freeland drainage basin (see Figure 2). Monthly precipitation totals recorded at these gauges are presented in Table 6. The 12-month precipitation total was 21.56 inches at the Freeland Plaza rain gauge and 23.67 inches at the Fish Road rain gauge. Based on long-term precipitation records compiled by the Island County Extension of Washington State University (2004), the average annual precipitation total for Freeland is 27.1 inches, indicating that 2003 was drier than normal.

Table 6. Monthly precipitation for the Freeland Plaza and Fish Road rain gauges, Freeland, Washington, 2003.

	Precipitation (inches)	
Month	Freeland Plaza	Fish Road [a]
January	4.24	2.76
February	1.00	1.19
March	2.77	3.10
April	2.21	2.19
May	1.37	0.50
June	0.67	0.52
July	0.03	0.04
August	0.23	0.37
September	0.97	1.33
October	0.27	3.32
November	4.37	4.23
December	3.43	4.10
Total	21.56	23.67

Source: Fakkema and Kingma, Inc. (2004).
[a] Rain gauge was installed January, 11, 2003.

Summary statistics (i.e., total precipitation, storm duration, and storm intensity) for the storm events sampled in 2003 are presented in Table 7 for each rain gauge. Based on data from the

Fish Road gauge, precipitation totals for sampled storms ranged from 0.37 to 2.60 inches, storm durations ranged from 8 to 42 hours, and average rainfall intensities ranged from 0.02 to 0.08 inches per hour. Similarly, data obtained from the Freeland Plaza gauge showed that precipitation totals for sampled storms ranged from 0.73 to 2.08 inches, storm duration ranged from 6 to 49 hours, and average rainfall intensities ranged from 0.03 to 0.06 inches per hour.

Table 7. Summary statistics for precipitation totals measured during sampled storm events for the Freeland water quality improvement project.

	Fish Road Rain Gauge			Freeland Plaza Rain Gauge		
Sample Date	Total Precipitation (inches)	Storm Duration (hours)	Precipitation Intensity (inches/hour)	Total Precipitation (inches)	Storm Duration (hours)	Precipitation Intensity (inches/hour)
1/22/2003	1.38	42	0.03	1.13	42	0.03
3/12/2003	0.61	24	0.02	0.59	23	0.03
4/13/2003	0.37	8	0.05	0.33	6	0.06
4/24/2003	NC	NC	NC	0.37	22	0.02
10/20/2003	1.54	31	0.05	NC	NC	NC
11/10/2003	0.37	15	0.03	0.32	12	0.03
11/16/2003	0.37	19	0.02	0.31	23	0.01
11/18/2003	2.60	32	0.08	2.08	49	0.04
Average:	1.03	24	0.04	0.73	25	0.03
Minimum:	0.37	8	0.02	0.31	6	0.01
Maximum:	2.60	42	0.08	2.08	49	0.06

Source: Fakkema and Kingma (2004).
NC: data not collected due to a data logger malfunction.

Water Quality Results

This section summarizes the results from water quality sampling conducted in 2003 for the Freeland water quality improvement project. The presentation of these results is organized into separate subsections for each of the following major study objectives: 1) characterize baseline water quality conditions in the Freeland drainage basin, 2) evaluate water quality impacts on Holmes Harbor due to pollutant sources within the basin, and 3) identify the extent of water quality treatment, if any, afforded by the existing open-channel ditch system associated with the Freeland Park outfall project. Additional supporting information for this section is also provided in Appendices A through D. For example, Appendix A presents the data quality assurance report for this project. All collected data are tabulated in the water quality database presented in Appendix B; while the associated laboratory reports, chain-of custody records, and data quality assurance worksheets are provided in Appendix C. Finally, results from the statistical trend analyses are summarized Appendix D.

Baseline Water Quality Characterization

This section describes baseline water quality characteristics in the Freeland drainage basin based on water quality data obtained through this study. The presentation of these data is organized in separate subsections for each major parameter category (e.g., conventional parameters, nutrients, bacteria, etc.). In each case, the significance of the parameter is described at the start of each subsection. Results from the associated data analyses are then presented in generally the following order: 1) summary statistics for base and storm flow samples; 2) comparisons of data to other regional data, where applicable; 3) an evaluation of any spatial trends in the basin as identified through statistical analyses; 4) comparisons of data to state water quality standards, where applicable; and 5) results from pollutant source identification analyses, where applicable.

Conventional Parameters

Temperature

The species composition and activity of aquatic organisms are regulated by temperature. For cold-blooded aquatic organisms, water temperature regulates their metabolism and ability to survive and reproduce effectively. Temperature also affects the natural self-purification processes that occur in water bodies. Thus, increased temperatures accelerate the biodegradation of organic matter present in water and sediments, resulting in increased demands on the dissolved oxygen resources of a system. In addition, increased water temperatures decrease the solubility of oxygen. The Washington state standard for streams in the Freeland drainage basin requires that the seven-day average of the daily maximum temperatures (7-DADMAX) shall not exceed 17.5˚C or increase more than 0.3˚C as a result of human activities. For this discussion, temperatures measured in the field during sampling events were compared to the criteria on an instantaneous basis, and continuous temperature data collected at Station 3 were compared to the 7-DADMAX criteria.

Summary statistics for grab sample temperature data are presented in Tables 8 and 9 for storm and base sampling events, respectively. These data are also presented graphically using box plots in Figure 4. Grab sample temperature measurements for all stations and sampling events ranged from 3.2 to 15.4°C. Median temperatures during storm flow (Table 8) ranged from 9.7°C at Station 1 to 10.3°C at Station 4, and median temperatures during base flow (Table 9) ranged from 5.0°C at Station 3 to 6.6°C at Station 2. All four stations exhibited median temperatures during storm flow that were between the upper and lower quartiles of regional stream data (Figure 4). Median temperatures during base flow were cooler relative to the regional stream data.

Results from the spatial trend analysis (see Appendix D) indicated that storm flow temperatures were significantly lower ($p=0.0027$) at Station 1 relative to all the other monitoring stations. There were no significant differences between monitoring stations for temperature during base flow.

Table 8. Summary statistics for storm flow samples collected from the four Freeland drainage basin monitoring stations.

Table 9. Summary statistics for base flow samples collected from the four Freeland drainage basin monitoring stations.

Figure 4. Temperatures measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Grab sample temperature measurements never exceeded the state standard of 17.5°C during either storm or base flow (Table.10). However, 7-DADMAX temperature data obtained from the continuously logging probe at Station 3 (Figure 5) showed the state standard was exceeded continuously over the period between June 20, 2003 (the first date for which the 7-DADMAX could be calculated) and October 10, 2003. After this date, the state temperature standard was not exceeded again through the end of the instrument's deployment on December 31, 2003. These data suggest that temperature may be a limiting factor for some aquatic organisms in the lower reaches of the study area.

pH

pH is a measure of the hydrogen ion activity in water, which can have a direct effect on aquatic organisms, or an indirect effect by virtue of the fact that the toxicity of several common pollutants are markedly affected by changes in pH. Waters that exhibit a pH in the range of 0.0 to 7.0 are considered acidic, while waters with pH ranging from 7.0 to 14.0 are considered alkaline. Washington state standards for streams in the Freeland drainage basin dictate that acceptable pH values range from 6.5 to 8.5 and limit human-caused variation to 0.5 units.

Summary statistics for pH are presented in Tables 8 and 9 for storm and base sampling events, respectively. These data are also presented graphically using box plots in Figure 6. For all stations and sampling events, measurements of pH ranged from 6.02 to 10.20. Median pH values during storm flow (Table 8) ranged from 6.41 at Station 2 to 6.87 at Station 3, and median pH values during base flow (Table 9) ranged from 6.39 at Station 2 to 7.23 to Station 3. All four stations exhibited median pH values that were generally lower than those from the regional stream data during storm flow (Figure 6). Median pH levels during base flow were also lower at Stations 1 and 2 relative to regional stream data, while the median pH level at Station 3 fell between the upper and lower quartiles of these data. There were no significant differences in pH levels between stations during either storm flow or base flow (see Appendix D).

Measured pH levels from Stations 1, 2, and 4 were often low relative to the allowable range dictated by state water quality standards (i.e. 6.5 to 8.5). For example, the number of storm flow samples violating the standard for pH ranged from 25 to 75 percent at Stations 1 and 2, respectively (Table 10). During base flow, all of the samples collected from both Station 1 and Station 2 exceeded the standard. In contrast, none of the samples collected from Station 3 was found to exceed the standard. The low pH values observed at monitoring Stations 1 and 2 are likely related to humic acids emanating from several large wetland complexes in the headwater regions of the Freeland drainage basin. Stagnant water conditions also occur in a stormwater conveyance pipe located between Stations 1 and 2 (see Figure 2) due to a head differential within pipe's outlet structure. Related low dissolved oxygen concentrations in this pipe (see next section) are likely creating a reducing environment that decreases pH levels in the water.

Dissolved Oxygen

Dissolved oxygen (DO) is important to the survival of fish and other aquatic life and the protection of aesthetic qualities of water. To allow for differences among requirements by affected species of fish and other aquatic organisms, dissolved oxygen standards are based on

Table 10. Percentage of storm and base flow samples from the Freeland drainage basin that exceeded Washington state water quality criterion.

Figure 5. Instantaneous and 7-DADMAX temperature data from the continuously logging probe at monitoring Station 3 in the Freeland drainage basin.

8.5 X 11, b/w

Figure 6. Levels of pH measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

concentrations that supports a well-rounded population of fish. The Washington state standard for streams in the Freeland drainage basin requires that a short-term, 1-day minimum value for dissolved oxygen shall exceed 8.0 mg/L.

Summary statistics for dissolved oxygen data are presented in Tables 8 and 9 for storm and base sampling events, respectively. These data are also presented graphically using box plots in Figure 7. Dissolved oxygen measurements across all stations and sampling events ranged from 0.3 to 12.4 mg/L. Median dissolved oxygen concentrations during storm flow (Table 8) ranged from 7.3 mg/L at Stations 1 and 2 to 10.8 mg/L at Station 4. Median concentrations during base flow (Table 9) ranged from 1.5 mg/L at Station 1 to 10.4 mg/L at Station 3. Stations 1 and 2 exhibited median dissolved oxygen concentrations that were generally low relative to the regional data during both storm and base flow (Figure 7). Median concentrations for Station 3 fell within the upper and lower quartiles of the regional stream data for both storm and base flow, as did the median at Station 4 for storm flow samples.

Tables 8 and 9 also present summary statistics for dissolved oxygen data based on percent saturation during storm and base sampling events, respectively. (Percent saturation is the measured dissolved oxygen level divided by the maximum amount of oxygen that the water can hold under current temperature and atmospheric pressure conditions multiplied by 100.) Percent saturation across all stations and sampling events ranged from 2.2 to 105 percent. Median percent saturation values during storm flow (Table 8) ranged from 63.1 percent at Stations 2 to 96.6 percent at Station 4. Median percent saturation values during base flow (Table 9) ranged from 11.8 percent at Station 1 to 86.8 percent at Station 3.

Storm flow dissolved oxygen concentrations exhibited a significant ($p=0.0001$) increasing trend downstream through all four monitoring stations (see Appendix D). In contrast, there were no significant differences between monitoring stations during base flow. The downstream increasing trend for dissolved oxygen concentrations during storm flow is likely related to stagnant water conditions within the large wetland complexes that are located in headwater regions of the Freeland drainage basin. Stagnant water conditions also occur in a stormwater conveyance pipe located between Stations 1 and 2 (see Figure 2) due to a head differential within pipe's outlet structure. As stormwater moves progressively downstream from these areas, increased turbulent flow and the associated aeration may be contributing to the observed increase in dissolved oxygen concentrations.

Dissolved oxygen levels measured at Stations 1 and 2 were often below the allowable limit established pursuant to state water quality standards (i.e. 1-day minimum value of 8.0 mg/L). For example, 50 and 63 percent of the storm flow samples collected from Stations 1 and 2, respectively, exhibited dissolved oxygen concentrations that violated the state standard (Table 10). All of the base flow samples collected from Stations 1 and 2 had dissolved oxygen concentrations that violated this standard. In contrast, the standard was never exceeded at Stations 3 or 4 during either storm or base flow, although none of the sampling events occurred in the summer months when low dissolved oxygen conditions would be more likely to occur.

Figure 7. Dissolved oxygen measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Conductivity

Specific conductance or conductivity is a measure of the ability of water to conduct an electrical current, which is directly related to the content of dissolved ions (solids) in the water. This measurement is useful for identifying sources of dissolved pollutants and for determining the relative flow contributions attributed to ground water, because conductivity is typically higher in ground water than in surface waters. There are no state water quality standards for conductivity in streams.

Summary statistics for conductivity data are presented in Tables 8 and 9 for storm and base sampling events, respectively. These data are also presented graphically using box plots in Figure 8. Conductivity measurements for all stations and sampling events ranged from 27.5 to 1180 μmhos/cm. Median conductivity values during storm flow (Table 8) ranged from 41.5 μmhos/cm at Station 4 to 135 μmhos/cm at Station 1. Median conductivity values during base flow (Table 9) ranged from 280 μmhos/cm at Station 3 to 487 μmhos/cm at Station 1. During storm flow, median conductivity levels for Stations 1, 2, and 3 were within the upper and lower quartiles of regional stream data, while the median value for Station 4 was low relative to these data (Figure 8). Median conductivity values for base flow at Stations 1, 2, and 3 were all high relative to the regional stream data.

Results from the spatial trend analysis (see Appendix D) showed that conductivity levels were significantly ($p=0.0008$) higher at Station 1 relative to Station 4 during storm flow. Storm flow conductivity levels at Stations 2 and 3 were not differentiated from any other station in this analysis. There were also no significant differences in conductivity levels between stations during base flow.

Hardness

Hardness measurements are based on the concentrations of calcium and magnesium in the water, which directly affect the toxicity of some heavy metals (i.e., metals are more toxic at lower levels of hardness). Hardness measurements are necessary for determining compliance with state water quality standards for several dissolved metals, including copper and zinc.

Summary statistics for hardness data are presented in Tables 8 and 9 for storm and base sampling events, respectively. These data are also presented graphically using box plots in Figure 9. Hardness measurements across all stations and sampling events ranged from 10.0 to 178 mg/L (measured as equivalents to CaCO3). Median values for hardness during storm flow (Table 8) ranged from 14.6 mg/L at Station 4 to 59.8 mg/L at Station 1. Median values during base flow (Table 9) ranged from 74.7 mg/L at Station 1 to 94.2 mg/L at Station 2. Regional stream data for hardness are not available for comparison purposes.

Results from the spatial trend analysis (see Appendix D) showed that hardness concentrations were significantly ($p=0.0001$) higher at Stations 1 and 3 relative to Station 4 during storm flow. Storm flow hardness concentrations at Stations 2 were not differentiated from any other station in this analysis. Hardness concentrations at Station 4 are likely lower because flows at this

Figure 8. Conductivity levels measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Figure 9. Hardness concentrations measured during storm and base flow sampling events in the Freeland drainage basin.

8.5 X 11, b/w

station come mainly from direct surface runoff having low calcium and magnesium concentrations relative to water from ground water seepage. In contrast, ground water seepage likely represents a much higher proportion of the flow at Stations 1 and 3. There were no significant differences in hardness concentrations between stations during base flow.

Turbidity

Turbidity is a measure of particulate matter in water that reduces water transparency or clarity. Measurements of turbidity in nephelometric turbidity units (NTU) are used to determine whether state standards have been exceeded. There are no absolute turbidity standards for a water sample; rather, the standard states that changes in turbidity due to human activity shall not exceed 5 NTU over background when background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background is more than 50 NTU. For this discussion, modifications to the drainage by development are considered human activities, and compliance with the standards was determined at Station 2 based on background levels measured at Station 1, and at Station 3 based on background levels measured at Station 2.

Summary statistics for turbidity data are presented in Tables 8 and 9 for storm and base sampling events, respectively. These data are also presented graphically using box plots in Figure 10. Turbidity measurements for all stations and sampling events ranged from 1.6 to 82.6 NTU. Median turbidity levels during storm flow (Table 8) ranged from 14.8 NTU at Station 1 to 35.0 NTU at Station 4, and median turbidity levels during base flow (Table 9) ranged from 4.16 NTU at Station 3 to 6.20 NTU at Station 2. Median storm flow turbidity levels at Stations 1, 2, and 3 were within the upper and lower quartiles of regional stream data during storm flow, while the median level for Station 4 was higher relative to these data (Figure 10). Median base flow turbidity values for Stations 1, 2, and 3 were all higher relative to the regional stream data. There were no significant differences in turbidity levels between monitoring stations during either storm flow or base flow (see Appendix D).

As shown Table 10, state turbidity standards were only exceeded at Station 2 during one storm event (9 percent of all samples) and at Station 3 during 2 storms (18 percent of all samples). These data suggest that turbidity is only a moderate water quality concern in the basin.

Total Suspended Solids

Total suspended solids are the most widespread pollutants entering surface waters. Solids, especially the finer fractions, reduce light penetration in water and can have a smothering effect on fish spawning and benthic biota. Suspended solids are also closely associated with other pollutants such as nutrients, bacteria, metals, and organic compounds. These pollutants tend to adsorb onto the solids particles and are consequently transported in surface runoff to receiving waters if no on-site controls are implemented for solids removal. Thus, the presence of suspended solids is used to evaluate the overall pollutant loading within a basin. No state standards have been established for suspended solids.

Figure 10. Turbidity levels measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Summary statistics for total suspended solids data are presented in Tables 8 and 9 for storm and base sampling events, respectively. These data are also presented graphically using box plots in Figure 11. Total suspended solids measurements for all stations and sampling events ranged from 1.6 to 108 mg/L. Median storm flow total suspended solids concentrations (Table 8) ranged from 10.0 mg/L at Station 2 to 28.5 mg/L at Station 4, and median base flow concentrations ranged from 2.5 mg/L at Station 3 to 5.7 mg/L at Station 2. Median storm flow total suspended solids concentrations at Stations 1, 3, and 4 were within the upper and lower quartiles of regional stream data, while Station 2 had concentrations that were low relative to these data (Figure 11). Median base flow total suspended solids values at Stations 1, 2, and 3 were also within the upper and lower quartiles of regional stream data. There were no significant differences in TSS concentrations between stations during either storm flow or base flow (see Appendix D).

Median areal loading rates (Table 11) for total suspended ranged from 42 mg/day-ha at Station 1 to 416 mg/day-ha at Station 4. These data would suggest that the commercial and high/medium-density residential land uses in the subbasin associated with Station 4 (see Table 1) are a significant source for this pollutant relative to the rural and low-density residential land use that predominates in other subbasins (e.g., Station 1 and 2).

Nutrients

The nutrients of general concern in runoff are nitrogen and phosphorus. These elements are primary nutrients for the growth of algae and other plants in freshwater ecosystems, including wetlands, streams, and lakes. Inputs of large quantities of nitrogen and phosphorus can cause excessive algal growth and a general decline in the quality of receiving waters. Common sources of nitrogen and phosphorus are fertilizers and nutrient-containing soils that have eroded and washed into the stream. No state standards have been established for nutrients based upon their eutrophication affects (i.e. there are no standards for total phosphorus or nitrate + nitrite nitrogen), but there are standards for ammonia based upon its toxicity (see Table 5).

Total Phosphorus

Summary statistics for total phosphorus data are presented in Tables 8 and 9 for storm and base sampling events, respectively. These data are also presented graphically using box plots in Figure 12. Total phosphorus (TP) concentrations for all stations and sampling events ranged from 0.033 to 1.24 mg/L. Median storm flow TP concentration (Table 8) ranged from 0.104 mg/L at Station 4 to 0.151 mg/L at Station 1, and median base flow concentrations (Table 9) ranged from 0.071 mg/L at Station 3 to 0.287 mg/L at Station 1. All four monitoring stations exhibited median TP concentrations during storm flow that fell between the upper and lower quartiles of regional stream data (Figure 12). During base flow, median concentrations measured at Stations 1 and 2 were high relative to the regional stream data while the median at Station 3 was within the upper and lower quartiles of these data.

Results from the spatial trend analysis (see Appendix D) showed that storm flow total phosphorus concentrations were significantly higher ($p=0.0314$) at Station 1 relative to Station 4.

Figure 11. Total suspended solids concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Table 11. Median areal pollutant loading rates for storm flow samples collected from the Freeland drainage basin by monitoring station.

Figure 12. Total phosphorus concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Storm flow total phosphorus concentrations at Stations 2 and 3 were not differentiated from any other station in this analysis. Base flow total phosphorus concentrations were significantly (p=0.0498) higher at Station 1 relative to Station 3. Base flow total phosphorus concentrations at Stations 2 were not differentiated from any other station in this analysis.

Median areal loading rates for TP ranged from 1,155 mg/day-ha at Stations 1 to 1,010 mg/day-ha at Station 2 (Table 11). Land use within the subbasin for Station 1 is predominately rural (see Table 1). Thus, the higher areal loading rate for this subbasin may be related to agricultural activities (e.g., fertilizer applications) that are typically associated with rural areas.

Ammonia

Summary statistics for ammonia data are presented in Tables 8 and 9 for storm and base sampling events, respectively. These data are also presented graphically using box plots in Figure 13. Across all stations and sampling events, ammonia measurements ranged from <0.010 to 0.622 mg/L. Median concentrations during storm flow for ammonia (Table 8) ranged from 0.014 mg/L at Station 3 to 0.045 mg/L at Station 1, and median concentrations during base flow (Table 9) ranged from 0.020 mg/L at Station 3 to 0.217 mg/L at Station 2. Median storm flow concentrations at stations 1, 2, and 4 were all within the upper and lower quartiles of the regional stream data, while the median concentration for Station 3 was low relative to these data. During base flow, median ammonia concentrations at Stations 1 and 2 were high relative to the regional stream data, while the median value at Station 3 fell within the upper and lower quartiles of these data. There was no significant difference in median ammonia concentration between stations during either storm flow or base flow (see Appendix D). Furthermore, ammonia concentrations never exceeded the state water standard during either storm or base flow.

Median areal loading rates for ammonia (Table 11) ranged from 112 mg/day-ha at Station 3 to 487 mg/day-ha at Station 4. Again, these data would suggest that the commercial and high/medium-density residential land uses in the subbasin associated with Station 4 (see Table 1) are a significant source for this pollutant in the Freeland drainage basin.

Nitrate + Nitrite Nitrogen

Summary statistics for nitrate + nitrite nitrogen data are presented in Tables 8 and 9 for storm and base sampling events, respectively. These data are also presented graphically using box plots in Figure 14. Nitrate + nitrite nitrogen measurements for all stations and sampling events ranged from 0.13 to 2.4 mg/L. Median storm flow nitrate + nitrite nitrogen concentrations (Table 8) ranged from 0.126 mg/L at Station 1 to 0.417 mg/L at Station 3, and median base flow concentrations ranged from 0.035 mg/L at Station 1 to 0.340 mg/L at Station 3. All stations exhibited nitrate + nitrite nitrogen concentrations that were low relative to the regional stream data during both storm and base flow (Figure 14).

Results from the spatial trend analysis (see Appendix D) showed that nitrate + nitrite nitrogen concentrations were significantly (p=0.0336) higher at Station 3 relative to Station 4 during storm flow. Storm flow concentrations measured at Stations 1 and 2 were not differentiated from

Figure 13. Ammonia concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Figure 14. Nitrate + nitrite nitrogen concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

any other station in this analysis. There were also no significant differences in nitrate + nitrite nitrogen concentrations between stations during base flow.

Median areal loading rates for nitrate + nitrite nitrogen ranged from 1,243 mg/day-ha at Station 1 to 3,349 mg/day-ha at Station 3 (see Table 11). The subbasin for Station 3 contains a mix of rural, low-density residential, and commercial land uses (see Table 1). Thus, the high areal loading rate for this subbasin may be related to agricultural activities (e.g., fertilizer applications) that are typically associated with rural areas. Alternatively, failing septic systems in residential areas may also be a source for this pollutant.

Bacteria

Fecal Coliform Bacteria

Runoff from human development characteristically contains high levels of fecal coliform bacteria. These organisms are used as indicators of fecal contamination from humans and other warm-blooded animals. Human sources include failing septic systems, municipal wastewater discharges, and cross-connections with municipal wastewater systems. Animal sources include pets, livestock, and wildlife (birds and mammals). The simple presence of these bacteria does not necessarily indicate a threat to public health because only a small proportion, if any, are likely to be pathogenic to humans. However, their use as an indicator of potential fecal contamination is considered important in the early detection of problems that could lead to public health concerns.

Pursuant to state standards, fecal coliform bacteria concentrations in the Freeland drainage basin cannot exceed a geometric mean value of 100 organisms/100 mL, with not more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 organisms/100 mL. If fewer than 10 sample points exist, no single sample shall exceed 200 organisms/100 mL. Because only eight storms were sampled, the data will be compared to the latter criteria in this analysis.

Summary statistics for fecal coliform bacteria data are presented in Tables 8 and 9 for storm and base flow sampling events, respectively. These data are also presented graphically using box plots in Figure 15. Fecal coliform bacteria concentrations for all stations and sampling events ranged from 2 to 4,600 colony forming units (CFU)/100 ml at Station 1 during storm flow. Median storm flow fecal coliform bacteria concentrations (Table 8) ranged from 510 CFU/100 ml at Station 3 to 980 CFU/100 ml at Station 4, and median base flow concentrations (Table 9) ranged from 100 CFU/100 ml at Station 1 to 240 CFU/100 ml at Station 2. All four monitoring stations had median fecal coliform bacteria concentrations that were within the upper and lower quartiles of the regional stream data during storm flow (Figure 15). During baseflow, median concentrations for Stations 1 and 3 were also within the upper and lower quartiles for the regional stream data while the median for Station 2 was high relative to these data. There were no significant differences in fecal coliform bacteria concentrations between stations during storm flow or during base flow (see Appendix D).

Figure 15. Fecal coliform bacteria concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Fecal coliform bacteria concentrations measured during storm and base flow at all stations frequently exceeded the state standard (i.e., 200 CFU/100 mL). For example, the number of storm flow samples violating the state water quality standard for fecal coliform bacteria ranged from 63 percent at Station 1 to 100 percent at Stations 2 and 3 (Table 10). Similarly, the number of base flow samples violating the standard ranged from 33 percent at Station 1 to 100 percent at Station 2. These data suggest that fecal coliform bacteria are a significant water quality problem in the Freeland drainage basin.

Median areal loading rates for fecal coliform bacteria ranged from 3.6×10^7 CFU/day-ha at Station 2 to 1.3×10^8 CFU/day-ha at Station 4 (see Table 11). Again, these data suggest that the commercial and high/medium-density residential land uses in the subbasin associated with Station 4 (see Table 1) are a significant source for this particular pollutant in the Freeland drainage basin.

As noted previously, failing septic systems and waste from pets, livestock, and wildlife (birds and mammals) are common sources for fecal coliform bacteria. It should be noted that the entire Freeland drainage basin is served by septic systems (Parvin 2004). However, the specific sources for the observed contamination cannot be determined based on the available data from this study. In order to identify these sources, additional focused study would be required. This could include a microbial source tracking (MST) study and/or extensive sanitary surveys within the basin. (MST studies use a genetic fingerprinting [molecular ribotyping] technique to identify sources of fecal coliform bacteria [e.g., septic tanks, wildlife, pet wastes] in a given watershed.)

Total Petroleum Hydrocarbons

Total petroleum hydrocarbons (TPH) is a term used to describe a large family of several hundred chemical compounds that originate from crude oil. Crude oil is used to make petroleum products, such as diesel fuel and motor oil, which can contaminate the environment by leaking from fuel tanks or cars and trucks. TPH is concern because these compounds can be toxic to aquatic organisms. Two distinct fractions of petroleum hydrocarbons were analyzed in this study: the diesel-fraction and the motor oil fraction. Only storm flow samples were analyzed for TPH. There are no applicable state water quality standards for either parameter.

Total Petroleum Hydrocarbons – Diesel Fraction

Summary statistics for the TPH (diesel fraction) are presented in Table 8. These data are also presented graphically using box plots in Figure 16. The TPH (diesel fraction) was detected in only one sample (0.05 mg/L at Station 1) out of all the storm flow samples collected for this study. Based on this information, contamination from TPH (diesel fraction) does not appear to be a significant problem in the Freeland drainage basin.

Total Petroleum Hydrocarbons – Motor Oil Fraction

Summary statistics for the TPH (motor oil fraction) are presented in Table 8. These data are also presented graphically using box plots in Figure 17. During storm flow, TPH (motor oil fraction)

Figure 16. Total petroleum hydrocarbons (diesel fraction) concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Figure 17. Total petroleum hydrocarbons (motor oil fraction) concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

concentrations ranged from <0.10 to 1.47 mg/L. Median storm flow concentrations of TPH (motor oil fraction) ranged from <0.10 mg/L at Station 1 to 0.645 mg/L at Station 4. Regional stream data for TPH (motor oil fraction) are not available for comparison purposes.

Results from the spatial trend analysis (see Appendix D) showed that storm flow TPH (motor oil fraction) concentrations were significantly (p=0.0006) higher at Station 4 relative to Stations 1 and 3. Storm flow concentrations measured at Station 2 were not differentiated from any other station in this analysis.

Median areal loading rates for TPH (motor oil fraction) ranged from 595 mg/day-ha at Station 1 to 7,774 mg/day-ha at Station 4 (see Table 11). Again, these data would suggest that the commercial and high/medium-density residential land uses in the subbasin associated with Station 4 (see Table 1) are a significant source for this pollutant.

Metals

Metals are among the most common toxicants found in urban runoff. The form of a metal that is most toxic to aquatic biota is the free ionic (or dissolved) state. Water hardness directly influences the toxic effects on aquatic biota of a given metal concentration. Therefore, state surface water quality standards have been established for various dissolved metals based on water hardness (WAC 173-201A). Copper and zinc were the only two metals evaluated in this study. Dissolved and total concentrations of these metals were measured during storm flow whereas only dissolved concentrations were measured during base flow.

Dissolved Copper

Summary statistics for the dissolved copper are presented in Tables 8 and 9 for storm and base flow sampling events, respectively. These data are also presented graphically using box plots in Figure 18. Across all sampling events, dissolved copper concentrations ranged from <0.0010 to 0.0091 mg/L. Median dissolved copper concentrations during storm flow (Table 8) ranged from 0.0017 mg/L at Station 4 to 0.0036 mg/L at Station 2, and median base flow concentrations (Table 9) ranged from <0.0010 mg/L at Station 1 to 0.0040 mg/L at Station 2. During storm flow, median dissolved copper concentrations at Stations 1, 2, and 3 were high relative to the regional stream data whereas the median concentration for Station 4 fell within the upper and lower quartiles of these data. Base flow regional stream data were not available for comparison purposes.

Results from the spatial trend analysis (see Appendix D) showed that storm flow dissolved copper concentrations were significantly (p=0.0222) higher at Station 2 relative to Station 4. Storm flow concentrations measured at Stations 1 and 3 were not differentiated from any other station in this analysis. There were also no significant differences in dissolved copper concentrations between stations during base flow.

Dissolved copper concentrations measured during storm flow at Stations 2, 3, and 4 exceeded state standards on a number of occasions. For example, the number of storm flow samples

Figure 18. Dissolved copper concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

violating the state water quality standard for dissolved copper ranged from 13 to 38 percent at Stations 3 and 2, respectively (Table 10). Storm flow dissolved copper concentrations at Station 1 never exceeded the state standard. Similarly, base flow dissolved copper concentrations at all stations never exceeded the state standard. These results indicate that the storm flow dissolved copper concentrations in the lower reaches of the Freeland drainage basin may be acutely toxic to some aquatic organisms.

Median areal loading rates for dissolved copper ranged from 20 mg/day-ha at Station 2 to 26 mg/day-ha at Stations 3 (see Table 11). This narrow range in values would suggest that no single subbasin that can be identified as a primary source for this pollutant.

Total Copper

Summary statistics for total copper are presented in Table 8 for the sampled storm events. These data are also presented graphically using box plots in Figure 19. Total copper measurements for all stations and storm sampling events ranged from <0.0010 to 0.0157 mg/L. Median total copper concentrations (Table 8) ranged from 0.0041 mg/L at Station 4 to 0.0063 mg/L at Station 2. Median total copper concentrations were all within the upper and lower quartiles of the regional stream data. Furthermore, there were no significant differences in total copper concentrations between stations (see Appendix D).

The median instantaneous areal loading rates for total copper ranged from 31 mg/day-ha at Stations 1 to 42 mg/day-ha at Station 4 (see Table 11). Again, land uses in the subbasin associated with Station 4 appear to be a primary source for this pollutant in the Freeland drainage basin.

Dissolved Zinc

Summary statistics for dissolved zinc are presented in Tables 8 and 9 for storm and base flow sampling events, respectively. These data are also presented graphically using box plots in Figure 20. Dissolved zinc measurements for all stations and sampling events ranged from <0.005 to 0.171 mg/L. Median storm flow concentrations for dissolved zinc (Table 8) ranged from <0.005 mg/L at Station 1 to 0.055 mg/L at Station 2, and median base flow concentrations (Table 9) ranged from 0.013 mg/L at Station 1 to 0.039 mg/L at Station 2. During storm flow, median dissolved zinc concentrations at Stations 2, 3, and 4 were all high relative to the regional stream data for storm flow. Base flow regional stream data were not available for comparison purposes.

Results from the spatial trend analysis (see Appendix D) showed that storm flow dissolved zinc concentrations were significantly ($p=0.0030$) higher at Stations 2 and 4 relative to Station 1. Storm flow concentrations at Station 3 were not differentiated from any other station in this analysis. There were also no significant differences in dissolved zinc concentrations between stations during base flow.

Dissolved zinc concentrations measured during storm flow at Stations 2 and 4 exceeded state standards on a number of occasions. For example, 75 and 100 percent of the storm flow samples

Figure 19. Total copper concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Figure 20. Dissolved zinc concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

collected from Stations 2 and 4, respectively, exceeded the state standard (Table 10). Storm flow dissolved zinc concentrations at Stations 1 and 3 never exceeded the state standard. Similarly, base flow dissolved zinc concentrations at all stations never exceeded the state standard. These data indicate that storm flow dissolved zinc concentrations are a source of water impairment in some areas within the Freeland drainage basin.

The median instantaneous areal loading rates for dissolved zinc ranged from 67 mg/day-ha at Station 1 to 617 mg/day-ha at Stations 4 (see Table 11). Again, land uses in the subbasin associated with Station 4 appear to be a primary source for this particular pollutant in the Freeland drainage basin.

Total Zinc

Summary statistics for total zinc are presented in Table 8 for the sampled storm events. These data are also presented graphically using box plots in Figure 21. Total zinc concentrations for all stations and storm sampling events ranged from <0.005 to 0.238 mg/L. Median concentrations (Table 8) ranged from 0.009 mg/L at Station 1 to 0.068 mg/L at Station 2. The median total zinc concentration at Station 1 was within the upper and lower quartiles of the regional stream data while median concentrations for Stations 2, 3, and 4 were higher relative to these data.

Results from the spatial trend analysis (see Appendix D) showed that storm flow total zinc concentrations were significantly ($p=0.0096$) higher at Stations 2 and 4 relative to Station 1. Storm flow concentrations at Station 3 were not differentiated from any other station in this analysis.

The median instantaneous areal loading rates for total zinc ranged from 121 mg/day-ha at Station 1 to 810 mg/day-ha at Station 4 (see Table 11). Again, land uses in the subbasin associated with Station 4 appear to be a primary source for this pollutant (and others) in the Freeland drainage basin.

Evaluation of Water Quality Impact on Holmes Harbor

Areal loading estimates for pollutants delivered to Holmes Harbor were estimated based on the water quality and discharge data collected at Station 2 (see Figure 2). These loads were computed for the following subset of parameters evaluated in connection with this study: total suspended solids, fecal coliform bacteria, ammonia nitrogen, nitrate + nitrite nitrogen, total phosphorus, total petroleum hydrocarbons (motor oil fraction), total and dissolved copper, and total and dissolved zinc. As described in the Methods section, the load estimates were generated using a “rating curve” approach whereby models are developed from measured pollutant concentrations and discharge rates that allow pollutant loads to be predicted as a function of discharge (Helsel and Hirch 1992). These models are then used to predict pollutant loading for those periods between sampling. Loading estimates for this analysis were calculated for the 2003 calendar year using continuous discharge data (Figure 22) from the gauging station located at Station 2 and obtained from Fakkema and Kingma, Inc. (2004).

Figure 21. Total zinc concentrations measured during storm and base flow sampling events in the Freeland drainage basin compared to other Puget Sound lowland streams.

8.5 X 11, b/w

Figure 22. Discharge data from the continuously logging probe at monitoring Station 2 in the Freeland drainage basin.

8.5 X 11, b/w

Summary information for each model that was developed from this analysis is presented in Table 12. The actual loading rates (total and areal) that were computed based on these models are shown in Table 13. To provide a frame of reference for interpreting these results, published areal loading rates for various land uses (Horner 1994) were compiled and are summarized in Table 14. The published rates were derived from the general scientific literature and data collected specifically in the Pacific Northwest.

Table 12. Summary information for linear regression models used to predict annual pollutant loads at Station 2 for selected monitoring parameters.

Parameter	Slope (m)	Intercept (b)	Smearing Estimator (S)	R^2 Value [a]	p-Value [b]
TSS	1.22	14.14	1.23	0.90	<0.0001
TP	0.83	9.36	1.06	0.93	<0.0001
Ammonia	0.54	7.89	1.27	0.55	0.0091
Nitrate + Nitrite Nitrogen	1.17	10.36	2.08	0.69	0.0009
Fecal Coliform	1.14	20.46	1.32	0.83	0.0001
TPH - Motor Oil	1.13	10.16	1.20	0.75	0.0052
Copper - Dissolved	0.88	5.70	1.18	0.83	0.0001
Copper - Total	0.96	6.46	1.05	0.90	0.0003
Zinc - Dissolved	0.96	8.39	1.18	0.86	<0.0001
Zinc - Total	0.67	8.56	1.14	0.61	0.0223

General form of linear regression model is as follows: $L = \exp(m * \ln(Q) + b) * S$

where: b = slope
m = intercept
L = hourly load
Q = average hourly flow rate
S = smearing estimator as calculated from Helsel and Hirsch (1992).

[a] The R^2 value represents the proportion of variation in the dependant variable (load) that can be explained by the independent variable (flow rate).

[b] p-value for hypothesis test conducted on the slope of the regression equation (H_O: b = 0; $H_{A:}$ b <> 0).

Table 13. Total annual loads and areal loads measured at Station 2 for selected monitoring parameters.

Parameter	Total Annual Load (kg/year)	Areal Load (kg/ha-year)
TSS	1063	5.3
TP	13.1	0.065
Ammonia	6.3	0.032
Nitrate + Nitrite	44.0	0.22
Fecal Coliform Bacteria [a]	7.0E+11	3.5E+09
TPH - Motor Oil	21.6	0.11
Copper - Dissolved	0.3	0.0017
Copper - Total	0.6	0.0029
Zinc - Dissolved	4.5	0.023
Zinc - Total	8.4	0.042

[a] Units for fecal coliform bacteria are colony forming units (CFU)/year and CFU/ha-year.
kg: kilogram.
ha: hectare.

Table 14. Areal pollutant loading rates for various land uses.

Land Use	Total Suspended Solids (kg/ha-y)	Total Phosphorus (kg/ha-y)	Zinc, Total (kg/ha-y)	Copper, Total (kg/ha-y)	Fecal Coliform Bacteria (CFU/ha-y)
Road	502	1.100	0.310	0.0600	1.8E+08
Commercial	805	0.800	3.300	2.1000	5.6E+09
Single family low density	200	0.550	0.130	0.1800	9.3E+09
Single family high density	322	0.650	0.220	0.3000	1.5E+10
Multifamily residential	444	0.700	0.340	0.5100	2.1E+10
Forest	86	0.110	0.020	0.0300	4.0E+09
Grass	346	0.130	0.100	0.0300	1.6E+10
Pasture	343	0.130	0.100	0.0300	1.6E+10

Source: Horner et al. 1994.
kg: kilogram.
ha: hectare.
CFU: colony forming unit.

Based on a comparison of the data obtained through this study to published values, areal loading rates in Freeland drainage basin are extremely low. For example, with the exception of fecal coliform bacteria, none of the areal loading rates measured in the Freeland drainage basin exceeded published values for the various land uses in Table 14. Furthermore, most of the areal loading rates for the Freeland drainage basin were approximately one or two orders of magnitude lower than these published values. Areal loading rates for fecal coliform bacteria in the Freeland drainage basin were generally comparable to published values for the commercial and forest land uses in Table 14.

While there are many factors that affect areal loading rates for a given pollutant, these low areal loading rates may be influenced in part by localized weather patterns that stem from the “rain shadow” produced by the Olympic Mountains. At noted previously, the average annual precipitation total for the Freeland area is approximately 27.1 inches (Washington State University 2004). This value is considerably lower than the average from the other Puget Sound lowland regions that are not directly within the rain shadow. For example, the average annual rainfall total for the Seattle area as measured at Seattle-Tacoma (Sea-Tac) Airport is 38.15 inches (Western Regional Climate Center 2004a). Similarly, the average annual rainfall total for Bellingham, WA is 35.99 inches (Western Regional Climate Center 2004b). Thus, relatively low precipitation totals in the Freeland drainage basin may contribute to lower runoff volumes during storm events. It follows that loading rates for pollutants that are mobilized through erosion and wash-off during storm events would also be lower.

Soil characteristics in the Freeland drainage basin may also be influencing the low areal loading rates presented in Table 13. For example, the dominant soil type in the Freeland drainage basin is Keystone Loamy Sand (U.S. Department of Agriculture 1958). This soil type tends to drain extremely well; thus, infiltration rates in the Freeland drainage basin should be relatively high while runoff volumes are likely to be lower. As noted above, low runoff volumes should lead to lower overall loading rates for most pollutants.

Finally, the low areal loading rates for the basin are also likely influenced by the topography of the Freeland drainage basin. For example, the elevation difference from the outfall on Holmes Harbor to the highest point in the basin is only approximately 350 feet. Thus, erosive processes that tend to mobilize pollutants may also expected to be diminished in the Freeland drainage basin due to the relatively low relief and flat landscape of the area.

Water Quality Treatment Evaluation for Open-Channel Ditch System

As noted previously, the Freeland Park outfall project would divert high flows of stormwater from approximately 1,820 feet of an existing open-channel ditch (Figure 2). Because high flows from the bypass system will ultimately be routed directly into Holmes Harbor through a new stormwater outfall, any existing water quality improvements resulting from biofiltration and sedimentation processes in this open-channel ditch system would be eliminated. Thus, the quality of stormwater delivered to Holmes Harbor could potentially worsen as a result of the Freeland Park outfall project.

In order to investigate the level of water quality treatment, if any, that occurs in the open-channel ditch system, pollutant loads measured at upstream and downstream locations in the ditch (i.e., Stations 2 and 3, respectively) were compared using a one-tailed Wilcoxon signed-rank test. More specifically, this test was used to test the hypothesis that loads measured at the downstream end of the ditch (Station 3) are significantly lower than those measured upstream (Station 2).

Results from these statistical analyses are summarized in Appendix D. With the exception of dissolved zinc, this analysis showed that loads for all the parameters evaluated were not significantly lower at Station 3 relative to those measured at Station 2. Measured loads for dissolved zinc were shown to be significantly lower downstream at Station 3 in comparison to Station 2; however, the magnitude of this reduction in dissolved zinc loads appeared to be relatively small (i.e., instantaneous loads downstream were approximately 0.25 mg/s lower than those upstream). Based on these results, it can be concluded that there is very little water quality treatment occurring within the open channel ditch system.

Conclusions

Based on the water quality sampling conducted in 2003 for the Freeland water quality improvement project, the following major study conclusions were identified:

- Water temperatures exceeding state water quality standards were measured over an extended period of time (June through early October) at Station 3, which is located in lower reaches of the Freeland drainage basin near the point of discharge into Holmes Harbor. High water temperatures are likely related to stagnant water conditions in the tidal influenced ditch system at this location and a lack of shade providing riparian canopy cover.

- Samples for dissolved oxygen and pH at Stations 1 and 2 frequently showed violations of the associated state water quality standards for both parameters. The low dissolved oxygen levels at Station 1 were likely related to stagnant water conditions in upgradient wetland systems while low pH levels at this station were probably influenced by humic acids from these same wetlands. Low dissolved oxygen conditions at Station 2 were likely related to backwater conditions in a stormwater conveyance pipe located between Stations 1 and 2. Low pH levels at Station 2 were probably caused by chemical processes (i.e., reduction) that are occurring in this same pipe due to the stagnant water conditions.

- Contamination from fecal coliform bacteria was found to be a pervasive water quality problem at all monitoring stations during both storm and base flow. For example, the number samples violating the state water quality standard for fecal coliform bacteria ranged from 63 to 100 percent during storm flow, and from 33 to 100 percent during base flow. Failing septic systems and waste from pets, livestock, and wildlife (birds and mammals) are likely the primary sources for this contamination. It should be noted that the entire Freeland drainage basin is served by septic systems (Parvin 2004). However, in order to identify the specific source(s) of the observed contamination, additional focused study would be required. This could include a microbial source tracking study (MST) and/or extensive sanitary surveys within the basin.

- Contamination from copper and zinc was found to be a significant water quality problem in lower reaches of the basin (i.e., Stations 2 and 4, and to a lesser extent Station 3) during storm flow. For example, the number of storm flow samples from these three stations that violated the state water quality standard for dissolved copper ranged from 13 to 38 percent while the number violating the standard for dissolved zinc ranged from 0 to 100 percent. Commercial and residential land use activities in the region of the basin are the likely the sources for this contamination. Specific source for these pollutants that are often associated with these land use types include: insecticide and fungicide applications, corrosion of flashing and downspouts, tire and break lining wear, electroplating, and scrap yards.

- The comparison of areal loading rates for selected pollutants measured at each monitoring station showed that the subbasin associated with Station 4 was consistently identified as being a primary source for water quality contamination in the basin as a whole. Land use in the subbasin for Station 4 consist mainly of commercial and high/medium-density residential properties. Relatively high areal loading rates for this subbasin were measured for all the following categories of pollutants: suspended sediment, nutrients, bacteria, and metals.

- Based on comparisons to published data, areal loading rates for pollutants discharged into Holmes Harbor from the Freeland drainage basin are extremely low. These low areal loading rates may be influenced in part by localized weather patterns in the vicinity of the Freeland drainage basin, soil types in the basin, and the relatively flat topography of the area.

- With the exception of dissolved zinc, statistical analyses showed that loads for all the parameters were not significantly lower at a downstream end of the open channel ditch that will be affected by the Freeland Park outfall project. Based on these results, it can be concluded that there is very little water quality treatment occurring within this ditch system.

The study conclusions above will be utilized in combination with earlier habitat investigations (Herrera 2003) to formulate water quality treatment recommendations for the Freeland drainage basin. These recommendations will then be presented in a final report for the Freeland water quality improvement project that will be available for distribution in the spring of 2004.

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