Vashon- Maury Island Water Resources - A Retrospective of Contributions & Highlights

December 2013

King County

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King County
Department of
Natural Resources and Parks
Water and Land Resources Division

Vashon-Maury Island Water Resources - A Retrospective of Contributions & Highlights

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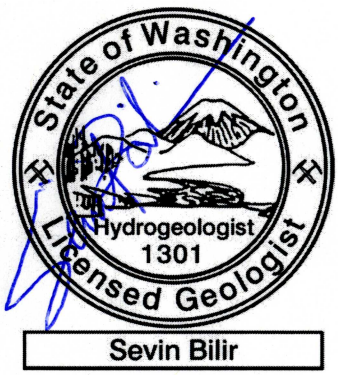
This document was prepared under the supervision and direction of the undersigned whose seal as licensed hydrogeologist is affixed below:



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12/19/2013

Date

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INDEX OF ABBREVIATIONS & ACRONYMS

~	Approximate
%	percent
°	degrees
7DADMax	Seven-day Average of the Daily Maximum
µg/L	micrograms per liter
µmhos/cm	micromhos per centimeters per centimeter
Ambient Study	Ambient Groundwater Monitoring Report
AFY	acre feet per year
bgs	below ground surface
BIBI or B-IBI	Benthic Index of Biological Integrity
C	Centigrade
Carr Report	Vashon-Maury Island Water Resources Study
cfu/100ml	colony forming units per 100 milliliters of sample
DOH	Washington State Department of Health
DNRP	Department of Natural Resources and Parks
Ecology	Washington State Department of Ecology
EPA	Environmental Protection Agency
F	Fahrenheit
gpd	gallons per day
gpm	gallons per minute
GeoMapNW	University of Washington Pacific Northwest Center for Geologic Mapping Studies (formerly known as University of Washington Seattle-Area Mapping Project)
GMA	Growth Management Act
GWMA	Groundwater Management Area
GWMC	Vashon-Maury Island Groundwater Management Committee
GWMP	Vashon-Maury Island Ground Water Management Plan
"the GWP Committee"	Vashon-Maury Island Groundwater Protection Committee
"the Island"	Vashon-Maury Island
kg/d	kilograms per day
KC	King County

INDEX OF ABBREVIATIONS & ACRONYMS *(CONTINUED)*

LiDAR	Light Detecting and Ranging
mg/L	milligrams per liter
ml	milliliters
mid	middle
MCL	maximum contaminant level
MSL	mean sea level
MGY	million gallons per year
NCDC COOP	National Climate Data Center Cooperative Observer Program
NOAA	National Oceanic & Atmospheric Administration
NS	not sampled
OSS	onsite septic system
Planning Department	Department of Planning and Community Development
Public Health	Seattle-KC Department of Public Health, Environmental Health Division
PWS	public water system
R-B Index	Richards - Baker Index
RCW	Revised Code of Washington
QAc	Pre-Vashon deposits upper coarse grained
QBc	Pre-Vashon deposits lower coarse grained
Qdbt	Double Bluff till
Qpdc	Possession Drift, coarse grained deposits
Qpf	Pre-Fraser deposits, undifferentiated
Qpfc	coarse grained deposits
Qpff	Pre-Fraser glaciation age, fine grained deposits
Qpoc	Pre-Olympia deposits, coarse-grained deposits
Qpof	Pre-Olympia deposits, fine-grained deposits
Qos	Owen silt
Qva	Vashon advance outwash deposits
Qvr	Vashon recessional outwash deposits
Qvrl	Vashon recessional lacustrine deposits
Qvt	Vashon till
Sea-Tac	Seattle-Tacoma International Airport
Sp. Conductivity	specific conductivity
TSS	total suspended solids

INDEX OF ABBREVIATIONS & ACRONYMS *(CONTINUED)*

µg/L	micrograms per liter
µmhos/cm	micromhos per centimeters per centimeter
UNK	unknown
U.S.	United States
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
UW	University of Washington
UWT	University of Washington-Tacoma
vs.	versus
VMI	Vashon-Maury Island
Watershed Plan	Vashon-Maury Island Watershed Plan
Work Plan	WRE Work Plan
WA	Washington State
WAC	Washington Administrative Code
WLRD	Water & Land Resources Division
WQI	water quality index
WRE	Vashon-Maury Island Water Resource Evaluation
WRIA	Water Resource Inventory Area
WY	water year

EXECUTIVE SUMMARY

The King County Water and Land Resource Division has been monitoring precipitation, stream flow and groundwater on Vashon-Maury Island (the "Island") for a number of years in an effort to better understand the water balance and resources on the Island. This report summarizes monitoring results and activities since the 1980's. In addition, a section is dedicated to summarizing key challenges in moving forward with maintaining the water resources on the Island.

CONTRIBUTIONS TO CLIMATE SCIENCE

All drinking water sources on Vashon-Maury Island (springs, surface water and groundwater) are supplied by precipitation on the Island. Geographical variability of climate conditions have been recorded since the 1980's and mapped across the Island. A difference of about 15 inches was measured in total precipitation from east to the west across the Island. In addition, the Island receives about 4 percent less than to 15 percent more than the precipitation observed at the Seattle-Tacoma International Airport. This difference occurs only about 4.5 miles southwest of the airport.

Recent analysis of historical data across the Pacific Northwest region indicates that local persistent changes in the climate are likely to have been and continue to be impacted by global warming. A warming trend has been reported in both local and regional data. The likely impacts of this trend on future water resources may include increased stream and water body temperatures, lower summer flows, and increased water resource consumption rates.

EXPANDING KNOWLEDGE OF ISLAND-WIDE SURFACE WATER RESOURCES

The impacts of development, landowner practices in areas close to water resources and pollutants are the dominant drivers determining the health and quantity of water resources on Vashon-Maury Island. Less forest cover and increases in impervious surfaces result in higher stream temperatures and more urban runoff. Failing septic systems, pet wastes and bird droppings can be washed into streams resulting in decreased water quality that affects human and aquatic life uses of the stream.

Much work has been completed to characterize and evaluate the quantity and quality of surface water resources on Vashon-Maury Island, such as, measuring stream bug populations, stream discharge rates, temperature, pH, fecal coliform bacteria, dissolved oxygen, turbidity, total suspended solids, and nutrients in streams and marine waters.

Overall conditions appear to be improving as measured by the stream water quality index. This index compares monthly temperature, pH, fecal coliform bacteria, dissolved oxygen, turbidity, total suspended solids, and nutrients (phosphorus

and nitrogen) relative to state standards and guidelines. Stream temperatures on various Island creeks typically meet the Washington State criteria for good water quality status.

The health of the benthic bug population in streams on Vashon-Maury Island has been reported as having some slight variability with some sampling locations improving and some sampling locations worsening.

Stream nitrate concentrations seem to be fairly typical of rural lowland streams in the Puget Sound area; highest concentrations during winter when plant uptake is lowest and rain flushes nitrate from surface soils and lowest during summer when plant uptake is greatest and soils are generally dry and accumulating nitrate.

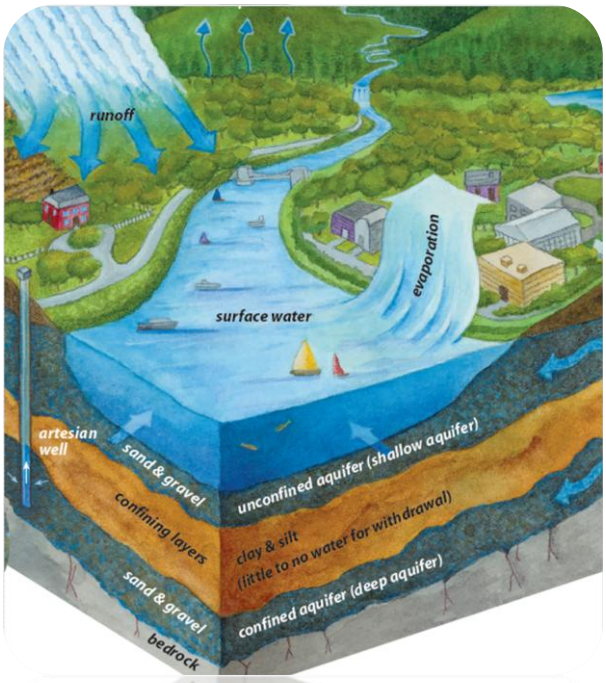
Monitoring of annual surface water quantity metrics, such as frequency and duration of high flow pulses, stream flashiness, and magnitude of low flows during a water year, indicate responses are as expected with increases during wet years and decreases during dry years.

Dissolved oxygen levels below the Washington State water quality standard (extraordinary criteria of 7 milligrams per liter (mg/L)) have been observed in Quartermaster Harbor over the last seven years. Ongoing sampling continues to record extremely low values of dissolved oxygen in the Quartermaster Harbor. For fecal coliform bacteria data collected since 2006, all marine water sampled met state water quality criteria. In addition, there also were no exceedances of the criteria by marine water quality samples collected by Washington Department of Health along Quartermaster Harbor. However, fecal coliform bacteria levels in Judd, Fisher, Mileta and Christensen Creeks had exceedances of the state extraordinary criteria for at least one year.

GROUNDWATER - THE HIDDEN RESOURCE

Groundwater is the portion of precipitation that soaks into the ground and gets stored in below ground surface geologic water systems called aquifers. Every groundwater system is unique and dependent upon the types of geologic materials, rate of precipitation, interactions of groundwater with the streams and other water bodies, the rate of evapotranspiration and in the case of the Island, interactions with the surrounding open waters of Puget Sound. Groundwater characterizations conducted by various technical studies on Vashon-Maury Island identified water bearing zones using differing definitions. The most commonly studied geologic water bearing zones were the Vashon recessional and advance outwash deposits and deeper coarse grained units.

Several reports indicated that water table contour maps of water bearing zones showed similar groundwater flow patterns and directions and that the patterns are consistent with our basic understanding of unconfined groundwater hydrology, where water level contours reflect overlying topography. Groundwater levels in wells show responses to seasonal and long-term recharge variations, tidal and barometric influences and pumping. Water level fluctuations tended to correlate with rainfall (with lags of time up to four months), with seasonal highs in during summer months and lows during fall months. Overall, data from 2001 through 2012 indicated that levels were generally stable with no significant declines.



A water-budget reflects the inputs (such as, precipitation) and outputs (such as, evapotranspiration and springs) of water in an area, in this case, the entire Vashon-Maury Island.

Various island-wide water budgets for the Island were assessed through analytical methods and computer models. These studies resulted in a range of average recharge from 9,800 to over 33,600 acre feet per year.

GROUNDWATER QUALITY

Groundwater water quality impacts may occur naturally or as a result of human activity, such as construction activities, improper household waste disposal, fertilizer and pesticide use and septic systems. Runoff, or water flowing over the land surface, may pick up pollutants from soils and paved surfaces. Wells having water levels close to the ground surface are at most risk.

The majority of the residents on Vashon-Maury Island obtain their water from shallow water sources, which are more vulnerable to contamination. These water sources include springs and shallow wells.

Overall, the groundwater quality on the Island is good. With the exception of arsenic above the U.S. Environmental Protection Agency drinking water standard in a few wells around the Island, there were no exceedances for all other parameters tested. The wells with arsenic exceedances withdraw water from deeper water bearing zones that appear to have naturally occurring arsenic. Public water systems results submitted to the Washington State Department of Health also reported no exceedances on Vashon-Maury Island.

There was no apparent change in arsenic and chloride concentrations at wells monitored on a regular basis between 1990 and 2010. Only one well (no longer used) had chloride above the drinking water standard, indicating that most wells had good to fair water quality with respect to chloride.

Recent monitoring shows maximum nitrate as nitrogen levels in most wells below 5 mg/L (USEPA drinking water standard for nitrate is 10mg/L)). Median nitrate levels in shallow public water system wells were typically higher than those in deep public water system wells. These results support the general principle that susceptibility to impacts is greater in shallow groundwater systems than in the deeper groundwater systems.

WATER RESOURCES CONSUMPTION

The major use of water on Vashon-Maury Island is for municipal and domestic purposes; lesser uses are for agricultural and commercial purposes. Based on a set group of volunteer permit exempt well owners, the measured average consumption of water was between about 100 and 120 gallons per user per day. Public water systems were reported as having an average daily use of about 100 to 200 gallons per day. Although Islanders have varying patterns of usage, it is common for increases in usage to occur during June through October. The ten year average (2001 through 2010) of total island-wide water consumption is 515 million gallons per year with consumption increasing during periods of lower rainfall totals and decreasing during periods of higher rainfall totals.

With projections of population growth on Vashon-Maury Island at about 100 people per year (1 percent of the population) and a modeled potential future water demand of about 10 percent of all population-related water use, lowering of water levels near larger public water system wells may occur in the future.

EDUCATION, OUTREACH AND ENGAGING STAKEHOLDERS

A variety of activities involving the public and stakeholders, have occurred on Vashon-Maury Island in the past, such as the Salmon Watchers and the Groundwater Well Self-Monitoring Programs. In addition, the Vashon-Maury Island Groundwater Protection Committee and King County hold public and policy meetings on a regular basis. The residents and stakeholders have become knowledgeable about their water resources and the impacts that may reduce the availability for future use on the Island.

Most recently, informational newsletters were prepared under contract by the Vashon-Maury Island Groundwater Protection Committee and shared with the public to encourage Islanders to learn more about many related issues to water resources on the Island. While the response from these efforts was welcoming, the amount of participation in the Salmon Watchers and the Groundwater Well Self-Monitoring Programs has declined.

KEY CHALLENGES

The ending of capital funding in recent years for the County's Groundwater Protection Program reduced the budget by about $200,000 per year for water resources related monitoring and outreach activities on the Island. While a variety of activities such as engaging stakeholders, publishing educational newsletters, managing volunteer well owners and salmon watchers, and holding public meetings have occurred on the Island, volunteerism for the Salmon Watcher program and Groundwater Well Self-Monitoring Program has declined. Reduced financial resources may have had a negative impact on volunteerism. Water resources data that may help with understanding the impacts on where water is available and where water is impacted are not being collected.

As a result of Earth Justice's recent legal challenge concerning permit exempt well management in closed stream basins there may be implications for quantifying water availability and for tracking water rights more closely.

The King County Vashon-Maury Island Watershed Plan posed that climate change could impact the Island in several ways, such as seawater intrusion, increased water usage, and/or reduced recharge. Recharge to the groundwater system of the Island will be affected by changes to precipitation patterns. Less total annual rainfall would lead to less groundwater recharge while increased rainfall may lead to more surface water discharge than groundwater recharge Any assessment of future water demands for the Island should include some consideration of potential climate change impacts and leave a margin of safety to help address the uncertainty that remains. Continuing to collect or analyze available scientific indicator data related to these impacts will assist in planning for adaptations to these changing environmental conditions and to reduce the impact of worsening conditions.

Although in the 1990s, several public water systems were experiencing shortages, since then, these water purveyors have been able to meet demand through increased conservation methods and improving infrastructure issues causing leakage. Changing climate conditions and aging infrastructure may have an impact on the water availability in the future. In 2007, Water District 19 reported that although the water rights are sufficient to meet the current and anticipated needs of the users, Water District 19 did not have enough source capacity to meet WA DOH recommendations during summertime peak usage. In part due to conservation by customers and a new well, the 15 year moratorium on new water shares for Water District 19 was lifted.

There is no current requirement for recording the volume of water pumped at exempt wells, nor for enforcing allowable amounts. As a result, it is unknown exactly how much water is consumed and used on the Island from these types of wells.

In summary, the key challenges for water resources on Vashon-Maury Island are in part a lack of volunteerism, funding source constraints, potential changes in the regulatory requirements for quantifying water availability and for tracking

water rights, addressing impacts of climate change and increasing demand as a result of population growth. These are all challenges to managing water resources to ensure that water resources on the Island are sustainable for future demands.

MOVING FORWARD

As part of the Sustainability Monitoring program, groundwater water quality sampling is ongoing, including sampling of arsenic, chloride, and nitrate+nitrite nitrogen at long-term monitoring locations. Coordination of water quality sampling activities and policy related work by the Vashon-Maury Island Groundwater Protection Committee with King County, state agencies and stakeholders will ensure that water resources on the Island are sustained long-term.

1.0. INTRODUCTION

1.1 Overview and Purpose of this Report

All drinking water sources (springs, surface water, and groundwater) on Vashon-Maury Island (hereafter referred to as the "Island" or "VMI"), King County are recharged by precipitation. Precipitation infiltrates through the soil and underlying sediment and is stored in water bearing zones of sediment or rock layers called aquifers. Every groundwater system is unique and dependent upon factors such as the rate of precipitation or evapotranspiration and the interaction of groundwater with the streams and other surface water bodies. These factors all contribute to the overall water budget. Understanding the water balance on the Island and the changes that occur in response to human activities and climate changes is important in evaluating the amount of water that can be pumped from the Island's aquifers on a sustained basis.

In addition to the importance of managing and quantifying water quantity on the Island, monitoring and protecting the water quality of the surface water and groundwater is key for maintaining healthy ecosystems and sustainable water sources. Adequate protection of groundwater includes protecting surface water supplies and protecting both from potential sources for water quality impairment, such as household and land management practices, urban runoff, landfill and wastewater treatment facilities, failing and functional septic systems and in some areas, seawater intrusion.

Several distinct data collection efforts were completed or are currently ongoing to monitor the Island's water resources. These efforts include:

- Carr Report: Water Resources Study - 1983
- Ground Water Management Plan - 1998
- KC DNRP Groundwater Protection Program - 2001 to present
    - Ambient Groundwater Monitoring Study – 2001 to 2004
    - Watershed Plan - 2005
    - Water Resources Evaluation – 2004 to 2010
    - Sustainability Indicator Development and Monitoring – 2011 to present
- Quartermaster Harbor Nitrogen Management Study – 2009 to 2012

A long-term plan to monitor and evaluate the different components of water resources was implemented to address needs and concerns identified by the residents of the Island and the staff of King County Department of Natural Resources & Parks and the Water & Land Resources Division (KC DNRP and KC WLRD). Much interest has been expressed over the years in the sustainability of the water supply on the Island.

Since about 2000, groundwater, surface water, and precipitation data have been collected more regularly and across a larger area on the Island than has before. Recent monitoring efforts were designed to serve three purposes; (1) to identify spatial and temporal changes and any trends in groundwater and surface water quantity and quality, (2) to provide necessary data for model development and calibration, and (3) to serve as an early warning system of the impacts of pollution sources and groundwater extraction. Recent and ongoing monitoring has and is being conducted by a combination of KC WLRD staff and Island resident volunteers.

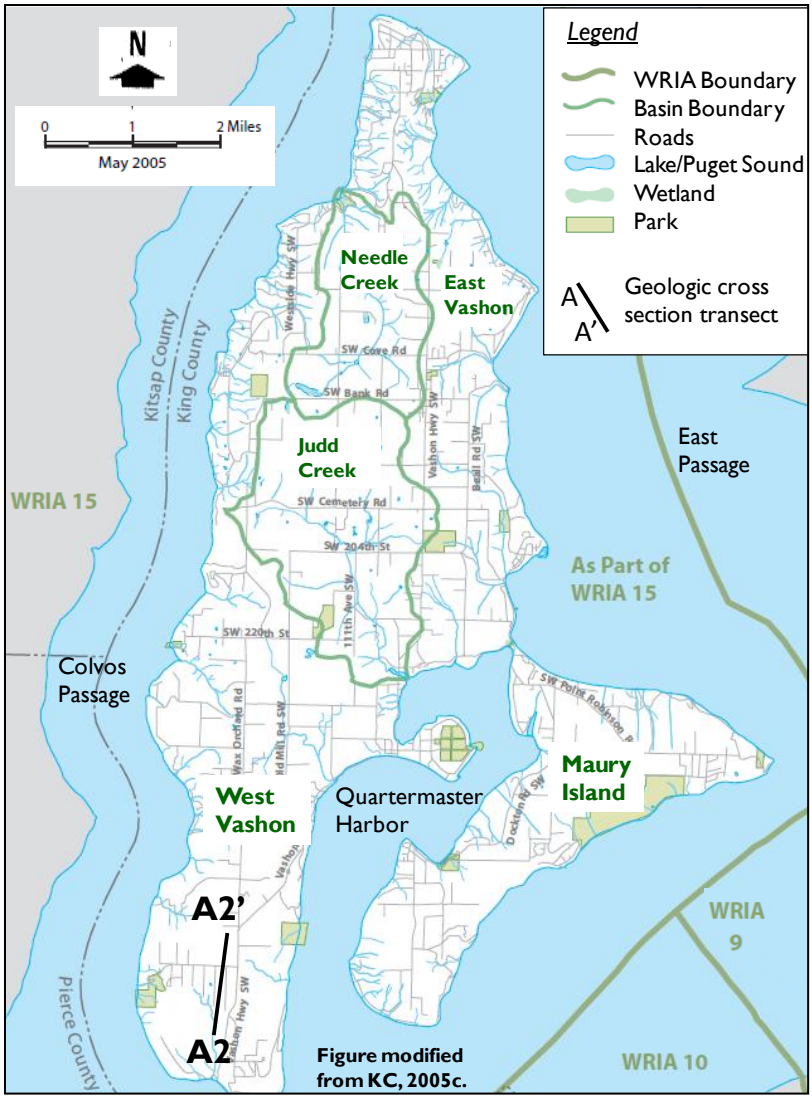
This document provides a compendium of water resources information in one place. In addition, it serves as a retrospective of contributions and highlights of the water resources studies and documents related to the Island. Included is an overview of the data collected from these reports as related to water resources and the various programs ongoing on the Island. Significant findings of spatial and temporal trends are highlighted. In conclusion, this report posits issues to consider when moving forward with future water resources management on the Island.

1.2 General Setting

1.2.1 Geography

The areal extent of the Island is about 36 square miles. The Island lies in Central Puget Sound within the boundaries of King County. According to delineations developed by Washington State Department of Ecology (Ecology), the Island lies within the boundary of Water Resource Inventory Area (WRIA) 15, known as the Kitsap Peninsula and Islands Watershed (Figure 1). The Island is included in WRIA 15 for the purposes of water quantity planning and is included in WRIA 9 for nearshore habitat planning.

Figure 1. Map of Vashon-Maury Island.



Vashon and Maury Islands are linked by a narrow isthmus and are not, therefore, truly independent islands (Figure 1). The Island is bordered on the west by Colvos Passage from the Kitsap Peninsula, on the south by Dalco Passage from Tacoma, on the east by Puget Sound and King County, and on the north by Puget Sound. Vashon Island is about 13 miles long (south to north) and four miles across (west to east) in the widest areas. Maury Island is about five miles long (southwest to northeast) and about one mile across (northwest to southeast).

1.2.2 Topography

The topography of the Island varies from sea level to elevations in excess of 460 feet above mean sea level (MSL) based on U.S. Geological Survey topographic maps (KC, 2005c). New LiDAR (Light Detecting and Ranging) data has improved the accuracy of the surface topography data. The maximum elevation was shown at over 500 feet above MSL at Maury Island Marine Park. The shoreline extent of the Island is just over 58 miles, most of which lies beneath steep, slide-prone slopes (KC, 2005c). Numerous stream basins drain into Puget Sound.

1.2.3 Geology

Geologic field mapping studies began as early as 1898 on the Island. A publication by the U.S. Geological Survey in1991 showed a wide variety of deposits reflecting the glacial and non-glacial history (Booth, 1991). The understanding of the geology has since been updated with a new geologic map in 2004. GeoMap NW, formerly known as University of Washington Seattle-Area Mapping Project, completed a detailed analysis of field data and data compiled from well logs for King County (KC, 2005c). The Island is composed of glacially derived sediments deposited during several glacial episodes. The predominant geological unit is glacial till. The glacial till and other till-like units on the Island cover approximately 68 percent of the land and is a significant contributor to the Island's topography. The remaining 32 percent of the Island cover is made of glacial outwash and alluvial deposits (KC, 2005c).

1.2.4 Land Use and Cover

As per the Vashon-Maury Island Watershed Plan (KC, 2005c), all of the Island is designated as rural and as such is outside the urban growth boundary. Low-density residential development covers much of the Island with zoning of one home per five and ten acres. Higher density residential areas are concentrated in the Vashon Town Center, Vashon Heights, Burton, Dockton, and along parts of the shoreline. Multifamily, commercial and industrial uses are presently concentrated in the unincorporated town of Vashon and adjacent areas where wastewater conveyance to a centralized treatment plan (with discharge to East Passage in Puget Sound) and other urban services are available (KC, 2005c).

The predominant land cover for the Island is forested land. Forested land covers about 73 percent. Non-forest and developed land have percentages of 16 and 11 percent, respectively (KC, 2005c).

1.3 Legal Setting

1.3.1 State Regulatory Framework

The Washington State (WA) Growth Management Act (GMA) Revised Code of Washington (RCW) 36.70A states the legislature found "that uncoordinated and unplanned growth, together with a lack of

common goals expressing the public's interest in the conservation and the wise use of our lands, pose a threat to the environment, sustainable economic development, and the health, safety, and high quality of life enjoyed by residents of this state." In RCW Section 36.70A.070 (1) it states that comprehensive plans "shall provide for protection of the quality and quantity of groundwater used for public water supplies." The GMA also provides direction to counties regarding the rural element, lands that are not designated for urban growth, agriculture, forest, or mineral resources. In RCW Section 36.70A.070 (5) the GMA states that the "rural element of shall include measures that apply to rural development and protect the rural character of the area, as established by King County," by "Protecting critical areas, as provided in RCW 36.70A.060, and surface water and groundwater resources."

The purpose of WA Chapter 90.44 RCW is to regulate and control groundwaters of the state of Washington and is "supplemental to chapter 90.03 RCW, which regulates the surface waters of the state, and is enacted for the purpose of extending the application of such surface water statutes to the appropriation and beneficial use of groundwaters within the state." In addition, RCW Section 90.44.430 provides that local government shall be guided by adopted groundwater management plans. From RCW 90.44.430 and Washington Administrative Code (WAC) 173-100 the Vashon-Maury Island Ground Water Management Plan (GWMP) (VMI GWMCa & VMI GWMCb, 1998) was designed as a monitoring program for collection of precipitation, surface water, sediment, shellfish, springs and groundwater data to further the understanding of the Island's water resources.

1.3.2 Local Regulatory Framework

The local Seattle-KC Department of Public Health, Environmental Health Division (Public Health) provided oversight for the development of the GWMP. The King County Groundwater Protection Program projects on the Island were developed by King County in association with the VMI Groundwater Protection Committee. King County works in conjunction with this committee to implement the recommendations of the GWMP and address current local groundwater issues. This committee was formed in late 2001 and has continued to meet since that time. Membership represents diverse stakeholders, water purveyors, sewer and water utilities and associations, residential well users, chamber of commerce, environmental organizations, tribal nation, commercial agriculturists, business owners, and unincorporated areas.

The VMI Watershed Plan (KC, 2005c) defined preferred water resource management strategies for the Island, identified septic systems as a potential source of contamination to water quality and provided multiple recommendations to reduce the risks of nitrate contamination from septic systems.

In accordance with RCW 70.118A, Seattle & King County - Public Health (Public Health) has evaluated existing information concerning areas where shellfish harvest is threatened or restricted because of contamination originating from septic systems. Based on the information, Public Health designated a Marine Recovery Area on the Island in 2008. A Marine Recovery Area is a specific designation under state law that establishes the goal of protecting, preserving and restoring shellfish harvest opportunities by assuring that property owners within the Marine Recovery Area inspect, and repair or replace as necessary, their septic system. In 2008, the "King County On-Site Septic System Management Plan" (Public Health, 2007) called for enhanced Onsite Septic System (OSS) Operation and Maintenance for the Island sensitive areas for the protection of groundwater quality. Integration with Public Health is ongoing to manage these exempt well and OSS issues and to ensure that the on-site septic systems are not impacting the water resources.

2.0. TECHNICAL ACTIVITIES AND REPORTS

The following is a list of the technical and management documents summarized in this section:

- Carr Report: Water Resources Study - 1983
- Ground Water Management Plan - 1998
- KC DNRP Groundwater Protection Program – 2001 to present
    - Ambient Groundwater Monitoring Study – 2001 to 2004
    - Watershed Plan – 2005
    - Water Resources Evaluation – 2004 to 2010
        - Annual Data Reports – 2005 through 2010
        - Phase I Groundwater Model – 2005
        - Phase II Hydrologic Modeling: Technical Report – 2009
    - Sustainability Indicator Development and Monitoring – 2011 to present
- Quartermaster Harbor Nitrogen Management Study – 2009 through 2012
    - Initial Assessment of Nutrient Loading to Quartermaster Harbor – 2010
    - Mileta Creek Nitrogen Source Tracking Study – 2012
    - Quartermaster Harbor Nearshore Freshwater Inflows Assessment – 2012
    - Quartermaster Harbor Benthic Flux Study – 2012

Results and trends described in these documents are incorporated in Sections 3.0 (Island-wide Climate Conditions) and 4.0 (Island-wide Water Resources) and summarized in Section 5.0 (Summary of Scientific Findings).

2.1 Carr Report: Water Resources Study

In the first island-wide assessment, the Vashon-Maury Island Water Resources Study (Carr Report) (Carr/Assoc., 1983) monitored characteristics of the water resources such as precipitation, surface and groundwater. This report was prepared for the KC Department of Planning and Community Development (KC Planning Department) to generate information about the water resources of the Island as a limit on population and land use.

Although there were limited available data and several assumptions made in the course of this study, a major effort was put forward to address the following four topics:

- Where does the Island's water supply originate? Where is it located and what is the water quality?
- How much water is available for human use on the Island?
- What constraints does the water resource place on population density and land use?
- What must be done to protect and enhance the water resource for future generations?

The Island's water supply source was reported as primarily from wells and springs. Two aquifers were identified; (1) a "Principal" aquifer generally located above sea level yielding moderate amounts of water to wells and (2) a "Deep" aquifer at depths of about 100-300 feet below sea level capable of yielding larger quantities of water.

The hydrologic system can be quantified using a water budget. This budget is a balance between the inflow of water into the system, such as, precipitation, and the outflow of water from the system, such as, evapotranspiration, runoff, baseflow (amount of groundwater seeping into a stream) and subsurface outflow (to the Puget Sound). The Carr Report suggests this simplified equation:

Precipitation = Evapotranspiration + Runoff + Infiltration

where: Precipitation = rainfall or snow
Evapotranspiration = water evaporated by surface water, soils, and plants
Runoff = water in streams and overland flow
Infiltration = water infiltrating into soil and deeper aquifers

Recharge is defined as water infiltrating soil and replenishing the groundwater. Runoff was divided into both direct runoff and infiltrated runoff (that which is captured by the aquifer through the stream). Infiltration can be further applied to calculate the recharge to the steams and aquifers (and eventually the Puget Sound). Runoff and infiltration together equal the water surplus in the budget, the amount available as groundwater resources. Further discussion and details of the Carr Report budget are presented in Section 4.3.

Recharge for the Principal aquifer was reported to be local precipitation with no off-island recharge. The main area of recharge to the Principal aquifer was reported as along a north-south corridor of west-central Vashon Island, whereas the major recharge area for the Deep aquifer as west-central Vashon Island. Total rainfall in1982 varied across the Island from 53.5 inches on the west side of Vashon Island to 35.5 inches on the east side of Maury Island. The Carr Report indicates that half the annual precipitation evaporates and the other half either runs off or infiltrates through the soil.

Water level contour maps of the major aquifers, using data from 54 sites, show flow directions in the Principal aquifer as generally to the east and west from the topographic high that extends along a north-south axis on Vashon Island and from a high near each end of Maury Island towards Quartermaster Harbor. Groundwater levels measured from 61 wells show responses to seasonal and long-term recharge variations, tidal and barometric influences and pumping.

Selected water quality analysis was conducted at locations on six creeks and at 71 groundwater well locations. The report presented several island-wide isochemical maps of groundwater water quality parameters specific conductance, chloride, iron, and nitrate.

The Carr Report indicates that of the total groundwater recharge, about 578 million gallons per year (MGY) could theoretically be recovered from the Principal aquifer when the factors of drought conditions and recharge rate were taken into account. When taking into consideration water quality conditions, stream flow requirements, and water use (at that time), the amount of groundwater available from the Principal aquifer for future population growth was reported at about 98.5 MGY, allowing for the addition of about 2,300 new residents to the existing population.

The Carr Report presents basic options for water resources management. In addition, the primary recommendations to King County were to create or designate a specific agency with the responsibility for managing the Islands' water resources, to integrate the findings into the Vashon Community Plan, and produce a comprehensive water management plan, and to implement the water management plan as soon as possible.

Interim measures to protect the resources were:

- Limit the Island's total population; adopt zoning to limit density; preserve high recharge potential areas; refine codes to maintain and enhance recharge capability and water quality; and enact building moratoria to reduce or stabilize groundwater degradation by septic systems in areas far above recommended housing densities.
- Monitor solid waste disposal; provide sewage collection, treatment and disposal off-island for all high population density areas; exclude infiltration of treated sewage water to stormwater and shallow groundwater; remove or regulate intense agricultural activities from recharge areas; and review local codes and regulations on transportation, storage and disposal of potentially hazardous wastes.
- Continue collecting water resources data for verification and refinement of the findings.
- Implement an outreach program for conservation and protection of the water resource.

2.2 Ground Water Management Plan : Area Characterization

From Revised Code of Washington (RCW) 90.44.430 and Washington Administrative Code (WAC) 173-100 the Vashon-Maury Island Ground Water Management Plan (GWMP) (VMI GWMCa & VMI GWMCb, 1998) was designed as a monitoring program for collection of precipitation, surface water, sediment, shellfish, springs and groundwater data to further the understanding of the Island's water resources. Although the data collection effort occurred between 1989 and1992, the report was not published and submitted to Ecology until December 1998. Seattle-KC Department of Public Health, Environmental Health Division (Public Health) was a participant in the VMI Groundwater Management Committee (GWMC) and provided oversight for this study. The GWMP was presented in two topics; (1) Area Characterization and (2) Management Strategies. The GWMP Area Characterization report presents a compilation of historical data, new data, results and recommendations. The GWMP Management Strategies report presents recommended management strategies and implementation processes for programs related to groundwater quantity and quality.

Precipitation was measured at nine locations between December 1988 and January 1992. Only three locations were measured continuously through this time period. The GWMP generated total rainfall maps for those years as well as a combined total rainfall map of 1989-1991.

Geologic data from more current studies were incorporated and compared with results of the Carr Report and shown to be similar in interpretation. The GWMP presents a more detailed description and interpretation of the hydrostratigraphic complexities; introducing aquifers identified as Zones 1 through 4, based on water levels in wells, whereas the Carr Report based the zones on hydrostratigraphy. The following table correlates the two report interpretations:

Carr Report	GWMP
Principal Aquifer	Zone 1
	Zone 2
Deep Aquifer	Zone 3
	Zone 4

Groundwater levels and water quality data were collected from 24 wells at 21 locations between 1989 and 1992. Generated groundwater contour maps showed similar flow direction and gradients as in the Carr Report. In addition, seasonal fluctuations and long-term trends were similar to that reported in the Carr Report. Selected groundwater water quality parameters included chloride, nitrate, inorganics and total dissolved solids.

Surface water flow data at nine locations on eight creeks were recorded between July 1989 and April 1992. All locations have gaps in data collected and only two were monitored the full time period. Monthly high and low stream gauge readings are summarized in the GWMP. Surface water quality data were collected at eight locations on these same creeks in 1991 and 1992. Stream sediment data were collected at three of these creek locations. This study collected marine water quality, marine sediments, and marine shellfish data from surface water in the marine environment near the mouth of the same eight creeks. In addition, spring water quality data were collected from six creeks between 1989-1990 for fecal coliforms, metals, sulfate, fluoride, and total dissolved solids.

The GWMP describes current land use activities on the Island that may have impacts on groundwater. In 1992, the GWMP study created a susceptibility island-wide map by compiling slope, depth to water, and surface geology into one map. Areas of susceptibility were designated 'high', 'medium' or 'low' susceptibility potential based on this map, similarly to the 1983 recharge potential map generated in the Carr Report. This map was later updated in 1995 & 2004 and is available in digital format on the King County Geographic Information System (GIS) Center's metadata webpage (KC, 2008a).

The GWMP discusses Island water resource issues, such as demand, services, rights and uses. New projections for water demand were reported as 408 MGY for 1990 with an increase of up to 486 MGY by 2000. There were seven major water systems on the Island, along with more than 100 Group A and Group B public water systems (PWS). The exact number of private wells and the amount of withdrawal from those wells on the Island was unknown.

The GWMP also presents an updated island-wide water budget/balance for the Island in the following simplified equation:

Precipitation = Evapotranspiration + Surface Runoff + Base flow + Subsurface flow

where: Precipitation = rainfall or snow
Evapotranspiration = water evaporated by soils and transpired by plants
Surface Runoff = amount of water that does not infiltrate (directly to Puget Sound)
Base flow = amount of groundwater discharging into streams and rivers
Subsurface flow = discharge of groundwater to Puget Sound

Further discussion and details of the GWMP budget are presented in Section 4.3. In summary, the budget assumed an island-wide average of 29,696 MGY of potential recharge (precipitation) and 4,263 MGY of potential groundwater available for consumption, indicating a significant amount of runoff from the Island.

2.3 King County Groundwater Protection Program

The King County Groundwater Protection Program projects on the Island were developed by King County in association with the VMI Groundwater Protection Committee (hereafter referred to as "the GWP Committee"). King County works in conjunction with the GWP Committee to implement the recommendations of the GWMP and address current local groundwater issues. The GWP Committee serves the Island's community and advises King County and others on groundwater related actions and activities.

The GWP Committee was formed in late 2001 and has continued to meet since that time. The GWP Committee membership represents diverse stakeholders with interests from the groundwater advisory committee (which originally developed the GWMP), water purveyors, sewer and water utilities and associations, residential well users, chamber of commerce, environmental organizations, tribal nation, commercial agriculturists, business owners, and unincorporated areas.

The following are studies associated with recent (2001 to present) monitoring by the King County Groundwater Protection Program:

- Ambient Groundwater Monitoring Study – 2001 to 2004
- Watershed Plan – 2005
- Water Resources Evaluation – 2004 to 2010
    - Annual Data Reports – 2005 through 2010
    - Phase I Groundwater Model – 2005
    - Phase II Hydrologic Modeling: Technical Report – 2009
- Sustainability Indicator Development and Monitoring – 2011 to present

2.3.1 Ambient Groundwater Monitoring Study

The Ambient Groundwater Monitoring Report (Ambient Study) (KC, 2005a) presented water quality and water quantity data from 68 wells and spring locations monitored by King County from 2001 to 2004. This work covered King County's four groundwater management areas (GWMA) of East King County, Issaquah Creek Valley, Redmond- Bear Creek Valley and Vashon-Maury Island.

The Ambient Study was comprised of 19 well and two springs data collection locations on Vashon-Maury Island. These locations are a subset of the locations monitored as part of the GWMP groundwater monitoring locations. Landowners of these locations also participated in the work done to support the GWMP (VMI GWMC, 1998b). Because of changes to the wellhead at ten of the 19 wells, water level data collection was no longer an option at those locations. All locations were monitored for water quality twice a year for three years (2001-2003) and once in 2004. When possible, water level data were also collected at the time of water quality sampling.

In 2001, a volunteer water level data collection effort began with 27 landowners participating in the 12 month study. Five volunteers have continued participating for more than 10 years. Selected water quality locations that allowed additional visits for water level data were included in this effort as well. After the initial 12 month period, volunteers were allowed to continue self-monitoring. After 18 months, the number of volunteers dropped dramatically. In 2004, only five volunteers continued to collect regular monthly water level data.

2.3.2 Watershed Plan

The Vashon-Maury Island Watershed Plan (Watershed Plan) (KC, 2005c) was developed under RCW 90.82 Watershed Planning Chapter to address water supply issues on the Island. The Watershed Plan was initially part of an effort to prepare an overall WRIA 15 report with the GWP Committee being the lead writer of the VMI chapter. After a draft was completed and adopted in June 2005 the process ended as the WRIA members were unable to reach consensus. At the request of the GWP Committee, King County wrote and published the VMI Watershed Plan as a separate report.

The Watershed Plan provides a description of water quantity and quality issues for which recommendations have been made. It was intended that recommendations provide broad guidance and be implemented in close coordination with ongoing programs and mandates of state and local jurisdictions. Included in a full summary of recommendations, the Watershed Plan recommended that a representative sample of the Island exempt wells be monitored for water use. Volunteers were to be solicited to participate in this study. In addition, strategies to implement protection and enhancement of stream ecology were recommended (such as increasing the stream flow data collection network) and prioritizing monitoring of streams and groundwater for traces of pesticides, herbicides, and fertilizers.

The Watershed Plan provided the following paraphrased key findings:

- A management program is needed to preserve and protect limited groundwater resources.
- King County needs to develop a comprehensive strategy to coordinate to the extent of its powers the present and future use of King County's limited groundwater resources.
- King County should encourage Group A water systems to make service available to small water systems within their Comprehensive Plan area.
- The King County code should be amended to require that plats with more than four lots connect to existing public water supply systems if the plat is located in their logical service areas.
- New developments should be required to become part of an existing purveyor's system when they are within the purveyor's logical service area.
- The Island is facing an immediate water supply problem and three purveyors (Burton, Dockton, Heights) at that time did not have adequate water supply to meet estimated peak demand.
- The Island's peak day demand will soon exceed supply.
- Many Island purveyors have experienced summer water shortages.
- The Island needs to develop new water sources, or import water, and conserve water or reduce future demand.
- King County needs to further regulate future land development to make it compatible with water supply limitations.
- There is no off-island water source based on the work reported in the Carr Report, groundwater recharge areas should be protected, and population growth and water use should be carefully managed.
- The Island's population should be limited to prevent depletion of the groundwater and prevent water quality problems.

2.3.3 Water Resources Evaluation

In response to the GWMP, the Vashon-Maury Island Water Resource Evaluation (WRE) Work Plan (KC, 2004a) was prepared and designed to provide a scientific evaluation of the water supply issues (both water quantity and quality related) on the Island between 2004 and 2010. The EPA Quartermaster

Harbor Nitrogen Management Study grant (Section 2.4) supplemented WRE funding for monitoring related to identifying nitrogen sources to Quartermaster Harbor.

The WRE plan laid out the objectives, the overall scope of work, the estimated schedule, and expected deliverables. The main objectives were to:

- Coordinate activities with the GWP Committee and the Land Use Committee, the WRIA 15 watershed planning unit, and the residents of the Island;
- Satisfy the goals of the countywide data management work plan for the Island region;
- Monitor the Island's groundwater and surface water quantity and quality in order to evaluate possible temporal trends; and
- Build a comprehensive groundwater flow model that evaluates groundwater and surface water quantity and quality under various climate change and land-use scenarios.

The WRE Work Plan included activities to characterize the hydrogeology of the study area, such as quantifying the recharge and discharge on the Island, mapping the distribution of aquifer parameters, and constructing hydrogeologic cross-sections and maps. Groundwater, surface water, and precipitation data were collected to better describe the Island's water budget and overall water quality. Monitoring efforts on the Island were to (1) identify changes and trends in groundwater and surface water quantity and quality, (2) provide necessary data for model development and calibration, and (3) have an early warning system on the impacts of pollution sources and groundwater extraction. On an annual basis, a data report was prepared (KC, 2006, 2007, 2008b, 2009a, 2010b) and the King County groundwater database updated with the latest collected data, available online through a web-based interface (KC, 2013c). Table 1 summarizes the data collection activities for the WRE years (2005-2010).

Three main areas of communication included project management, project coordination and education and outreach. The coordination occurred through the development of a technical subcommittee of Island residents that met regularly with King County to discuss issues related to the scope, schedule and budget. At these regularly scheduled meetings, there were opportunities for input from the public and stakeholders. Project updates were prepared on an annual basis. Education and outreach efforts were used to promote stewardship.

2.3.3.1 Precipitation and Surface Water

The WRE added three precipitation gauging locations for a total of five, to improve understanding of the diverse rainfall (Figure 2). In addition, the WRE expanded stream gauging activity from two continuous stream gauging locations to five and added an annual assessment of another 13 creeks around the Island. Instantaneous and continuous data were collected at various locations. Annual mean, maximum and minimum flows and various other annual hydrologic indicators were calculated and presented in annual data reports.

Stream water quality sampling, last conducted in 1992, was conducted at seven creeks during a 14 month (Nov 2006 – Dec 2007) period. These creeks were Shinglemill, Christensen, Tahlequah, Fisher, Judd, Mileta, and Gorsuch Creeks. Based on results observed, stream water quality sampling continued for another year in 2008 at five locations - Shinglemill; Fisher; Judd; Mileta; and Gorsuch Creeks (Figure 2).

Table 1. Water Resources Evaluation Activities Summary.

Water Year	Precipitation	Surface Water Quality			Groundwater				
		Continuous/ Instantaneous Gauging Sites	Water Quality Sites		Water Level Sites	Water Quality Sites		Exempt Well Meter Sites	Newly Drilled Well Sites
2005	5 sites	5/27	--	--	27	Environmental Indicators[1]; organics sampling[2]	20	--	6
2006	5 sites	5/0	Conventionals, nutrtients, and microbiology [3]	--	23	Environmental Indicators[1]; arsenic speciation sampling As, As(III) & As(V)	19	--	--
2007	5 sites	5/27	Conventionals, nutrtients, and microbiology [3]	7	16	Environmental Indicators[1]; arsenic speciation sampling As, As(III) & As(V); plus other[4]	33	8	4
2008	5 sites	5/27	Conventionals, nutrtients, and microbiology [3]	5	20	Environmental Indicators1	17	7	--
2009	5 sites	5/27	Conventionals, nutrtients, and microbiology [3]	5	22	Environmental Indicators1	21	7	--
2010	5 sites	5/27	Conventionals, nutrtients, and microbiology [3]	4	21	Environmental Indicators1	23	7	--

Notes:

1 = Environmental indicators = Arsenic, Chloride, Nitrate+Nitrate

2 = Organics sampling included chlorinated pesticides & herbicides, organophosphorus pesticides, and endocrine disrupting compounds.

3 = Surface Water Parameters (Conventionals, nutrtients, and microbiology)

Ammonia Nitrogen
Conductivity, Field
Dissolved Oxygen, Field
Escherichia coli
Fecal Coliform
Nitrite + Nitrate Nitrogen
Orthophosphate Phosphorus
pH, Field
Sample Temperature, Field
Total Alkalinity
Total Nitrogen
Total Phosphorus
Total Suspended Solids
Turbidity

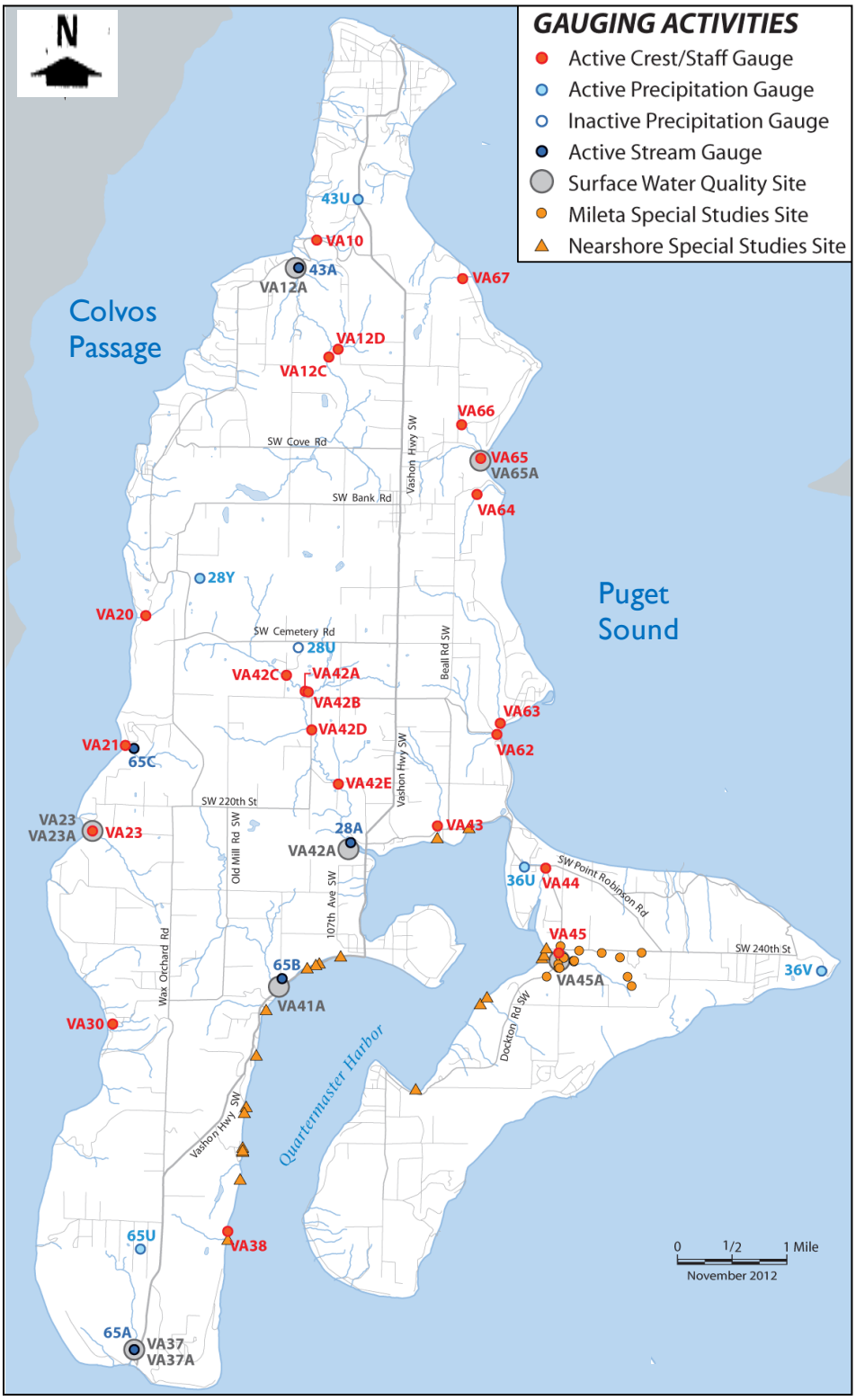
Data collection during 2010 was not incorporated in an annual report.

As = Arsenic

4 = Groundwater Parameters

Cadmium	*pH, Field*
Calcium	*Potassium*
Chromium	*Sample Temperature, Field*
Conductivity, Field	*Silver*
Copper	*Sodium*
Dissolved Oxygen, Field	*Sulfate*
Fluoride	*Total Alkalinity*
Hardness	*Total Dissolved Solids*
Iron	*Total Phosphorus*
Lead	*Total Suspended Solids*
Magnesium	*Turbidity, Field*
Manganese	*Zinc*
Mercury	
Nickel	

Figure 2. Precipitation and Surface Water Locations.



Note: These locations represent activities related to the WRE; Quartermaster Harbor Nitrogen Management Study and VMI Sustainability Monitoring.

2.3.3.2 Groundwater

At the start of the WRE, locations for dedicated new monitoring wells were chosen based on data gaps and/or closest available location, as well as the probable presence of the aquifer of interest. For this study, the aquifer units defined in the Carr Report and in the GWMP were redefined and grouped as follows based on geologic data:

Carr Report	GWMP	WRE
Principal Aquifer	Zone 1	Zone 1 - shallow Vashon recessional outwash deposits (Qvr) & Principal/ Main Vashon advance outwash deposits (Qva) & alluvium deposits (Qal)
	Zone 2	
Deep Aquifer	Zone 3	Zone 2 - Deep 1 Pre Fraser coarse grained deposits (Qpfc)
	Zone 4	Zone 3 - Deep 2 Olympia coarse grained deposits (Qpoc) and deeper units

The aquifer of interest was identified as the Qva geologic unit in Zone 1. Wells were installed in the Qva geologic unit or the next available aquifer. The purpose of these wells was to have dedicated monitoring locations for water quantity and quality for long term assessment of groundwater conditions.

Groundwater levels were collected annually from selected water quality sampling locations (between 2004 and 2010), monthly by five volunteers (between 2004 and 2010) and daily from monitoring wells (between 2006 and 2010). Water level data were collected across the Island in 2006 at 29 locations and an updated map was prepared of data from wells representing water table elevations within the Qva geologic unit (KC, 2007). Volunteer monitored sites were added into the monitoring data set. Currently in 2013, four volunteers are actively self-monitoring water levels. Several of these volunteer wells are some of the longest water level datasets on the Island.

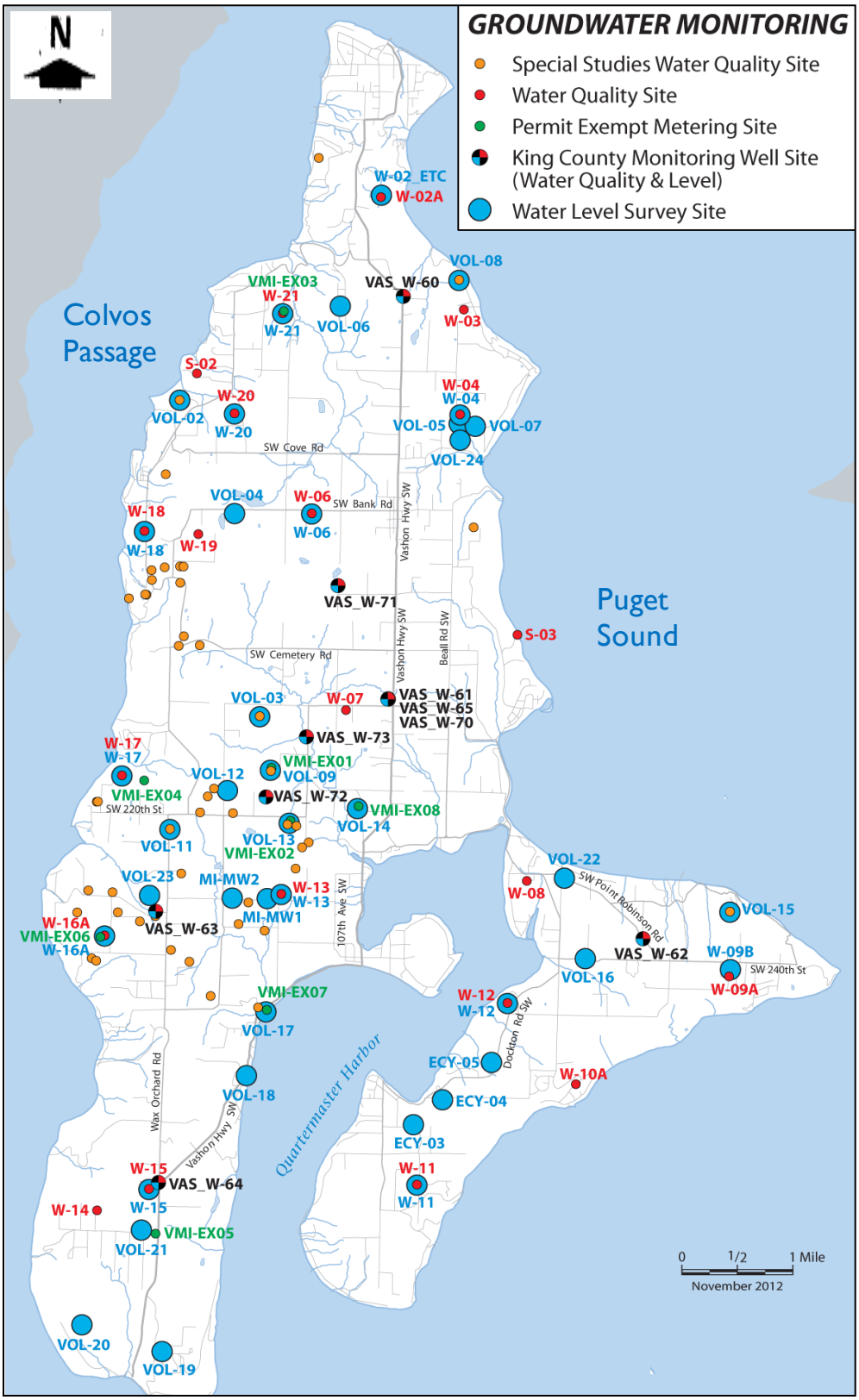
Groundwater quality sampling continued at the Ambient Study monitoring locations. The frequency of collection was changed from twice a year to annually in 2004. Additions and changes in the water quality monitoring occurred in 2005 with a focus on nitrate, arsenic and chloride, as shown in Table 1.All WRE groundwater locations are noted in Figure 3.

2.3.3.3 Exempt Well Water Use

On the Island, there are four subsets of water users — Group A (large) public water systems, Group B (small) public water systems, irrigation, and exempt wells. Exempt wells are wells that are "permit exempt" for water rights and are used by individuals. Although the WRE was designed to provide data on many aspects of the water resources on the Island, there is still not much data on water use from exempt wells. To better understand the overall water balance of the Island, it is important to know who is using the resource and how much is being used. Ideally, a water source would be metered to know how much water is being used and/or to show compliance with a water right. The permit exempt well owners are not required to meter their usage.

Table 2 is a summary of all groundwater wells in the volunteer, long term program and the monitoring program.

Figure 3. Groundwater Related Activities – Water Quality & Quantity Monitoring Locations.



Note: These locations represent activities related to the KC DNRP WLRD projects – Ambient Study; WRE; Quartermaster Harbor Nitrogen Management Study; and Sustainability Monitoring.

Table 2. Groundwater Well Details for WRE and Ongoing Work

WRE Aquifer Zone - Geologic Unit (as per WRE)		Use of Well	Well Name	Location	Active	Easting	Northing	Ground Surface Elevation (feet above MSL)	Average Water Level Elevation (feet above MSL)	Well Depth (feet bgs)
ZONE I	Qvr	Volunteer	vol-07	Nyberg	No	1241557.80	171548.62	200.20	193.48	20
	Qal	Monitoring	VAS_w-73	111th Ave SW	Yes	1233520.75	156745.44	145.0	134.9	57
	Qva	LongTerm	s-03	Atlas Water Corp #1 (Klahanie)	Yes	1243557.81	161598.77	-2.642	0.0	0
		LongTerm	W-10a	Gold Beach Water Company	Yes	1246332.48	140215.28	106.597	19.7	114
		Volunteer	vol-03	Taylor	No	1231302.33	157725.08	355.98	171.68	304
		Monitoring	VAS_W-60	Vashon Hwy SW, near 145th Pl	Yes	1238126.78	177709.28	400.0	179.4	240.0
		Volunteer	w-21	Kuperberg	Yes	1232395.71	176904.52	298.82	184.02	133
		LongTerm	W-21	Kuperberg	Yes	1232395.71	176904.52	298.823	185.2	133
		Volunteer	vol-06	Needle Creek Water System	Yes	1235138.74	177269.28	360.00	198.43	240
		LongTerm	W-15	Anderson	No	1226036.47	135232.21	369.824	210.0	188
		LongTerm	W-13	Misty Isle Farms	Yes	1232322.97	149267.62	223.301	211.3	80
		Volunteer	vol-19	Sunnyslopes	Yes	1226661.27	127520.10	291.74	227.43	102
		LongTerm	W-16a	Baker/Klemka	Yes	1223926.61	147292.52	282.628	229.1	67
		Monitoring	VAS_W-65	Valley Center Park-n-Ride 6" well	Yes	1237393.75	158570.14	325.0	240.2	159.5
		Monitoring	VAS_W-61	Valley Center Park-n-Ride 2" well	Yes	1237415.33	158544.96	325.0	240.6	155.0
		Volunteer	vol-11	Ammon	No	1227036.23	152357.60	384.80	246.77	150
		Volunteer	vol-21	Wolff	No	1225674.19	133298.03	338.05	250.13	150
		LongTerm	W-06	Packard/Healy	Yes	1233777.06	167375.23	405.662	259.2	169
		Monitoring	VAS_w-72	Paradise Ridge Park	Yes	1231599.89	153882.27	382.0	261.2	135
		Volunteer	vol-23	Harper	No	1226063.91	149225.63	321.56	264.27	UNK
		LongTerm	W-19	Thorsen Rd Water Association	No	1228382.08	166391.41	412.611	268.8	173
		LongTerm	W-20	Johnson	Yes	1230103.08	172135.11	362.961	275.8	122
		Monitoring	VAS_w-71	Island Center Forest	Yes	1235024.82	163939.60	367.0	283.1	104
		Volunteer	vol-04	Coulson	No	1230107.74	167393.89	406.98	301.04	140
		Volunteer	vol-12	Davison_Clegg	No	1229768.23	154215.58	390.93	310.27	UNK
	Qva ?	Monitoring	VAS_W-64	Wax Orchard Rd @ Vashon Hwy	Yes	1226485.09	135533.47	380.0	198.5	244.0
	Qva/Qac	LongTerm	W-14	Krishnan	Yes	1223562.98	134210.22	376.455	211.5	183

(continued on next page)

Table 2. Groundwater Well Details for WRE and Ongoing Work. *(continued)*

WRE Aquifer Zone - Geologic Unit (as per WRE)		Use of Well	Well Name	Location	Active	Easting	Northing	Ground Surface Elevation (feet above MSL)	Average Water Level Elevation (feet above MSL)	Well Depth (feet bgs)
ZONE 2	QAc	LongTerm	W-03	Glen Acres	Yes	1241007.87	177076.64	145.601	17.3	142
		LongTerm	W-17	Perla	Yes	1224748.77	154907.21	223.123	52.9	220
		LongTerm	W-02a	Heights Water District	Yes	1237066.70	182426.33	260.316	115.2	177
		LongTerm	W-18	Whelan-Miller	No	1225821.93	166542.07	207.347	131.9	116
		Monitoring	VAS_W-70	Valley Center Prk-n-Ride Deep	Yes	1237379.22	158547.99	325.0	188.5	335
		Monitoring	VAS_W-62	Maury Island - 63rd Ave SW	Yes	1249531.29	147138.50	330.0	dry	243.0
	Qpf	Volunteer	vol-05	Palmer	No	1240788.94	171668.80	190.83	51.60	197
		Volunteer	vol-16	Svinth	No	1246789.32	146211.61	150.62	59.41	249
		Volunteer	vol-22	Jansen	No	1245797.62	150042.30	65.50	62.09	UNK
		Volunteer	vol-27	Heights Water	Yes	1237044.10	182535.11	192.20	68.7	155
		Volunteer	vol-14	Abel	No	1235950.63	153352.41	134.01	87.33	UNK
		Volunteer	w-02b	Heights Water Dept. Well #2	Yes	1237075.90	182457.93	199.55	87.82	148
		Volunteer	w-02a	Heights	Yes	1237066.70	182426.33	260.32	114.48	177
		Volunteer	vol-15	Luana Water Association	No	1253664.98	148427.47	166.00	119.61	79
		Volunteer	vol-20	Crockett	No	1222849.84	128787.21	316.46	147.45	189
		Volunteer	vol-13	Meeker	Yes	1232707.61	152657.99	299.86	160.78	210
		Volunteer	vol-09	Graham	No	1231813.03	155178.09	368.26	163.01	350
	Qva/Qpfc	Monitoring	VAS_W-63	SW Redding Beach Rd	Yes	1226357.60	148438.41	290.0	180.9	145.0

(continued on next page)

Table 2. Groundwater Well Details for WRE and Ongoing Work. *(continued)*

WRE Aquifer Zone - Geologic Unit (as per WRE)		Use of Well	Well Name	Location	Active	Easting	Northing	Ground Surface Elevation (feet above MSL)	Average Water Level Elevation (feet above MSL)	Well Depth (feet bgs)
ZONE 3	Qpf	Volunteer	vol-08	Sage	No	1240783.47	178488.83	93.53	24.36	94
		Volunteer	vol-17	Putnam	No	1231599.26	143680.71	41.72	31.69	120
		Volunteer	vol-18	Oellien	No	1230670.95	140647.11	118.20	33.12	150
		Volunteer	vol-24	Bogaard	No	1240837.79	170889.12	207.55	34.88	UNK
	QBc	LongTerm	W-04	Rodriques	Yes	1240833.87	172083.67	198.261	0.0	305
		LongTerm	W-12	Hollymere Water System	No	1243087.96	144080.74	110.421	15.4	473
		Volunteer	vol-02	Beardsley	Yes	1227498.68	172787.90	134.53	26.71	165
		LongTerm	W-08	Kiro/Entercomm, Inc.	No	1244002.63	149889.53	95.478	51.3	462
	QAc	LongTerm	W-09a	White #1	Yes	1253624.00	145340.00	411.055	20.2	450
		LongTerm	W-07	Toomey/Sorge	Yes	1235401.16	158016.56	259.819	26.6	297
		LongTerm	W-11	Docton Water Association	Yes	1238780.43	135435.73	320.512	81.6	423

Note:

bgs = below ground surface

MSL = mean sea level

UNK = unknown

WRE = KC Water Resources Evaluation

Main Geologic Units for King County	
Qal	alluvium
Vashon Stade	
Qva	Vashon advance outwash deposits
Qvr	Vashon recessional outwash deposits
Older Glacial and Nonglacial Deposits	
Qpf	Pre-Fraser deposits, undifferentiated
Qpfc	Pre-Fraser coarse grained deposits
QAc	pre-Vashon deposits upper coarse grained unit
QBc	pre-Vashon deposits lower coarse grained unit

2.3.3.4 Modeling and Water Budget Efforts

Understanding the water budget for the Island and how sensitive the system is to changes in human activities and climate is important in evaluating the amount of water that can be safely pumped from the aquifers on a sustained basis. As part of this work, a groundwater modeling effort addressed the water balance concerns on the Island. Results of the groundwater modeling and water budget efforts were reported in the following documents and are discussed in more detail in Section 4.3:

- Vashon-Maury Island Phase I Groundwater Model – A Part of the Vashon-Maury Island Water Resources Evaluation (KC, 2005b), and
- Vashon-Maury Island Hydrologic Modeling: Technical Report (KC, 2009b).

These models relied heavily on the monitoring and data management components of the WRE Work Plan. In Phase 1, a large-scale steady-state model was developed for the Island groundwater budget, using the MODFLOW-2000 model developed by the U.S. Geological Survey (KC, 2005b). MODFLOW is a finite-difference groundwater flow model capable of modeling in one-, two- or, three-dimensions.

The Phase 1 model was a three-dimensional (3-D) model made of ten layers based on a database of borings and well logs compiled by GeoMapNW. Boundary conditions included wells, recharge (natural and septic drainfields), streams, springs, and deep discharge to Puget Sound. Calibration was accomplished by successively modifying aquifer/aquitard properties (hydraulic conductivity) and some lesser-defined boundary conditions (streams and springs) to successively improve the fit. For simplicity, the properties for any given unit (aquifer and aquitard) were considered to be uniform across the entire Island, as were the boundary condition parameters for all streams and springs.

There were some uncertainties about the quantity of well production – agricultural irrigation in particular. The model was most sensitive to hydraulic conductivity in medium deep units, although this sensitivity may be associated with the chosen Puget Sound boundary condition. Less sensitive were the conductivities in shallower and deeper units and the stream and springs boundary condition parameters (KC, 2005b).

The WRE Phase I model presents an updated island-wide water budget/balance as the following:

Precipitation + Septic Systems + Rivers & Lakes =
Evapotranspiration + Runoff + Subsurface flow + Base flow + Wells + Springs

where: Precipitation = rainfall or snow
Septic Systems= recharge from septic systems
Rivers & Lakes = recharge from rivers and lakes
Evapotranspiration = water evaporated by soils and transpired by plants
Runoff = amount of water that does not infiltrate (goes directly to Puget Sound)
Subsurface flow = discharge of groundwater to Puget Sound
Base flow = amount of groundwater discharging into streams and rivers
Wells = discharge to wells
Springs = discharge to springs

The Phase 1 model also provided some guidance for future phases of groundwater modeling of the Island's aquifer system and provided suggestions for investigation to address data gaps that were found to be limiting to the modeling effort. The following actions were among several suggested:

- Correcting well locations;
- Incorporate more recent reinterpretations of hydrostratigraphy and boundary conditions;
- Add monitoring wells to inform models during later phases;
- Refine understanding of geographic variations in aquifer properties;
- Improve detailed grid and subdomain modeling to model localized issues of lateral flow or contaminant transport;
- Conduct surface water modeling to better define recharge issues and surface water / groundwater interaction;
- Consider instrumenting wells to improve estimations of pumpage rates;
- Improve mapping of springs; and
- Adjust boundary conditions offshore to improve accuracy in modeling saltwater interface.

Phase II modeling work involved refining the Phase I groundwater model and linking it to a surface water model. More specifically, it included the development of a time-varying, integrated groundwater-surface water model and an assessment of the impacts of possible future build-out along with climate change scenarios on the water resources. In order to refine the ability to simulate historical groundwater conditions on the Island and improve the ability to model future conditions scenarios, a transient integrated hydrologic model was developed using DHI's MIKE SHE code and the existing MODFLOW model (Phase I) as a starting point (KC, 2009b). Location-specific parameters used to construct the Phase II model included land use, precipitation, evapotranspiration, geologic and hydrogeologic parameters, well locations, and pumping and withdrawal rates. Several parameters were assumed to vary based on season, including precipitation, evapotranspiration, pumping, and withdrawal rates.

The WRE Phase II model presents an updated island-wide water budget/balance that is most similar to the WRE Phase I model budget. As seen in the following equation, recharge by irrigation activities were included:

Precipitation + Septic Systems + Irrigation =
Evapotranspiration + Runoff + Subsurface flow + Base flow + Wells + Springs

where: Precipitation = rainfall or snow
Septic Systems= recharge from septic systems
Irrigation = recharge from irrigation
Evapotranspiration = water evaporated by soils and transpired by plants
Runoff = amount of water that does not infiltrate (goes directly to Puget Sound)
Subsurface flow = discharge of groundwater to Puget Sound
Base flow = amount of groundwater discharging into streams and rivers
Wells = discharge to wells
Springs = discharge to springs

The output generally agreed with previous evaluations of water resources, and the model calibration was acceptable for understanding the general flow direction, magnitude, and location of the water resources and assessing potential areas of concern. The Phase II model evaluated two possible future pumping scenarios representing additional development on the Island associated with population growth, four possible future climate change scenarios representing possible changes in temperatures and precipitation, and four possible future scenarios that combined the development and climate conditions.

The future climate change scenarios suggest that both mean annual precipitation and evapotranspiration will increase over the next century, and that runoff and baseflow will decrease slightly. Results showed that relatively small declines in mean annual groundwater recharge will occur. In addition, projected decreases of groundwater levels in the upper aquifers and stream summer baseflows were present under all of the future scenarios evaluated. Mean annual groundwater levels were projected to decline from between 0.3 and 5.2 feet depending on the scenario, the area of the island, and the aquifer in question.

Under a pumping scenario, where additional wells are completed within the Qva, mean water levels in the Qva may decrease by up to 0.9-ft. Stream baseflow may also decrease slightly under this pumping scenario by up to 0.3%.

The model did a reasonably good job of estimating the observed streamflows in Shingle Mill Creek. The model represents summertime baseflow conditions quite well in this creek, but under-predicts flows during runoff events. The model does not predict streamflows nearly as well in Judd Creek, where runoff events are significantly under-predicted and baseflows are significantly over-predicted.

The Phase II report posited the following paraphrased recommendations:

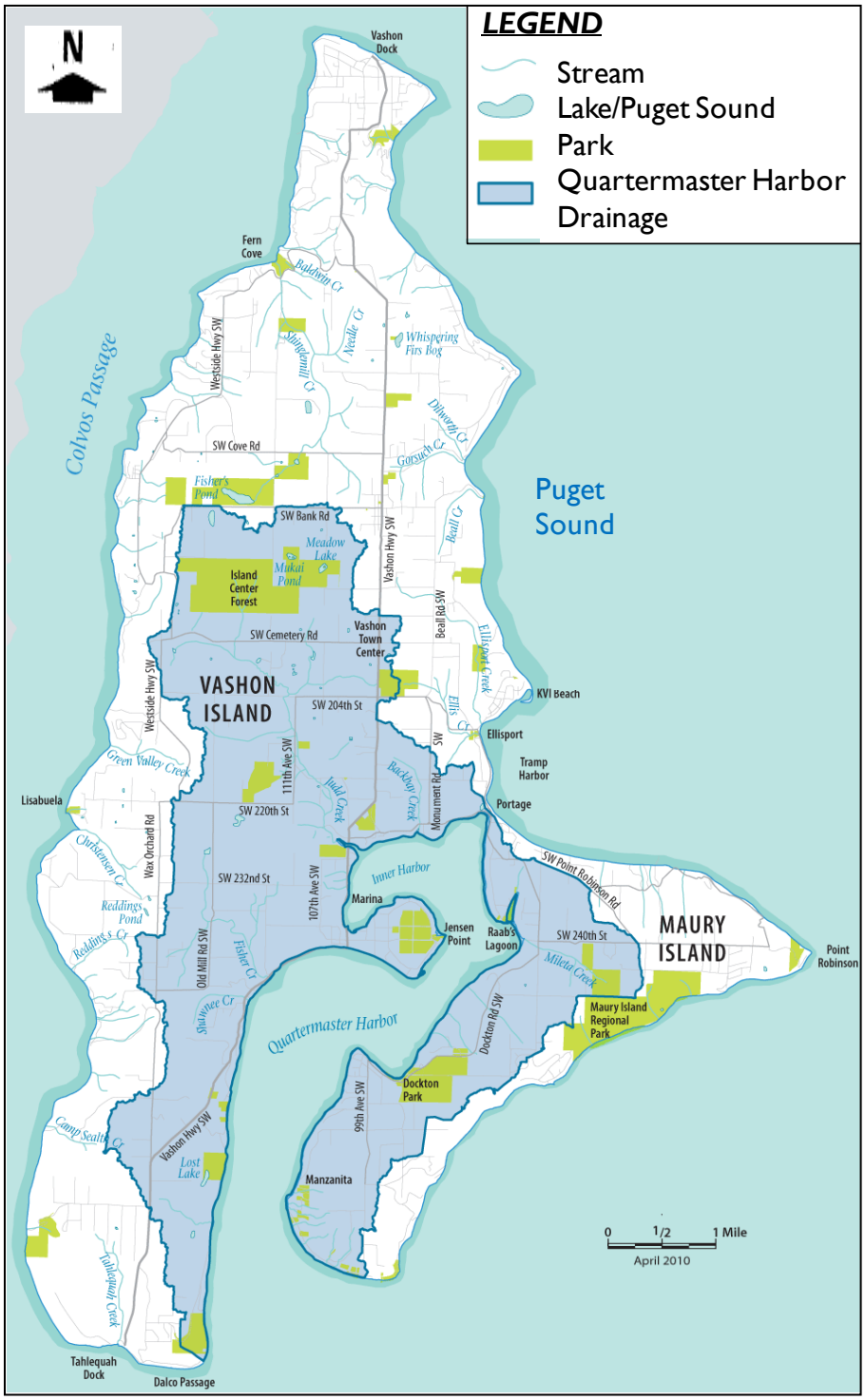
- Refine the MIKE SHE model and/or develop a finite-element groundwater model using a more advanced model such as DHI's FEFLOW program.
- Evaluate additional climate change scenarios to investigate the range of possible climate change impacts on water resources of the Island, especially to include regional climate model data specific to the Island.

2.4 Quartermaster Harbor Nitrogen Management Study

The Quartermaster Harbor Nitrogen Management Study is a four year (2009 - 2012) project with a goal to support the protection and restoration of Quartermaster Harbor – a high value, coastal aquatic resource on the Island (Figure 4). Partners working with King County on this U.S. Environmental Protection Agency (EPA) grant-funded study include the Groundwater Protection Committee, the University of Washington-Tacoma (UWT) and Ecology. The EPA Quartermaster Harbor Nitrogen Management Study grant ("see below for details regarding that study") supplemented WRE funding for monitoring related to identifying nitrogen sources to Quartermaster Harbor.

Quartermaster Harbor is a shallow bay that has approximately 3,000 acres of water surface area in an inner and outer harbor (KC, 2012c). The largest freshwater source to the sheltered inner harbor is Judd Creek. Transition zones exist between freshwater sources and marine water along estuaries at the mouth of Judd Creek, Fisher Creek and Raab's Lagoon and at various small streams (KC, 2012c). Dissolved oxygen levels below the state marine water quality standard have been observed in the harbor over the last seven years (monthly harbor monitoring began in 2006) and the harbor typically experiences low dissolved oxygen concentrations during late summer/fall that fall below the applicable state marine water quality standard. The likely cause of these low oxygen levels is the growth and subsequent die-off of microscopic organisms that live in watery environments (otherwise known as phytoplankton) that consume dissolved oxygen in the water column and sediments as they decompose and settle to the bottom of the water column(KC, 2012c).

Figure 4. Drainage Area to Quartermaster Harbor.



The Quartermaster Harbor Nitrogen Management Study monitored many aspects of surface, ground and marine waters of the Island. Stream water quality monitoring was conducted on Fisher, Judd and Mileta Creeks. The stream water quality work continued through 2012.

Marine monitoring was conducted by King County and UWT staff within and just outside Quartermaster Harbor for this study. King County conducted monitoring at three intertidal locations (Dockton marina, Inner Harbor marina and Burton Beach) along with two subtidal sampling locations (Dockton and Inner Harbor docks). UWT sampling occurs at seven vessel-based sampling locations from outside of the entrance of Quartermaster Harbor into the inner harbor area.

This study has so far produced the following reports:

- Initial Assessment of Nutrient Loading to Quartermaster Harbor – February 2010
- Mileta Creek Nitrogen Source Tracking Study – February 2012
- Quartermaster Harbor Nearshore Freshwater Inflows Assessment – March 2012
- Quartermaster Harbor Benthic Flux Study – March 2012

The *Initial Assessment of Nutrient Loading to Quartermaster Harbor* report (KC, 2010a) documents available data sources and methods used to develop initial estimates of nutrient loading to the harbor from the atmosphere, tributary streams, nearshore septic systems, groundwater, and harbor sediments. The nutrients considered were forms of nitrogen, phosphorus, and silica, which are the common essential nutrients for phytoplankton growth in estuaries and freshwater systems. Of the external sources of nutrients evaluated, tributary streams were the most significant source of the forms of nitrogen most readily available to estuarine phytoplankton on an annual basis. A tributary is a freshwater stream that flows into a larger stream, river or other body of water. Assessment of seasonal loadings indicated that nearshore septic systems may be the largest external source of nitrogen on the Island during the critical late summer/fall period when harbor dissolved oxygen concentrations are lowest. Estimates of internal benthic nutrient flux from harbor sediments indicated that this may be a far more significant source of nutrients during the same late summer/fall period. Nutrient influx from the Puget Sound through the entrance to the harbor has not yet been quantified.

This initial report recommended:

- Estimate the nutrient contribution from Puget Sound to the harbor as a result of estuarine circulation using available data and the hydrodynamic model under development for this project;
- Develop plan and budget for conducting benthic nutrient flux measurements in the harbor during late summer/fall of 2010;
- Evaluate the possibility of sampling currently unmonitored freshwater inflow sources to the harbor during late summer/fall of 2010;
- Develop plan and budget to track source of high winter nitrate levels in Mileta Creek; and
- Attempt to balance groundwater and stream nutrient inputs with specific upland sources.

The *Mileta Creek Nitrogen Source Tracking Study* (KC, 2012a) was conducted to identify locations on Mileta Creek where nitrate concentrations are elevated in winter and to evaluate if the source could be identified. Mileta Creek is a relatively small tributary to Quartermaster Harbor and it is the only tributary routinely monitored on Maury Island. Elevated nitrate concentrations of over 4 milligrams per liter (mg/L) have been observed during winter months in Mileta Creek since routine monthly water quality monitoring began in late 2006. The peak nitrate concentrations in Mileta Creek (and the smaller peaks in the other monitored creeks) typically occur after the minimum oxygen concentrations are observed in Quartermaster Harbor. Data for this study was collected at 16 locations in the drainage area, representing Mileta Creek and associated smaller tributaries. The timing and shape of the nitrate

peak in Mileta Creek was reported as similar to that in Shingle Mill, Judd, and Fisher creeks – particularly Fisher Creek, but the peak concentration is of significantly greater magnitude. In summary, the study was not able to identify the actual source. However, the report indicated that the source location was isolated to the reaches upstream of the mainstem of Mileta Creek. The study was able to eliminate the golf course and the abandoned chicken barns as the cause of the elevated nitrate concentrations observed in Mileta Creek. Potential sources of nitrate to Mileta Creek were posited as:

- Human activities (historic or current) in the upland reaches of the watershed;
- Release of summer accumulation of dissolved nitrate from nitrogen fixing plants, such as red alder, in surface soils during initial winter storms;
- Excreta from a possible nearby historic heron rookery; and
- Forest clearing, especially clearing of red alder stands.

The following paraphrased recommendations were suggested:

- Further attempts to isolate the source(s) of elevated winter nitrate concentrations should include a more rapid way to identify the timing of peak nitrate concentrations;
- Focus should be on the longitudinal variation of nitrate in the two forks of Mileta Creek upstream from the mainstem;
- Identifying other small creeks with similarly elevated nitrate concentrations might help to determine if elevated nitrate concentrations are isolated to Mileta Creek or associated with a particular combination of land cover and surface soil or subsurface geologic characteristics; and
- Include red alder density in a more detailed forest classification to more directly relate the amount of red alder to observed nitrate concentrations and loads in streams.

The *Quartermaster Harbor Nearshore Freshwater Inflows Assessment* (KC, 2012d) was completed to identify small previously unmonitored small tributaries, pipes, culverts and seeps discharging to Quartermaster Harbor that might have relatively high nitrate concentrations. Data were collected in October 2010 along the perimeter of the harbor. Many of the freshwater source locations (inflows) had been inventoried in previous studies, but they had not been sampled for water quality. Results from this study reported the median nitrate concentration range measured in small freshwater inflows to the harbor was similar to the median nitrate concentration measured in October in the three largest tributary streams to the harbor from 2007 to 2010. The data suggested spatial variability in nitrate from these previously unmonitored sources.

The initial estimate of total nitrate loading from freshwater inflows to the harbor used an average areal loading from routinely monitored tributaries to estimate loading from the unmonitored portion of the harbor drainage basin (KC, 2010a). The total estimated October 2010 nitrate loading from Judd, Fisher and Mileta Creeks was 6.3 kilograms per day (kg/d) and the total estimated loading from the previously unmonitored freshwater inflows was 3.1 kg/d. Judd, Fisher and Mileta Creeks were reported to represent drainage from approximately half of the total drainage to the harbor. Based on an areal extrapolation approach, the total load from the remainder of the basin would be approximately 6 kg/d in October 2010.

The *Quartermaster Harbor Benthic Flux Study* (KC, 2012c) documents the results of an *in situ* study of benthic oxygen demand and nutrient fluxes from sediments in the harbor during critical dissolved oxygen conditions in the harbor for use in water quality model calibration and testing. The results from

data collected from locations in the harbor were reported as similar to the range of results reported by a recent study conducted in four South Puget Sound bays that used the same equipment and methods. There was a distinct gradient in the results with the greatest sediment oxygen demand and nutrient flux observed at the shallowest location in the inner harbor. Lowest nutrient release was estimated for the two deepest stations in the outer harbor. The flux estimates provided by this study will provide location-specific data for the development and testing of a water quality model of the harbor and also provide data to refine the initial estimate of sediment nutrient loading to the harbor. Because sediments may provide a long-term reservoir of nitrogen for phytoplankton growth that could delay the response of the harbor to management activities designed to reduce nitrogen loading from terrestrial sources, additional studies of sediment nutrient flux may be warranted.

2.4.1 Sustainability Indicator Development and Monitoring

In 2011, the King County Groundwater Protection Program transitioned from the WRE to on-going monitoring requested by the GWP Committee. This work continues water resources (precipitation, surface water and groundwater) monitoring initiated or expanded during the WRE. Precipitation, stream gauging, and groundwater monitoring has continued with five precipitation locations, five continuous stream gauge locations, and over 20 groundwater wells.

Data from this monitoring work is being incorporated into the VMI Sustainability Indicators, a set of measures to evaluate the overall hydrologic conditions on the Island. The Sustainability Indicators are listed in Table 3 and described in more detail in Appendix A

As noted in the prior section, stream water quality work is conducted as part of the Quartermaster Harbor Nitrogen Management Study along with shared groundwater water quality work through 2012.

Table 3. Sustainability Indicators for Vashon-Maury Island.

Topic	Subtopic	Indicators
Water Quality	Groundwater	Nitrate
		Arsenic
		Chloride
	Surface Water	Stream Water Quality Index
	Marine Water	Quartermaster Harbor Dissolved Oxygen
		Quartermaster Harbor Fecl Coliform
Water Quantity	Groundwater	Water Levels
	Surface Water	Summer Low Flows
		Stream Flashiness
Ecosystem Health	Stream Life	Stream Benthic Macroinvertibrate population (B-IBI)
		Salmon Population
Water Use / Management	Island-Wide Water Usage	Annual Total Usage
		Per Capita Usage
		Peaking Factor

3.0. ISLAND-WIDE CLIMATE CONDITIONS

Although it's been over 50 years since this narrative summary of Vashon-Maury Island's climate, as prepared by the U.S. Weather Bureau State Climatologist in 1962 (Carr/Assocs., 1983), the observations are still applicable to current conditions on the Island. Local differences and climatic trends are discussed in further detail in the following sections.

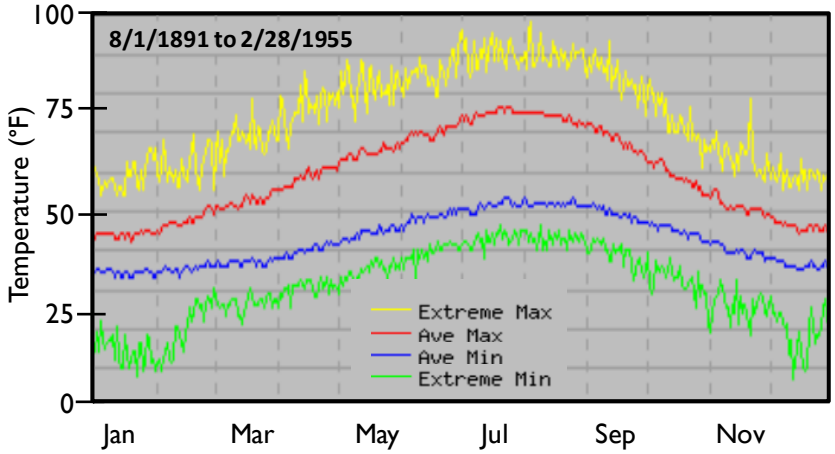
> "In a northwesterly direction and within a distance of 40 miles, the Olympic Mountains rise to elevations of 4,000 to 7,000 feet. This range is very effective in protecting the Island from the more intense winter storms moving inland from over the Ocean. In an easterly direction and within 50 miles, the Cascade Mountains reach elevations of 5,000 to 7,000 feet with snowcapped peaks in excess of 10,000 feet. The Cascades shield the Puget Sound area from the higher summer and lower winter temperatures observed in eastern Washington.
>
> The climate is predominantly a mid-latitude, west coast marine type with cool dry summers, mild but rather rainy winters and a small range in temperature. During the spring and summer, a clockwise circulation of air around the large high pressure area over the north Pacific brings a flow of comparatively dry and cool air from a northwesterly direction into western Washington. As the air moves inland, it becomes warmer and drier, resulting in a dry season beginning in the late spring and reaching a peak in mid-summer. During July and August, it is not unusual for 2 to 4 weeks to pass with only a trace of precipitation. Afternoon temperatures in the warmest months are in the 70's and nighttime readings are in the 50's. Maximum temperatures reach 80° or 85° on a few afternoons; however, 90° is unusual. The hottest days occur when hot dry air from east of the Cascades reaches this area. The humidity is low under these conditions and the warmest afternoons are not especially uncomfortable. Following one or two hot days, cooler air from over the Ocean moves inland and temperatures return to the 70's. Fog or low clouds sometimes form during the early morning hours and disappear' before noon.
>
> During the fall and winter seasons, the low pressure area near the Aleutian Islands intensifies and the high pressure area over the north Pacific becomes smaller and moves southward. A circulation of air around these two pressure centers brings a prevailing flow of warm moist air from a south-westerly direction into the State. This results in mild winter temperatures and a rainy season beginning in October, reaching a peak in mid-winter and gradually decreasing in the spring. Snowfall is light and seldom remains on the ground longer than a few days."

Statewide trends of worsening conditions are evident and projections follow a similar trend. In addition, Washington State reports that "climate-influenced conditions and events such as temperatures, sea levels, and storms can no longer be expected to remain within their historical ranges, and these trends are likely to continue well beyond the end of the 21st century." (WA Ecology, 2012). To address this issue and to compare results of local versus regional data, this section of the report presents trends and/or spatial variability, if present, of air temperature, precipitation, and stream flow data. In general, there is some evidence of local air temperature data showing similar warming rates as that seen in global data. Due to the lack of long term data for precipitation and stream flow data on Vashon-Maury Island, it is not known if trends exist.

3.1 Air Temperature

On Vashon Island, the mean monthly average air temperature for the period from 1891 to 1955 ranged between 38.7 to 62.9 degrees Fahrenheit (F) (WRCC, 2013). This location was a former weather station, located near the Agren Memorial Park on the northwest side of Vashon Island. The daily air temperature averages and extremes for this station identified as National Climate Data Center (NCDC) Cooperative Observer Program (COOP) station number 458802 (Figure 5; WRCC, 2013).

Figure 5. Daily Air Temperature Averages and Extremes on Vashon Island.

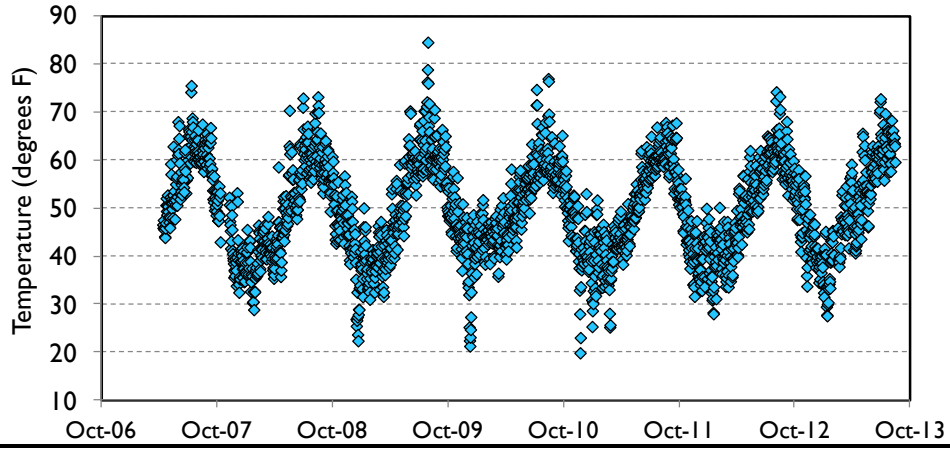


Note: Location is Station 458802. Figure modified from WRCC, 2013.

Although the Carr Report did not present data or discuss air temperature and movement, the report did comment that although there was probably considerable variation within the study area, the differences were not significant in evaluation of evaporation. When needed for the report, data from the Seattle-Tacoma International airport (Sea-Tac) weather station was considered representative of the entire Island's conditions (Carr/Assoc., 1983).

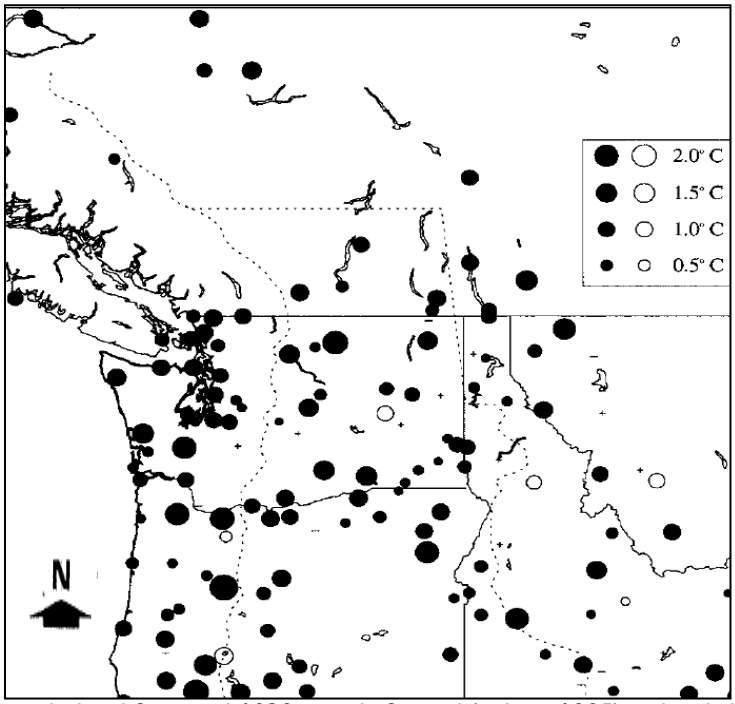
King County installed and has maintained an air temperature gauge (West Judd Creek Rain Gage 28Y) on the Vashon Island Closed Landfill property since June of 2007. The daily mean air temperature for the period June 2007 through August 2013 ranged mostly between 30 and 70 degrees F (Figure 6).

Figure 6. Daily Mean Air Temperatures at West Judd Creek Rain Gage 28Y located at the Vashon Island Closed Landfill (June 2007 through August 2013).



More recent regional data indicates that the average annual temperatures in the Pacific Northwest rose on average about 1.5 degrees F in the last century (Mote, 2003 and WA DOE, 2012). Figure 7 shows the linear trends of temperature for this region per 100 years (Mote, 2003).

Figure 7. Linear Trends in Temperature in the Pacific Northwest.



Note: Trends are calculated for period 1930 to end of record (at least 1995) and scaled to give temperature change per 100 year. Positive trends are shown as filled in circles and negative trends are shown as empty circles. The area of the circle is proportional to the magnitude of the trend (Mote, 2003).

In addition, more recently reported local data from the Sea-Tac airport weather station shows an increase in temperature since 1949 (Figure 8). The ten-year running average for 2003 through 2012 was 0.42 degrees F above the ten-year running average for 1958 through 2002 (KC, 2013d). A more recent change in warming rates over the last 10-15 years is present in the data for Sea-Tac (Figure 8) and is also evident in upper ocean heat content anomalies (Figure 9). This pause in the global warming rates have been observed in local and global data over the last few decades and continues to be widely discussed among scientists and various explanations are being considered (The Economist, 2013 and 2013b; Guemas et al, 2013; PMEL 2013; Tung and Zhou, 2013). An article by the United Kingdom's National Weather Service (UK NWS, 2013) states:

> "It is not possible to explain the recent lack of surface warming solely by reductions in the total energy received by the planet, i.e. the balance between the total solar energy entering the system and the thermal energy leaving it. Observations of ocean heat content and of sea-level rise suggest that the additional heat from the continued rise in atmospheric carbon dioxide concentrations has been absorbed in the ocean and has not been manifest as a rise in surface temperature. Changes in the exchange of heat between the upper and deep ocean appear to have caused at least part of the pause in surface warming, and observations suggest that the Pacific Ocean may play a key role."

Figure 8. Temperatures at Seattle-Tacoma International Airport Weather Station.

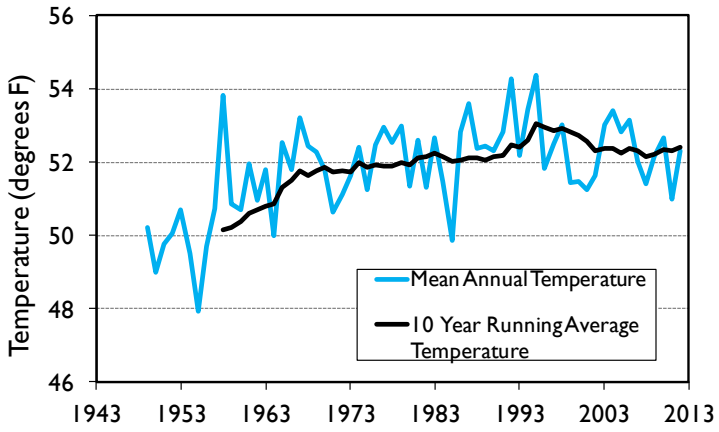
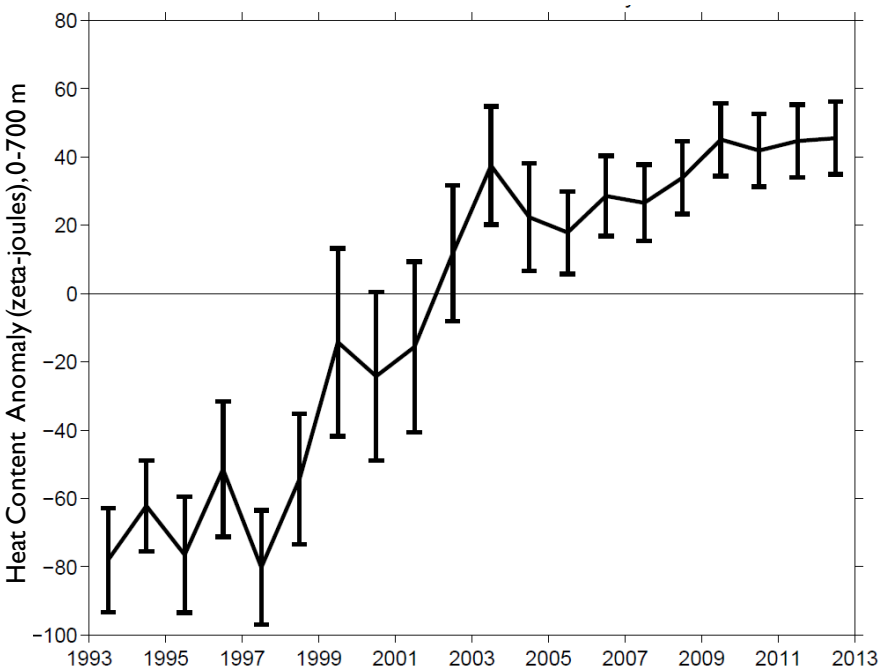


Figure 8. Upper Ocean Heat Content Anomaly.



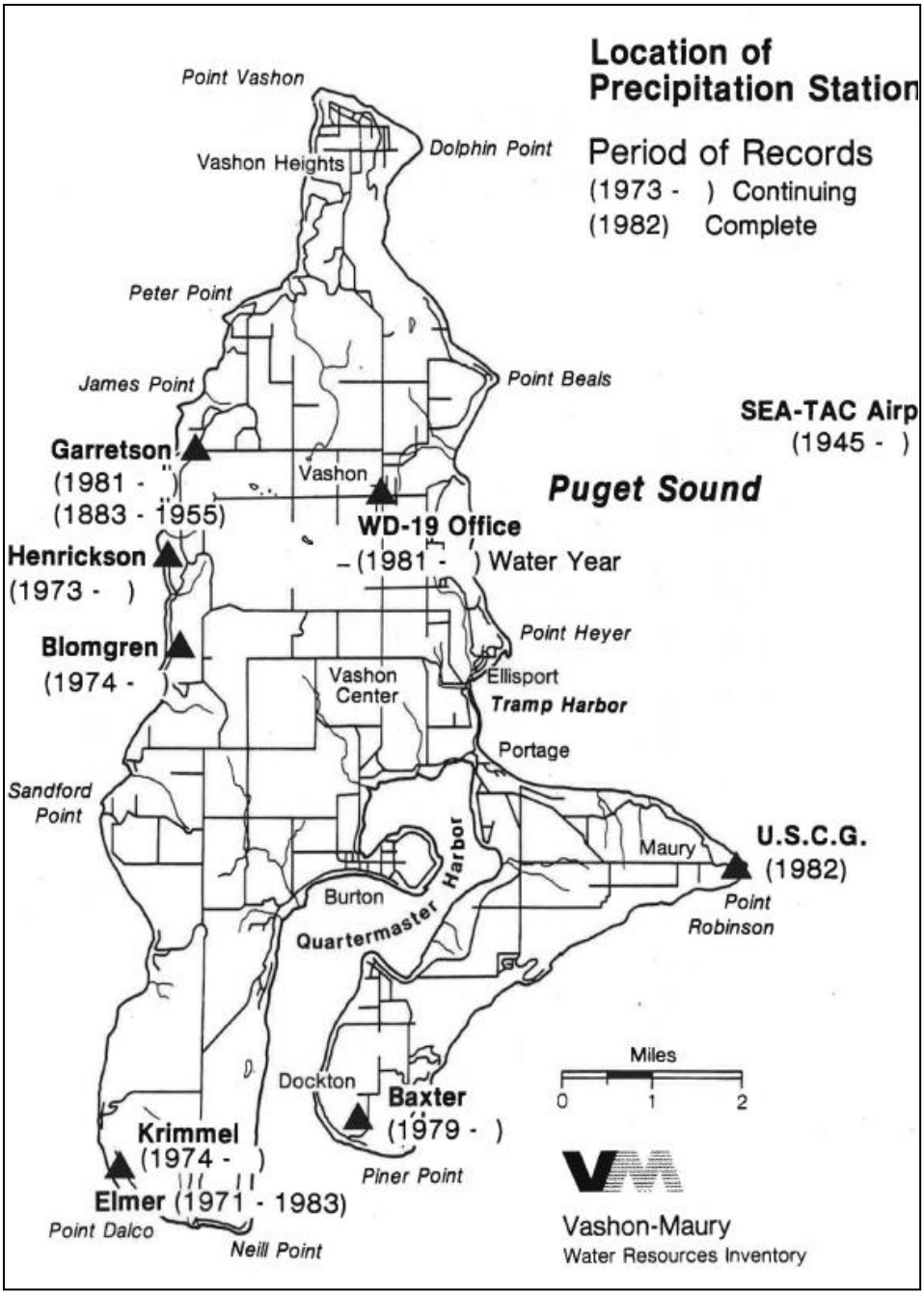
Note: Modified from Lyman et al (2010) and updated by PMEL (2013). A zeta-joule is equal to 10^{21} joules.

3.2 Precipitation

Precipitation data collection has been sporadic and sparsely located across both islands. The location and time period of data collection is represented in an updated figure from the Carr Report (Figure 10). Historical data (1945-1954) indicated average annual precipitation was about 40 inches per year on the Island (Carr/Assoc., 1983). The Carr Report indicated that weather patterns from the nearby Sea-Tac airport weather station paralleled that of the station on the Island. Limited data during that time period indicated decreasing annual total precipitation from west to east across the Island (Figure 11). Total precipitation measured from seven locations during Water Year 1982 (October through September)

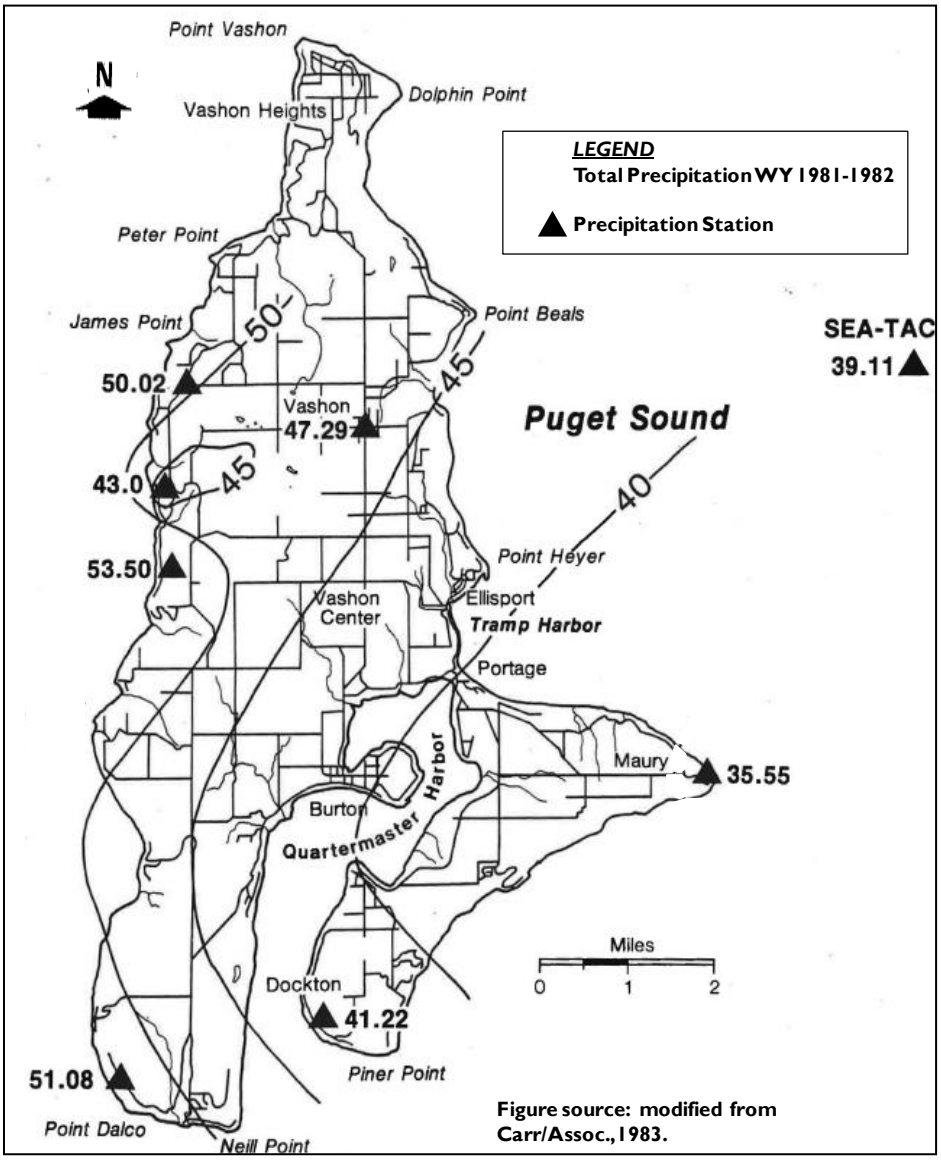
showed an 18 inch difference across the Island; 53.5 inches on the west side of the Island to 35.5 inches at Point Robinson(Carr/Assoc., 1983). The Carr Report also presented that the Island was receiving about 18 to 26 percent more precipitation than the Sea-Tac airport weather station.

Figure 10. Location and Duration of Precipitation Data Collection.



Total precipitation measured from seven locations during Water Year 1982 (October through September) showed an 18 inch difference across the Island; 53.5 inches on the west side of the Island to 35.5 inches at Point Robinson(Carr/Assoc., 1983). The Carr Report also presented that the Island was receiving about 18 to 26 percent more precipitation than the Sea-Tac airport weather station.

Figure 11. Annual Rainfall Contours for Water Year 1982.



Similar to the Carr Report, the GWMP reported annual rainfall on the Island ranging from 40 to 62 inches per year. Monthly rainfall ranged from 0 to 15 inches with driest months in August and September. This data is consistent with information from the Sea-Tac airport weather station. The GWMP data for rainfall was reported as calendar years. When recalculated for water years (WY), two years of data (WY1990 and WY1991) showed about 10 inches of difference across the Island (VMI GWMC, 1998b). For locations that had a full 12 months of data, a difference of 9, 14 and 12 inches was observed around the Island for calendar years 1989, 1990 and 1991, respectively.

Average precipitation zones for the Puget Sound area produced by the U.S. Department of Agriculture (USDA) (Figure 12) and the National Oceanic and Atmospheric Administration (NOAA) (Figure 13), show a range of 45 to 37 inches per year and 45 to 35 inches per year across the Island, west to east, respectively (KC, 2005b and 2005c). The USDA used data from 1961-1990; NOAA used data from the 2000s.

Figure 12. Precipitation Zones for 1961-1990 by USDA.

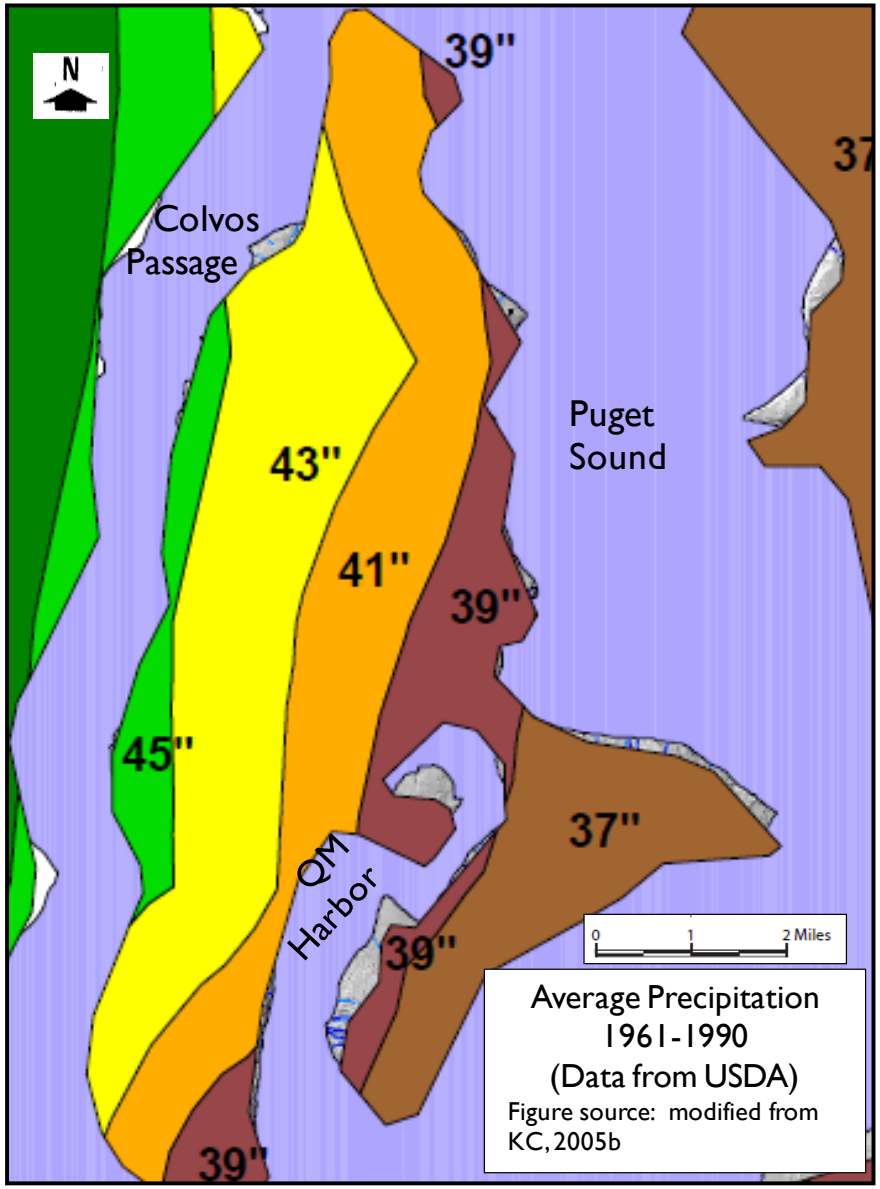
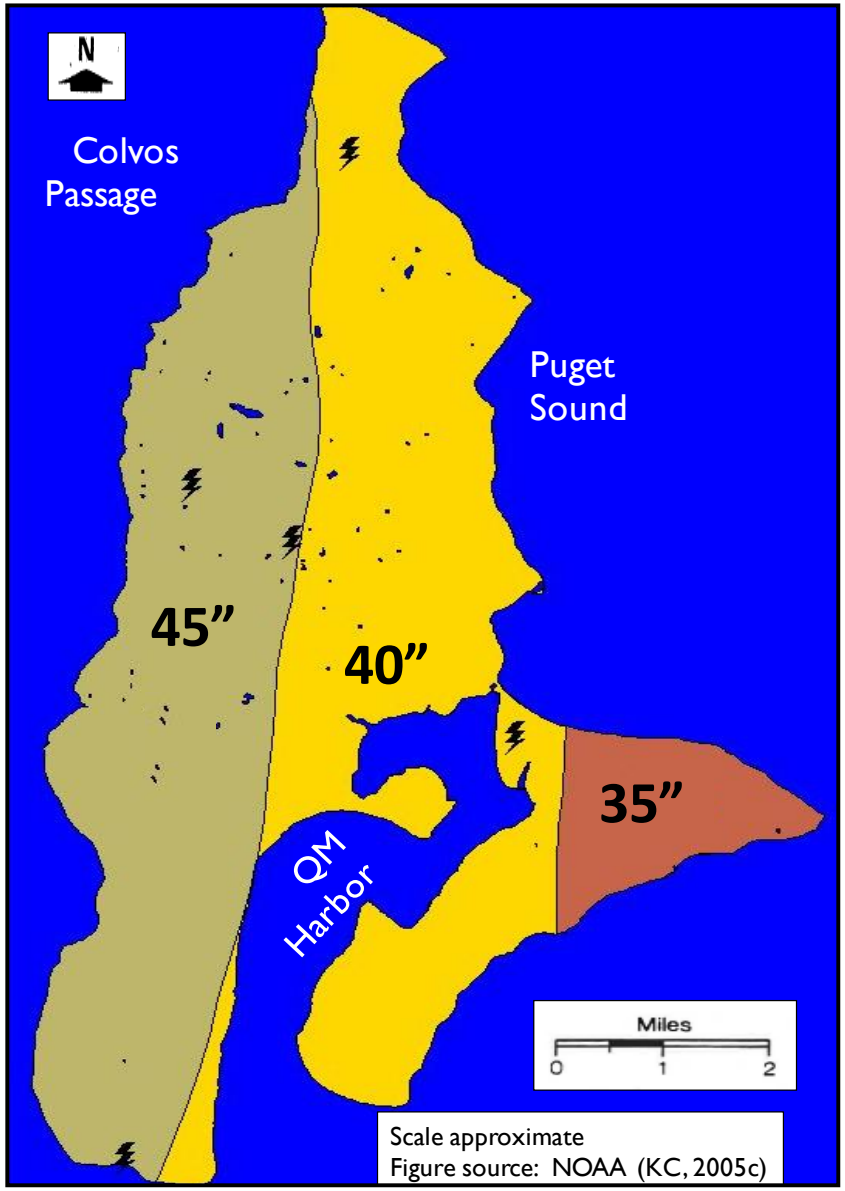


Figure 13. Puget Sound Precipitation Zones for 2000's by NOAA.



A more comprehensive rainfall data collection network was implemented for the WRE (Figure 2). Daily, monthly and annual totals were reported in annual reports to the GWP Committee. Results from the WRE related locations are shown in Table 4. WRE results indicated that since 2005 the Island receives between about -4 and 15 percent of the precipitation observed at the Sea-Tac airport and that this difference occurs about 4.5 miles southwest from Sea-Tac airport. In addition, this range occurs over a small geographic area of the Island.. Figure 4 shows the cumulative daily precipitation totals for each precipitation station over water years 2005 through 2012.

Table 4. Total Rainfall.

Water Year	North Vashon	Mid Vashon	NW Judd Creek	South Vashon	Maury Island	East Maury	Sea-Tac
	43U	28U	28Y	65U	36U	36V	
1999	57.3	--	Sites started in 2005				49.27
2000	45.1	46.1					36.8
2001	32.9	34.7					28.06
2002	43.9	49.8					39.48
2003	36.2	37.7					32.33
2004	44.1	52.1					40.38
2005	36.6	Moved site to NW Judd Creek (28Y)	39.2	31.2*	31.9	12.5*	30.38
2006	44.1		46.8	45.9	43.7	35.8	39.33**
2007	61.6		54	54.2	50.6	25.0*	47.32
2008	43.8		38.7	36.3	28.5*	27.4*	34.05
2009	39		37	40.1	35.1	19.1*	33.98
2010	59.7		51.3	51	47.3	27.3*	45.26
2011	57.2		51.7	52.9	45.6	44.9	44.52
2012	47.18		41.19	42.24	36.49	36.17	37.27
Average (all years)	46.3	44.1					38.4
Average (2005-2012)	48.6	--	45.0	46.1	43.1	--	39.0

Notes:

39.2	*Color denotes maximum value for water year; calculated using full dataset (2005-2012 years only).*
35.1	*Color denotes minimum value for water year; calculated using full dataset (2005-2012 years only).*

**= refers to sites with missing data – incomplete water year dataset.*

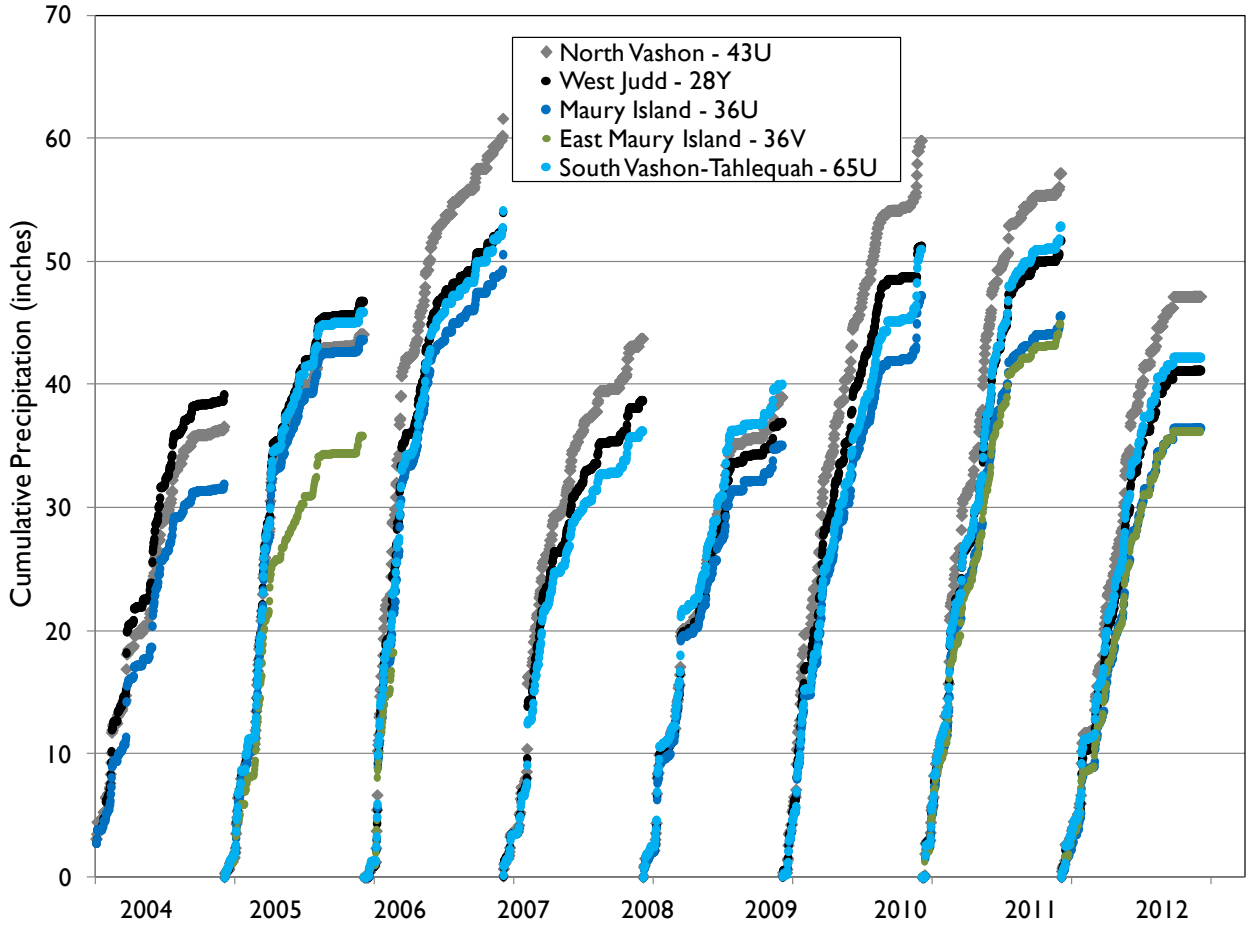
^ = refers to sites with incomplete water years – average calculated on 7 vs. 8 years.

***= refers to one day missing in data*

Data collected at King County gauge sites and local weather reference site, Sea-Tac.

Water Year is a 12 month period starting Oct-1 through Sept-30; Water Year 2012 is from Oct-2011 through Sept-2012

Figure 14. Cumulative Daily Precipitation at Vashon-Maury Island Stations per Water Year.



The updated WRE 2007 rainfall map (Figure 15) shows a 13-inch variation across the Island with typically more rainfall on the west and less on the east side, specifically on eastern tip of Maury Island. This is similar to the Carr Report 1983 map (Figure 11). It is likely that due the placement of off-island data points and the method used to create the map created the different pattern. Figure 16 is the most recent map of annual precipitation totals generated by King County and includes all data from 2005 through 2011. The pattern of decreasing annual rainfall totals across the Island from west to east with the East Maury Island station consistently drier than the rest of the Island is similar to that of all earlier mapping exercises (KC, 2010b).

Figure 15. Precipitation Totals Map of Vashon-Maury Island for Water Year 2007.

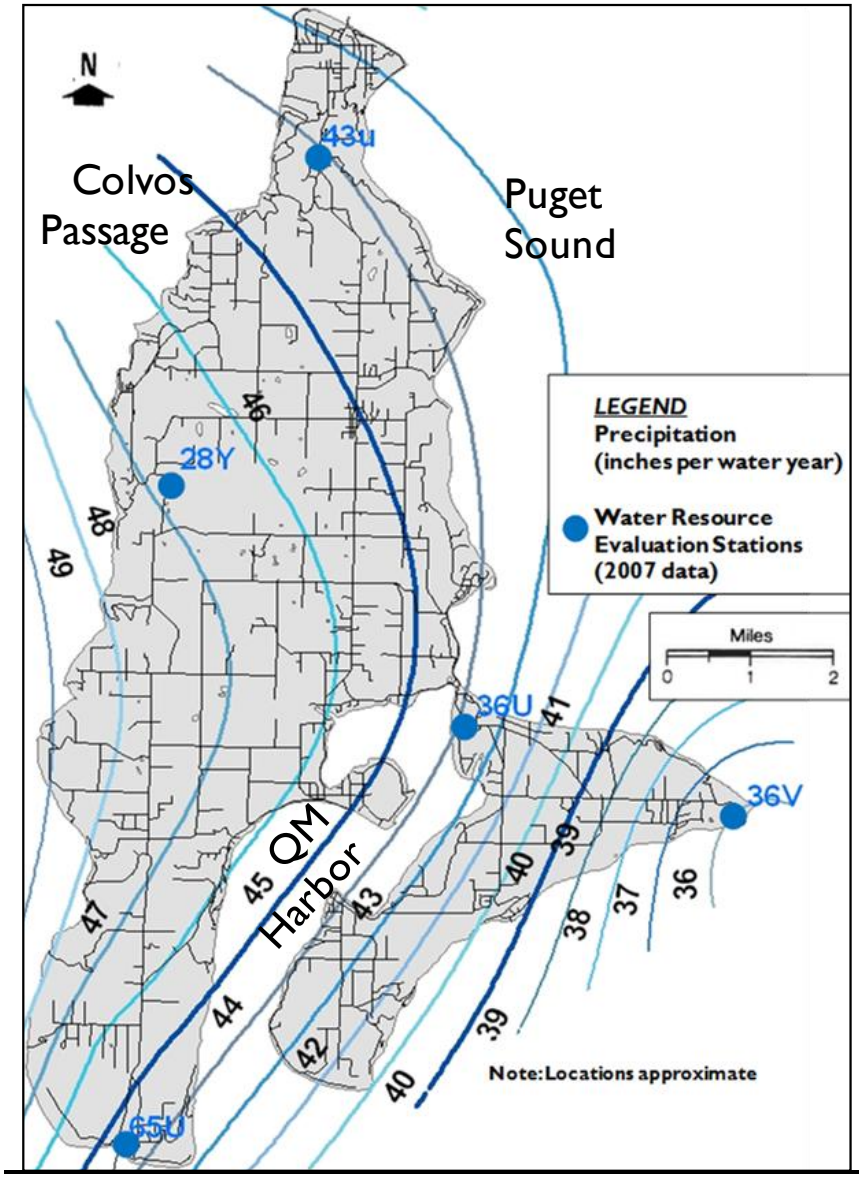
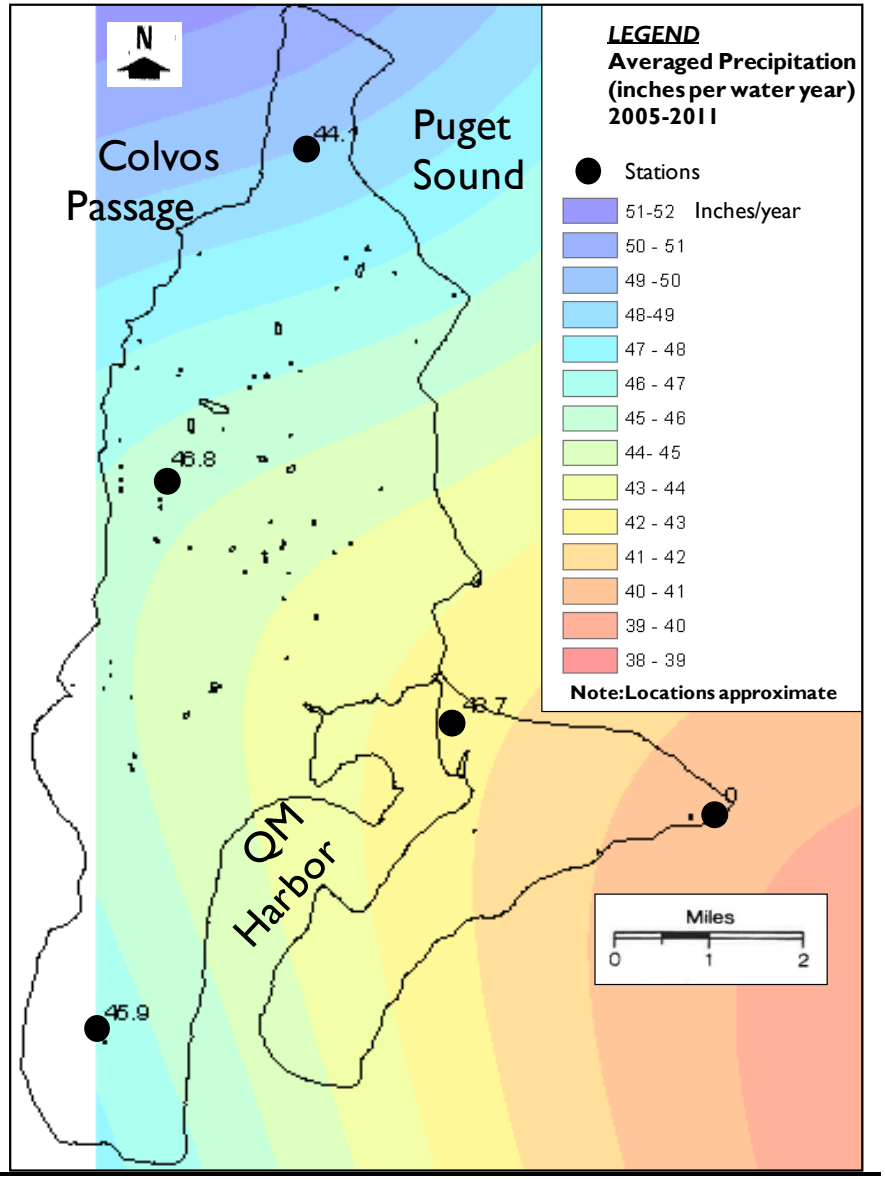


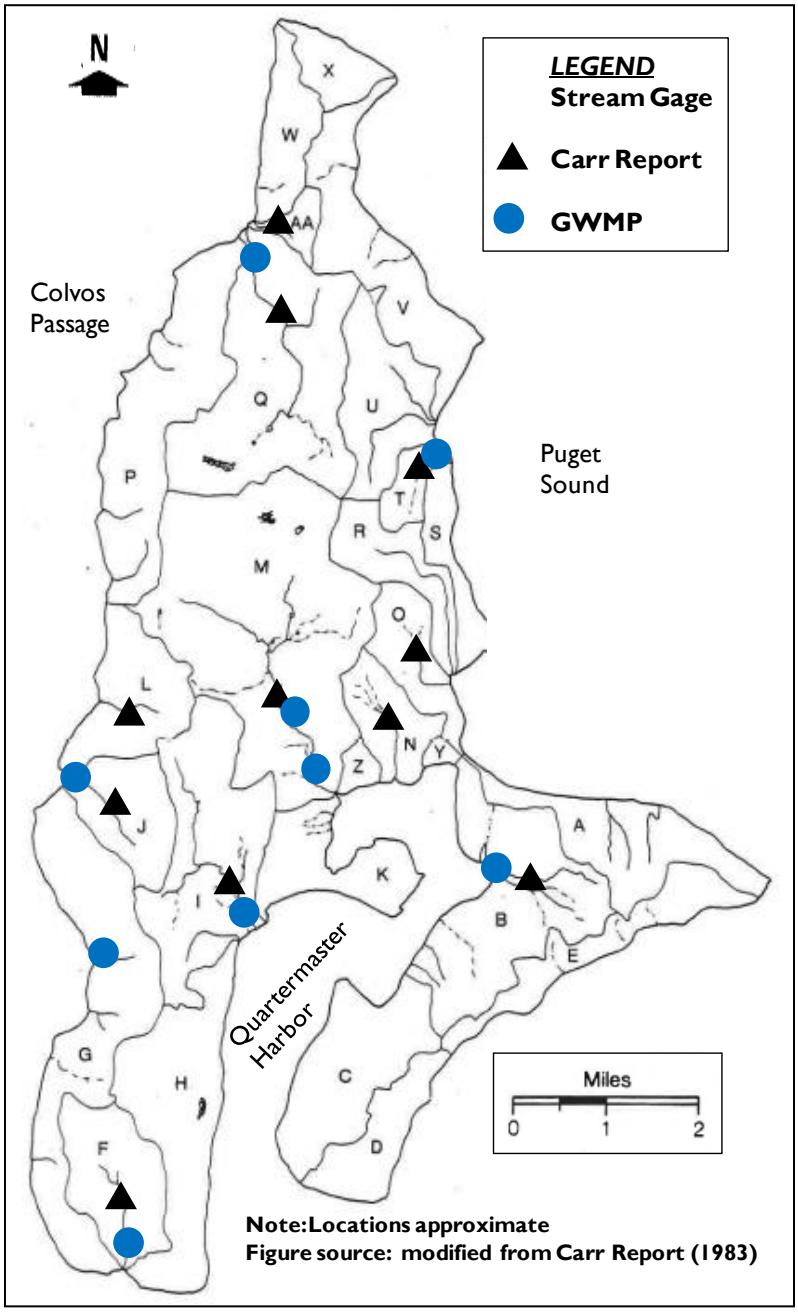
Figure 16. Precipitation Averages Map of Vashon-Maury Island for Water Years 2005-2011.



3.3 Stream Flows

Judd Creek is the largest stream basin on the Island with 3,292 acres and flows into Puget Sound through the Quartermaster Harbor (Figure 1; Carr/Assoc., 1983). Mileta Creek is the principal surface water drainage on Maury Island at 1,546 acres (Carr/Assoc., 1983), although it only represents about 33 percent of the total drainage area on Maury Island. Stream flow data collection on the Island has been conducted in various creeks and basins across Vashon-Maury Island. The location of data collection is represented in an updated figure from the Carr Report (Figure 17) and in a compilation map of locations in Figure 2.

Figure 17. Location of Stream Gage Data Collection Locations on Vashon-Maury Island.



Surface water monitoring is an important component of the Island's water resources monitoring. The Island has 75 drainage basins as identified in the Rural Rapid Recon Report (KC, 2004b). The creeks on the Island originate from a series of upland seeps and springs and flow down steep and incised ravines into Puget Sound. All of the streams travel downhill through these steep, 10-15 percent gradient channels across the bluff line present around the Island (KC, 2004b). Seasonally varying spring discharges emerge in valleys or on hillsides, making spring discharge difficult to quantify (Carr/Assoc., 1983).

The Carr Report presented hydrographs of McCormick, Shinglemill, Tsugwalla, and Tahlequah Creeks that showed peak flows during winter months in response to increased precipitation and low flows occurring through the summer months (Carr/Assoc., 1983). Summer low flow or baseflow was reported as quite uniform from late May through August. Stream flow data from the GWMP was consistent with these temporal variations reported in the Carr Report (VMI GWMC, 1998b).

Stream flow has been monitored on Judd Creek since 1999. Shinglemill Creek, the second largest basin on the Island with 1,846 acres, has been monitored since 1998. Fisher and Tahlequah Creeks were added into the continuous stream-gage network in 2004. Judd, Shinglemill, Fisher, and Tahlequah Creeks are the four largest basins, representing 32 percent of the total area of the Island. Annual mean daily flows (1999-2009) for Judd, Shinglemill, Fisher, Green Valley and Tahlequah Creeks as measured by King County are summarized in Table 5.

Table 5. Annual Mean Flows for Selected Vashon-Maury Island Creeks.

Water Year	Judd Creek	Shingle Mill Creek	Tahlequah Creek	Fisher Creek	Green Valley Creek
	28A	**43A**	**65A**	**65B**	**65C**
1999	2.56*	7.63	--	--	--
2000	6.67	5.67	--	--	--
2001	3.82	2.66	--	--	--
2002	6.68	5.05	--	--	--
2003	4.87	3.85	--	--	--
2004	5.92	4.43	--	--	--
2005	3.42	3.03	0.48	1.01	0.45*
2006	6.12	4.55	0.92	1.68	0.50*
2007	5.94*	5.77	1.16	2.13	0.62
2008	4.93	3.77	0.53	1.35	0.6
2009	4.76	3.44	0.64	1.23	0.53

Notes:

39.2	*Color denotes maximum value for water year; calculated using full dataset*
35.1	*Color denotes minimum value for water year; calculated using full dataset*

Q_{mean} = Mean daily flow for measured time period of water year in cubic feet /second

Water Year – 12 month period starting October 1st through September 30th of next year

– = No data for this site for this water year.

"" =Sites having incomplete (estimated) data record for the time period measured.*

Results reflect estimate using available data.

Source (KC, 2010b)

The data from the four continuous gauge locations on the largest creeks (Shinglemill, Judd, Fisher and Tahlequah Creeks) on the Island was assessed for the period 1999 through 2011 using a variety of surface water hydrologic indicators (KC, 2012e). Table 6 is a summary and definition of hydrologic indicators used to evaluate the hydrologic response of Island streams to development and water resource management. The resulting annual metrics are presented in Table 7.

Table 6. Definitions of Hydrologic Indicator Components and Metrics.

Component	Metric Name	Definition
Pulse Metric		
Frequency	High Pulse Count	Number of times each water year that discrete high flow pulses occur.
Duration	High Pulse Range	Range in days between the start of the first high flow pulse and the end of the last high flow pulse during a water year.
Flashiness Metric		
Flashiness	T_{Qmean}	The fraction of time during a water year that the daily average flow rate is greater than the annual average flow rate of that year.
Flashiness	Richards-Baker Index (R-B Index)	A dimensionless index of flow oscillations relative to total flow based on daily average discharge measured during a water year.
Low Flow Metric		
Magnitude	7-day low flow	Centered 7-day moving average annual (calendar year) minimum flow.
	Base flow (July - October)	Base flow during summer determined using a base flow separation method

Notes:

All metrics based on daily average flow.

Indicates metric is currently used for the VMI Sustability Indicators

Chart modified from DeGasperi et al. (2009)

The Richards-Baker Index (R-B Index) was chosen as the main Flashiness Metric to measure stream flashiness (KC, 2012e; KC, 2013b; Tables 5 and 6). Stream flashiness is influenced by changes in development patterns and land cover and can influence the habitat quality of a stream. The R-B Index is based on mean daily flows, measuring oscillations in flow (or discharge) relative to total flow (or discharge). The R-B Index can detect changes in how fast and how much water gets to our streams after a typical rain storm. This index is positively correlated with increasing frequency and magnitude of storm events, and negatively correlated with baseflow and watershed area (Baker et al, 2004). Compared with other hydrologic indicators, this index has lower interannual variability and reveals many more trends in discharge data. Baker et al (2004) suggests that this index appears to provide a useful characterization of the way watersheds process hydrologic inputs into the streamflow outputs and is well suited for detecting gradual changes in flow regimes associated with changes in land use and in land management practices. More information on this metric is presented in Appendix A.

There does not appear to be a systematic trend in stream flow flashiness; however, additional data is required to determine if any changes are occurring beyond the variability induced by interannual variation in precipitation. Ten years or more of continuous data is likely needed to assess longer term trends for this hydrologic indicator (KC, 2013b).

Table 7. Hydrologic Flow Indicators for Selected Vashon-Maury Island Creeks.

Site Name	Year	High Pulse Count	High Pulse Range	T_{Qmean}	R-B Index	7-day Low Flow (July-October)	Base Flow (July - October)
Shinglemill Creek	1999	9	129	0.25	0.3	2.5	2.7
	2000	14	114	0.31	0.24	2	2.2
	2001	1	0	0.35	0.16	1.4	1.6
	2002	11	153	0.24	0.37	1.4	1.6
	2003	6	101	0.22	0.28	1.5	1.8
	2004	8	104	0.25	0.35	1.5	1.6
	2005	4	127	0.24	0.27	1.4	1.5
	2006	5	44	0.17	0.34	1.6	1.8
	2007	9	126	0.23	0.35	1.8	2
	2008	5	69	0.22	0.28	1.4	1.7
	2009	8	181	0.21	0.26	1.4	1.6
	2010	14	147	0.24	0.35	1.4	1.9
	2011	14	197	0.22	0.45	2	2.2
Judd Creek	2000	18	215	0.34	0.32	1.9	2.2
	2001	8	150	0.38	0.23	1.4	1.8
	2002	14	183	0.25	0.39	1.5	1.7
	2003	8	120	0.28	0.29	1.3	1.6
	2004	12	121	0.3	0.32	1.2	1.6
	2005	7	130	0.23	0.31	1.2	1.5
	2006	5	107	0.2	0.32	1.2	1.5
	2007	15	139	0.32	0.33	1.5	2
	2008	10	134	0.28	0.3	1.3	1.5
	2009	10	189	0.22	0.35	1.1	1.5
	2010	16	315	0.29	0.33	1.4	2
	2011	14	218	0.26	0.39	1.8	2.2
Fisher Creek	2005	3	107	0.33	0.2	0.4	0.5
	2006	4	66	0.27	0.23	0.4	0.6
	2007	14	147	0.32	0.25	0.6	0.8
	2008	6	57	0.37	0.21	0.3	0.5
	2009	6	181	0.32	0.24	0.4	0.5
	2010	13	315	0.38	0.22	0.4	0.7
	2011	17	218	0.34	0.24	0.6	0.7
Tahlequah Creek	2005	4	127	0.24	0.24	0.2	0.2
	2006	4	66	0.22	0.29	0.2	0.2
	2007	11	139	0.25	0.33	0.3	0.3
	2008	4	41	0.29	0.26	0.2	0.2
	2009	6	181	0.23	0.32	0.2	0.3
	2010	13	315	0.33	0.26	0.2	0.3
	2011	13	218	0.28	0.32	0.3	0.4

Note: Four sites have continuous gauging data that can be assessed using different flow metrics for the period of record.

Indicates metric is currently used for the VMI Sustability Indicators

Chart modified from KC (2012e)

Under the Water Resources Act of 1971, Ecology is authorized to "establish minimum water flows or levels for streams, lakes, or other public waters for the purposes of protecting fish, game, birds, or other wildlife resources, or recreational or aesthetical values of public waters. Judd, Shinglemill, Fisher and Christensen Creeks have been designated as closed basins by Ecology to preserve flows. Judd Creek was closed in 1951 on the basis that there were no waters available for further appropriation for consumptive use. Christensen, Fisher and Shinglemill Creeks were closed in 1981 on the basis of the need to maintain instream flow for anadromous fish.

The 7-day moving average low-flow rate is a low flow metric used to measure the changes in summer flows (KC, 2012e; Tables 6 and 7). This metric is important as it is a measure of the amount of the minimum amount of water in the stream during summer, a time critical for aquatic biota, such as salmon. Data analysis indicated that 2001 – 2010 summer low flows were maintained or improved (KC, 2013b).

Baseflow Index is a metric used to measure the magnitude of stream flow sourced from groundwater inflow (i.e., baseflow) relative to the total stream flow (KC, 2012e; Tables 5 and 6). The Baseflow Index can indicate the importance of groundwater inflows during summer months that typically have lower flows. Ecology estimated the proportion of baseflow relative to total stream flow (i.e., Baseflow Index) in selected Washington rivers and streams (Sinclair and Pitz, 1999). Over 500 active and inactive gauging stations with at least three years of data were included in the study. On average, baseflow represented approximately 68 percent of total annual stream flow for the stations evaluated. Estimated baseflow contributions to stream flow for the typical low flow months of July, August, September, and October averaged 86, 86, 77, and 69 percent, respectively (Sinclair and Pitz, 1999).

On the Island, the Baseflow Index has been estimated for Shinglemill, Judd, Fisher and Tahlequah Creeks (KC, 2012e; Table 8). For the period of record, the ratio of baseflow to total annual stream flow was 70, 69, 79 and 74 percent, respectively. Shinglemill Creek had the highest percentage of baseflow during the summer period with an average of 95 percent. Judd and Fisher Creeks had a slightly lower value of 89 percent. Tahlequah Creek had a value of 91 percent, (KC, 2012e; Table 8). Groundwater contribution to the total annual stream flow is between 69 to 79 percent. Relative baseflow contributions during summer were higher by about 17 to 25 percent. Results suggest that reductions in groundwater discharge to streams during this period, as a result of increased groundwater withdrawals for example, could impact the instream flows needed to sustain fish and maintain water quality.

Table 8. Total Annual and Summer Month Baseflows for Selected Vashon-Maury Island Creeks.

Creeks	Number of years of data	Annual	July	August	September	October	Jul-Oct average
Shinglemill	13	70%	98%	97%	97%	89%	95%
Judd	12	69%	96%	91%	89%	78%	89%
Fisher	7	79%	95%	93%	87%	83%	89%
Tahlequah	7	74%	96%	97%	89%	83%	91%

Note: Values are shown as percentages of baseflow to total stream flow.

Chart modified from KC (2012e)

4.0. ISLAND-WIDE WATER RESOURCES

This section presents and summarizes the water resources conditions on Vashon-Maury Island. The following subjects are discussed in more detail and summarized in Section 5.0 (Summary of Scientific Findings).

- Water Resources Usage
- Groundwater Quantity
- Hydrologic Water Budget
- Marine Water Quality
- Freshwater Surface Water Quality
- Groundwater Quality

4.1 Water Resources Usage

Water use is described in terms of both the purpose of use and the amount of water used for each purpose. The major use of water on Vashon-Maury Island is for municipal and domestic purposes. Lesser uses include agriculture and commercial purposes (KC, 2005c). Water use for municipal and domestic purposes depends upon the number of residences and population size. Figure 18 shows the locations of known permit exempt wells and public water systems on the Island (KC, 2005c).

The population of the Island is growing steadily, approximately two percent per year, from 6,516 in 1970; to 7,377 in 1980; to 9,309 in 1990; to 10,100 in 2000 (KC, 2009b); and 10,624 in 2010 (U. S. Census, 2013b). According to the Puget Sound Regional Council, the population of the Island will continue to grow at a rate of about 10 percent, or 100 people per year (KC, 2009b). The U.S. Census Bureau reported in 2013 that the annual population growth in King County and Washington State has been about 1.97 and 1.3 percent, respectively, since 2010 (U. S. Census Bureau, 2013a).

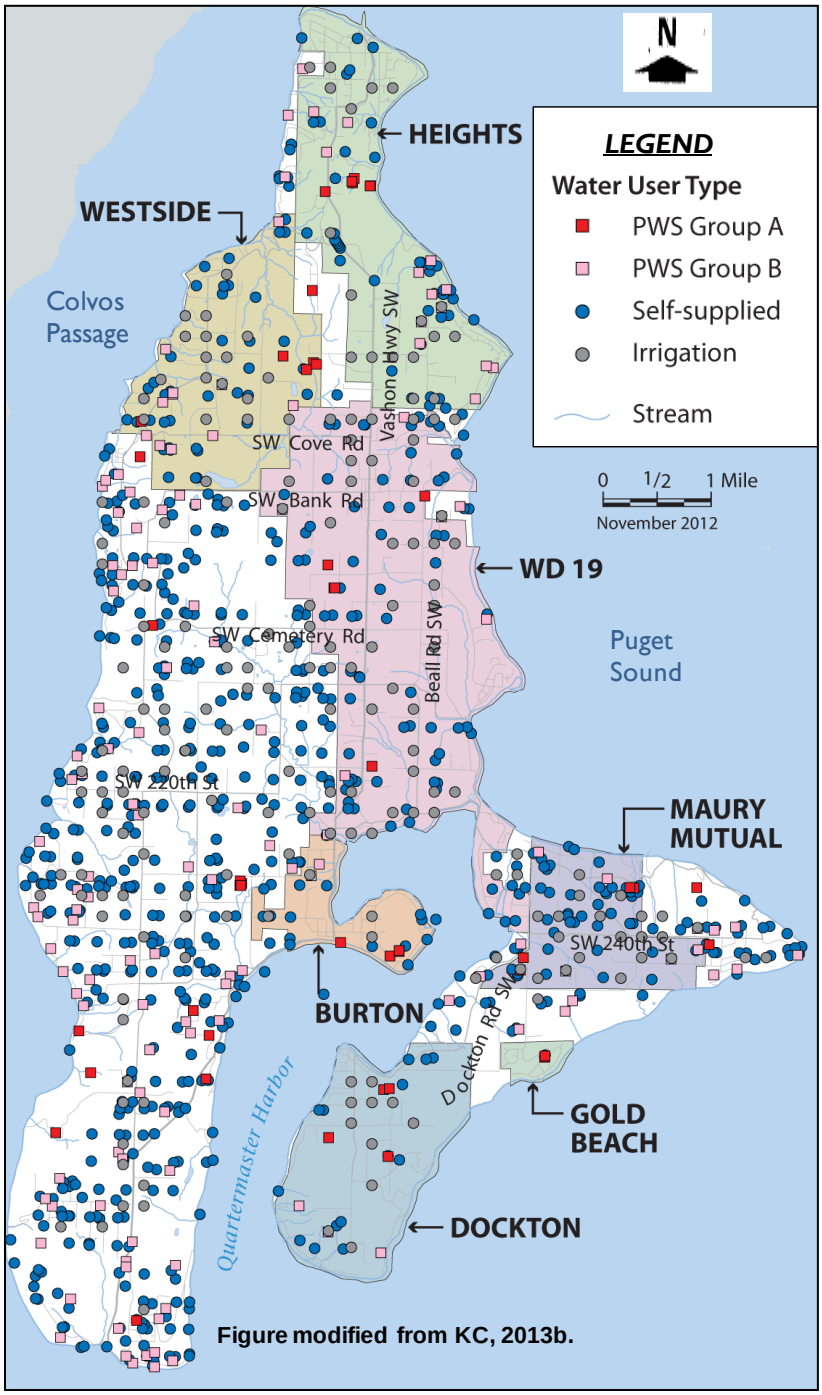
The Carr Report presented that the estimated average daily individual water use was 120 gallons per day (gpd) (Carr/Assocs., 1983). The GWMP revised that number to be 103 gpd (VMI GWMC, 1998b). In 2005, the municipal and domestic water demand on the Island was estimated to be approximately 375 MGY. The breakdown of municipal versus domestic was estimated to be 282 MGY for residences served by public water systems and 73 MGY for residences served by exempt wells. About 20 MGY is used by commercial connections (KC, 2005c).

The WRE started a unique project by metering self-supplied wells. On the Island, there are at least 1,000 wells that are self-supplied; also known as permit-exempt wells. It is unknown how much water is withdrawn at these types of wells. The Groundwater Permit to Withdraw RCW 90.44.050 is a Washington State (WA) water use law that allows permit-exempt wells to use up to 5,000 gpd for domestic purposes. Eight people volunteered to be part of a study assessing the usage of self-supplied wells (Figure 3).

The water usage data has yielded a range of usage patterns for a small subset of exempt well users. One volunteer consistently uses a low volume of water daily of about 30 gpd compared to a summertime usage of >800 gpd for another. On average, usage is approximately 100 gpd per well. Monthly totals

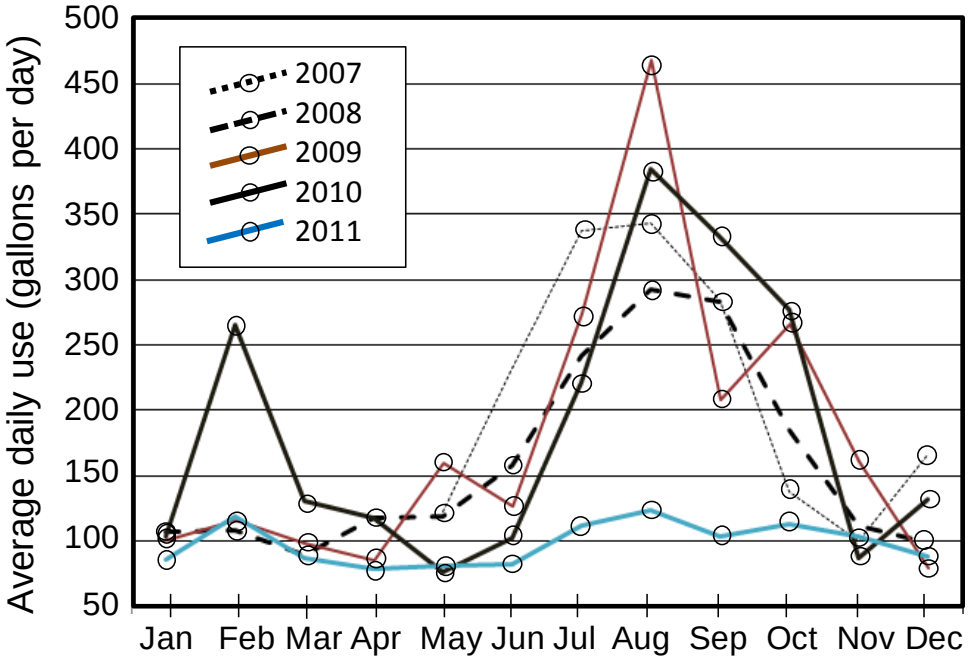
from a few of the volunteers show increases in usage during June through October (Figure 19). Other volunteers show a more consistent usage pattern throughout the year.

Figure 18. Locations of Exempt Wells and Public Water Systems (2012).



Group A public water providers have a range of average daily usage of 100 to 200 gpd per connection. Data from several of these public water systems show increased usage during May through October with 60 to 75 percent of the total annual use during this period, similar to some exempt well users (Figure 19).

Figure 19. Average Daily Usage Per Month of Permit Exempt Wells on Vashon-Maury Island.



Note: Eight wells are self monitored for usage. Data are provided approximately monthly as total usage. Average daily values are calculated for each volunteer and averaged together.

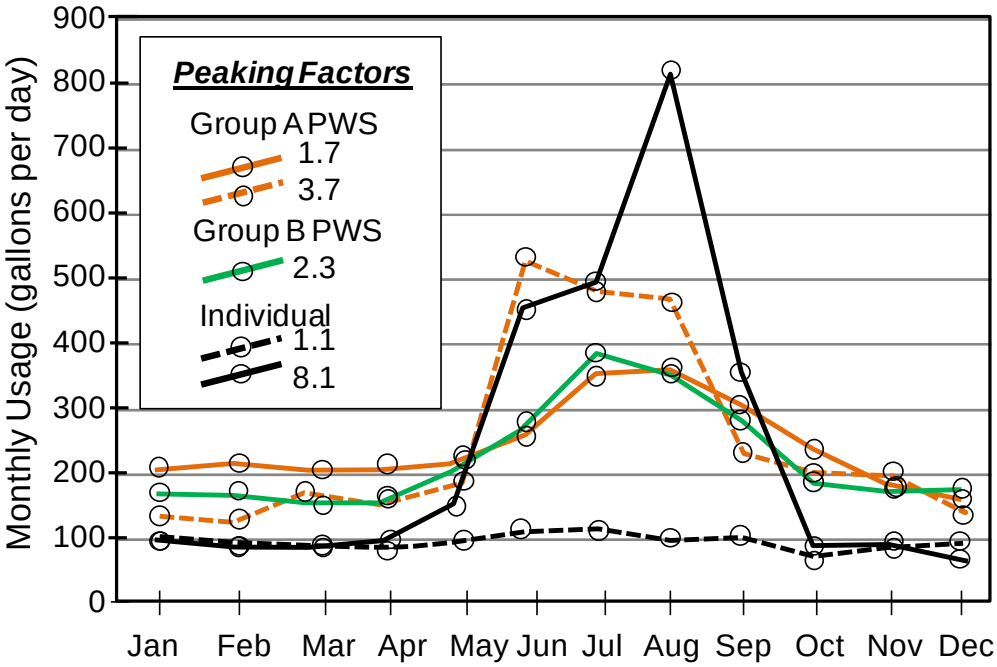
With respect to population growth and water use projections, one of the WRE-Phase 1model scenarios included a potential future outcome where all population-related water use is increased by 10 percent. The modeling results yielded noticeable drawdown in the vicinity of some Group A public water system wells, though generally very small numerically, and it also showed slightly higher shallow groundwater levels in many other areas of the Island, where increased septic system returns were modeled (KC, 2005b).

The VMI Sustainability Indicators (KC, 2013b) are metrics used for tracking water sustainable water resources use and management on the Island:

- Summer Water Use Peaking Factor Metric,
- Total annual Island-wide Water Consumption, and the
- Per Capita Water Consumption.

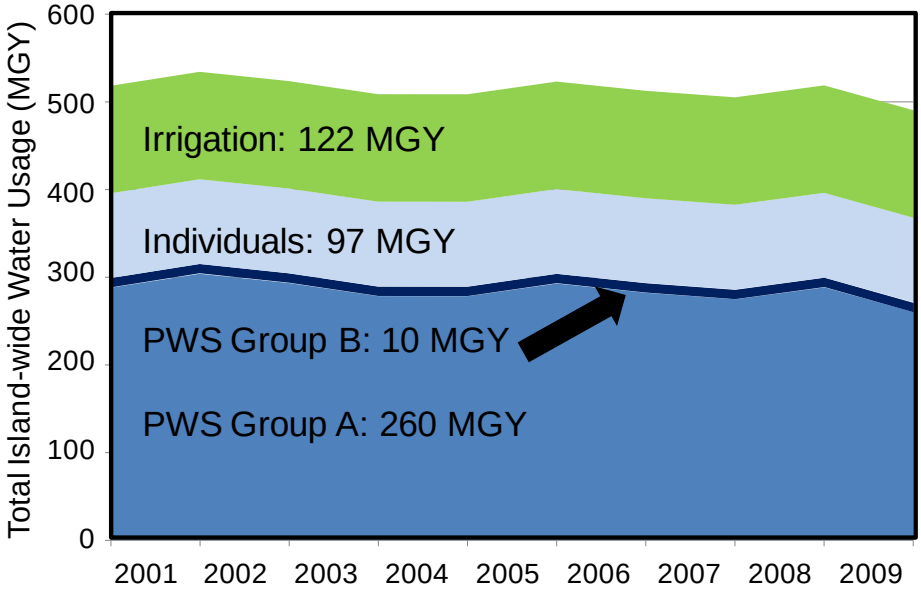
The Summer Water Use Peaking Factor Metric is calculated by dividing the maximum monthly usage by the average monthly usage. This value is tracked year to year at a few locations. The results for records over 2001-2010 indicates that water use peaks in the summer by a factor 1.8 based on an island-wide average (KC, 2013b). In 2010, the summer water use peaking factors ranged from 1.2 to 2.4 based on data from selected Group A public water systems. Figure 20 shows examples of the peaking factors by user type – Group A public water systems; Group B public water systems and individuals. The user with a peaking factor of 1.7 (Group A public water systems) uses the most water annually based on the cumulative total of the daily usage.

Figure 20. Example of Summer Water Use Peaking Factors by User Type.



The 10 year (2001-2010) average of total island-wide water consumption is 515 MGY (Figure 21). The annual total consumption ranged from 496 to 535 MGY during this period. Typically, consumption increased during periods with lower rainfall totals and decreased during periods with higher rainfall totals.

Figure 21. Estimated Total Island-wide Water Consumption for Group A & B Public Water Systems, Individuals and Irrigators.



Note: Individuals and Group B public water system well data represents ~10 percent of population served each; Group A public water system well data represents ~80 percent of population served.

Per capita consumption is calculated by dividing total annual usage by total population and is tracked from year-to-year. The overall per capita water consumption during the time period 2001 through 2010 was 83 gpd (KC, 2013b).

4.2 Groundwater Quantity Monitoring

The VMI Ground Water Management Area (VMI GWMA) was designated a Sole Source Aquifer by the U.S. Environmental Protection Agency (USEPA) in June 1994. While the singular term "aquifer" is used, groundwater resources actually occur in many discrete and discontinuous locations. Data indicates that aquifers underlying the Island are not connected to off-Island sources (Carr/Assoc., 1983); all water sources (groundwater, rainwater and surface drainages, springs, and seeps) on the Island are recharged by precipitation falling on the island.

4.2.1 Aquifer Zones

Various studies have divided the Island groundwater resources into two major water bearing zones. In addition to the reports presented in this document, the following are other hydrogeologic characterizations completed for both local and regional scale studies:

- Maury Island Gravel Mine Hydrogeologic Impact Assessment (PGG, 2000)
- Vashon Island Landfill Hydrogeologic Report Update (B&H/UES, 2004)
- Water Resources and Geology of the Kitsap Peninsula and Certain Adjacent Islands (Garling et al, 1965)

Although discussed earlier in Section 2.0 (Technical Activities & Reports), the various aquifer terminology are briefly explained again here. The Carr Report in 1983 identified two island wide aquifers – a Principal and a Deep aquifer. This assessment was based on the elevations of the screen zones, usually constructed to be centered at the water level elevation in a well. Wells with a screened elevation above mean sea level (MSL) were typically defined as being screened in the Principal aquifer while those locations with a screened elevation below MSL are defined as screened in the Deep aquifer. The GWMP in 1998 provided more detailed analyses of the hydrostratigraphy on the Island. Four hydrostratigraphic zones were described as generally laterally continuous across the Island with local areas of discontinuity (VMI GWMC, 1998b). These zones were defined as:

Name	Average Water Level Elevation (feet above Mean Sea Level (MSL))	Screen Elevation (feet above MSL)
Zone 1	255	varies
Zone 2	97	varies
Zone 3	18	at or below MSL
Zone 4	11	>200

After the surficial geology maps of the Island were updated by University of Washington staff in 2003, King County merged this new information of geologic units and the hydrostratigraphic zones. The resulting correlation of the aquifer names are:

Carr Report	GWMP	WRE
Principal Aquifer	Zone 1	Zone 1 - shallow Vashon recessional outwash deposits (Qvr) and Principal/ Main Vashon advance outwash deposits (Qva)
	Zone 2	
Deep Aquifer	Zone 3	Zone 2 – Deep 1 Pre Fraser coarse grained deposits (Qpfc)
	Zone 4	Zone 3 - Deep 2 Olympia coarse grained deposits (Qpoc) and deeper units

Figure 22 is a geologic cross section that is aligned along a north-south transect labeled A2-A2' (location displayed in Figure 1on the southern end of Vashon Island. The layer cake like image of the geologic units is common across the Island. The WRE aquifer zones are described in the legend and emphasized with a pattern, showing Zone 1 - Principal/ Main aquifer being the Vashon advance outwash deposits (Qva); Zone 2 – Deep 1 Pre Fraser coarse grained deposits (Qpfc) and Zone 3 – Deep 2 Olympia coarse grained deposits (Qpoc) and deeper units. Zone 2 is present in this area of the Island as the Possession Drift – coarse grained deposits (Qpdc).

Figure 22. WRE Aquifer Zones in Geologic Cross Section A2-A2' on Southern End of Vashon Island.

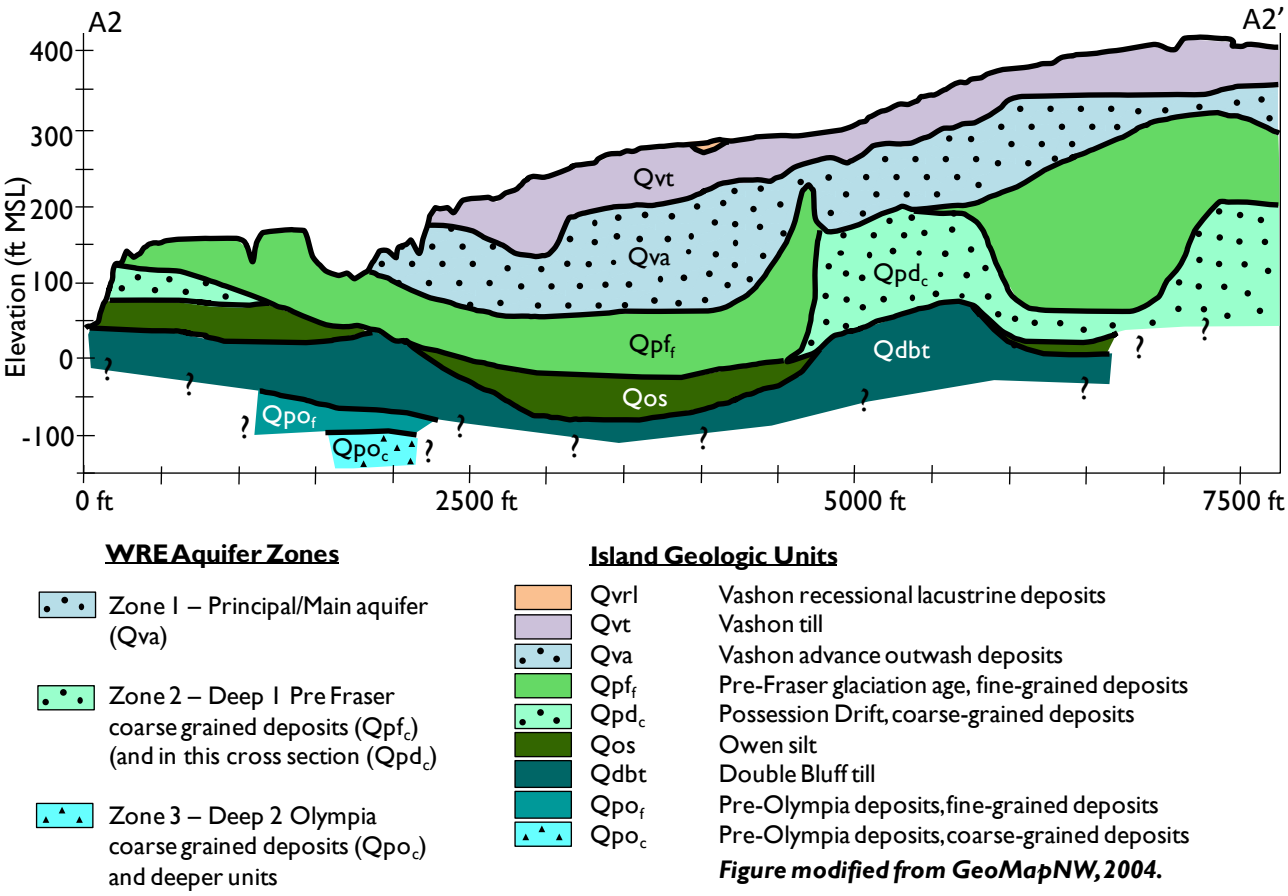


Figure modified from GeoMapNW, 2004.

4.2.2 Groundwater Level Responses and Trends

Groundwater level data collection on the Island has been sporadic and sparsely located across the Island for many years. The Carr Report indicated that water level fluctuations showed different patterns in the Principal aquifer from those in the Deep aquifer (Carr/Assoc., 1983). Groundwater levels measured from 61 wells showed responses to seasonal and long-term recharge variations, tidal and barometric influences and pumping. The largest responses were observed in the recharge areas of the Principal aquifer.

In the GWMP, seasonal fluctuations of the water levels were reported in Zone 1 wells up to 17.61 feet; Zone 2 up to three feet; Zone 3 up to nine feet, and in Zone 4, up to 2.79 feet change (VMI GWMC, 1998b). These fluctuations tended to correlate with rainfall (with lags of time up to four months), with seasonal highs in during summer months and lows during fall months (VMI GWMC, 1998b). Some wells showed little to no seasonal influence, indicating the wells were not screened in units directly recharged by rainfall.

Long-term trends of increasing water level elevations up to two feet per year in some Zone 1wells correlated to increasing rainfall trends during 1989-1992 (VMI GWMC, 1998b). In general, the GWMP reported that long-term trends indicated that the hydrostratigraphic zones were generally stable and had not been affected by ground water withdrawals (VMI GWMC, 1998b).

Water levels are currently being measured in multiple water bearing zones on the Island with the help of volunteers and monitoring wells (Figure 3), Water purveyors monitor their sources on a regular basis and have reported their data to King County upon request. Since 2006, the King County's Groundwater Program has been collecting water level data at 10 monitoring well locations. These wells typically have continuous data loggers recording daily water level information. Additional water level data is collected during annual water quality sampling if possible.

The frequency of this dataset varies from monthly to annual to longer periods of time between measurements. Sixty of the locations measured have water level data during 2001-2010. The majority of these locations are not being actively monitored or monitored on an infrequent (once a year) basis. The volunteer program was started in 2001 for well owners to self monitor their water levels for 12 months. Many of the owners in volunteer program continued to monitor after the initial period; however, by 2012, only four people are still actively self-monitoring water levels. Several of the volunteer locations are some of the longest water level datasets on the Island. No location appears to have a continuous record of water level data since the Carr Report in the1980's.

Overall, plotted well data from 2001 through 2012 indicated that levels were generally stable with no significant declines (Figure 23) (KC, 2013d). Water level records from different wells can be quite variable, as shown in Figures 23, 24, and 25. Figure 24 shows that at self-monitored well GWL_w-09 there was about ten feet of variability in measurements within the year as well as year to year changes. Figure 25 shows that at self-monitored well GWL_w-06/GrpA_55376_01 there have been small changes in measurements within the year and gradual changes year to year.

Figure 23. Groundwater Levels on Vashon-Maury Island from 2000 through 2012.

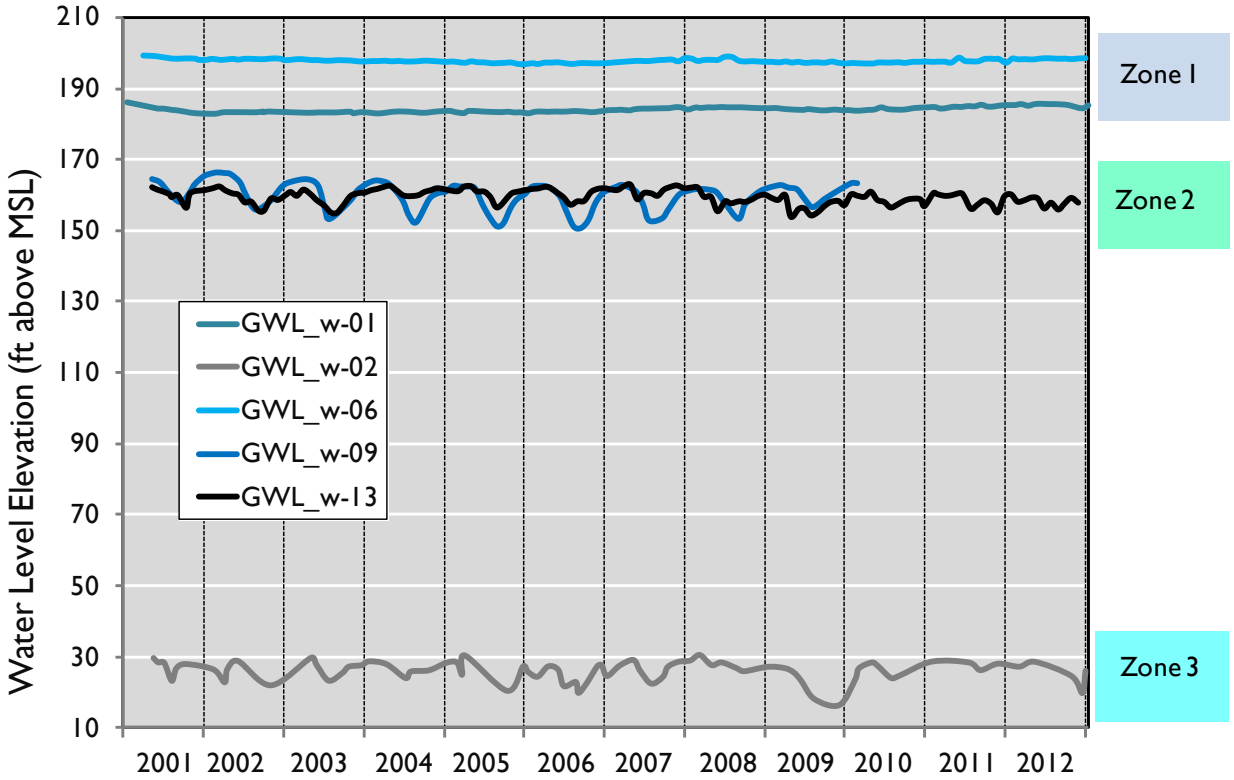
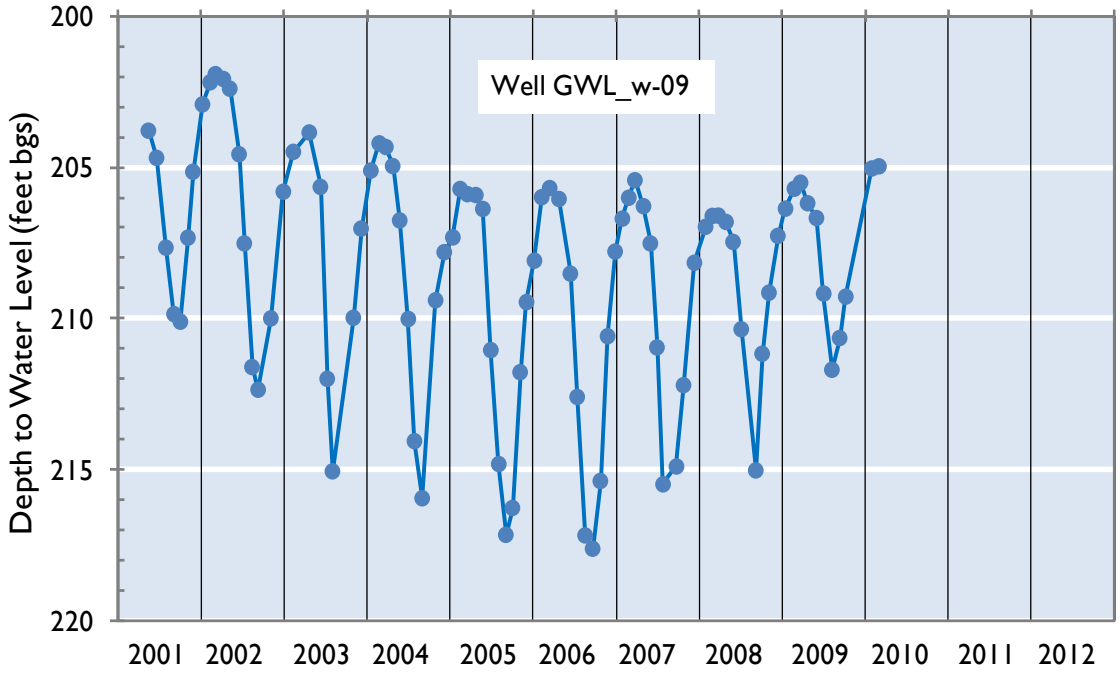
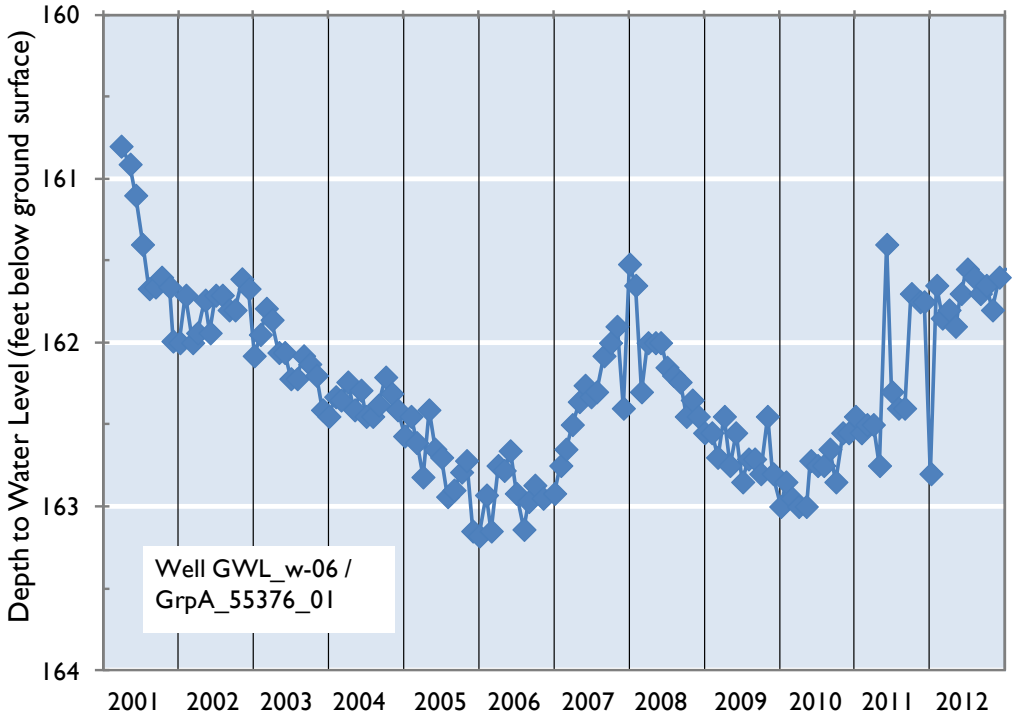


Figure 24. Depth to Water at Self Monitored Well GWL_w-09 in WRE Zone 2.



Note: Data collected shows about 10 feet variability in measurements within the year as well as year to year changes.

Figure 25. Depth to Water at Self Monitored Well GWL_w-06/GrpA_55376_01in WRE Zone 1.



Note: Data collected shows small changes within the year and gradual changes year to year.

An overall assessment for the VMI Sustainability Indicator of water level changes for 2001 through 2010 show that there was mostly no change in water levels when comparing a baseline average (based on 2001to 2008 data) to recently reported data (KC, 2013d). Figure 26 provides a snapshot of recent status conditions for monitored well water levels with one site having had lower recent water level elevation data compared to that site's baseline while one site had an increase in that site's recent water level data. Eleven sites had no change in the water levels when comparing the baseline average to recent data (2009-2010). The remaining 45 sites had too few data points to assess a baseline average. Appendix A describes the methods for analysis for the VMI Sustainability Indicators in more detail.

4.2.3 Groundwater Contour Maps

Water table elevation contour maps within the following water bearing zones have been published:

- Principal Aquifer — Carr Report — 1982
- Zone I Aquifer — Groundwater Management Plan — 1991
- Principal/Main Qva Aquifer — Water Resource Evaluation — 2005

The Carr Report presented groundwater elevation contour maps showing generally higher levels on the west side of Vashon Island and numerous local water level highs or mounds (Figure 27). On Maury Island, water level mounds appeared at each end of the Island (Carr/Assoc., 1983). Maps show flow directions in the Principal aquifer as generally to the east and west from the topographic high that extends along a north-south axis on Vashon Island toward Colvos Passage and Quartermaster Harbor

and from a high near each end of Maury Island radiating towards Quartermaster Harbor and East Passage in Puget Sound.

Figure 26. Groundwater Level Changes during 2001 through 2010.

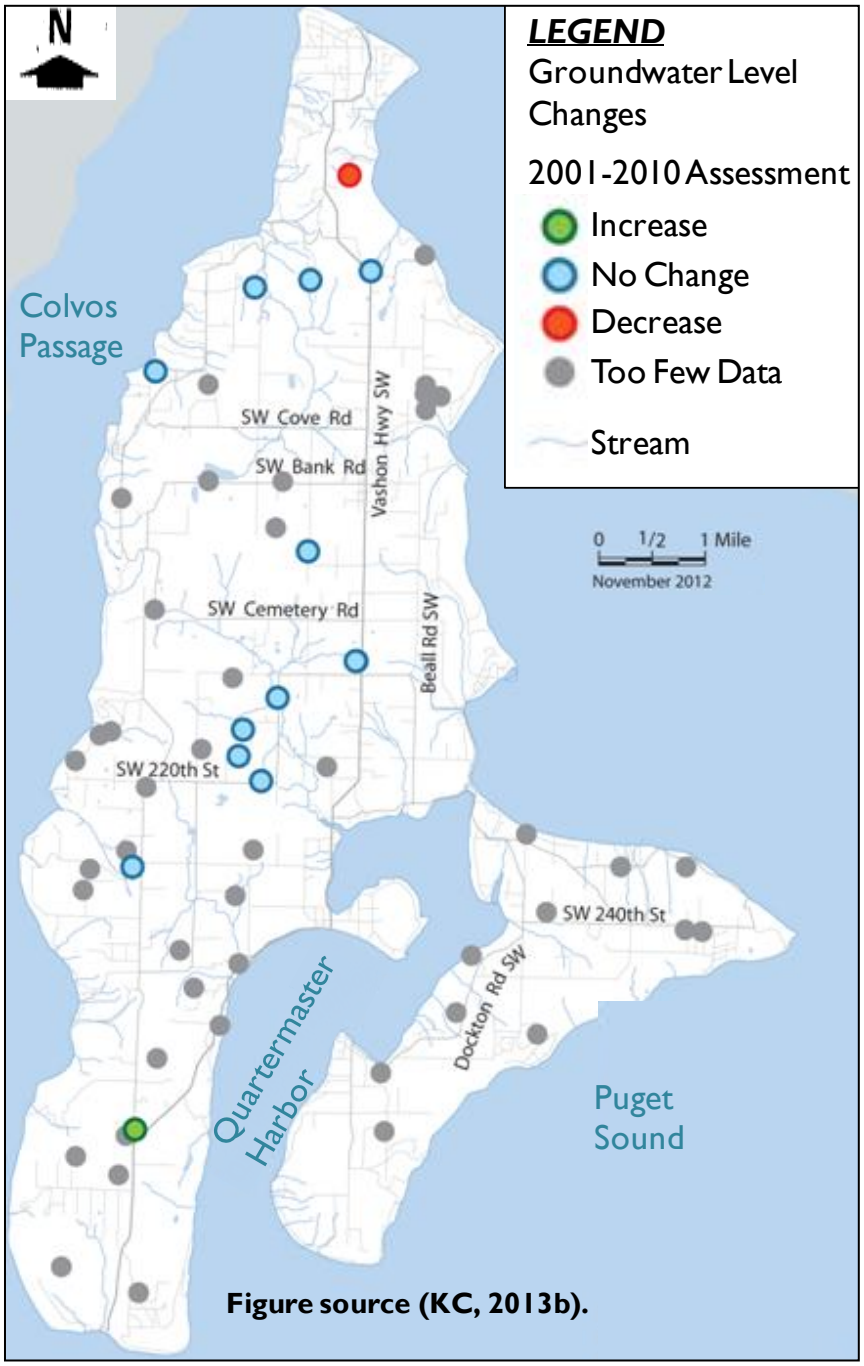


Figure source (KC, 2013b).

The GWMP incorporated newer Zone 1water level data and modified the Carr Report contour map for Zone 1 wells (the near surface aquifer) (Figure 28). Groundwater gradient were generally steeper on the west than on the east and steeper in the spring than in fall. Flow directions and gradients were reported as similar to that of the Carr Report (VMI GWMC, 1998b).

Figure 27. Water Table Elevation Map of the Carr Report's Principal Aquifer for 1982.

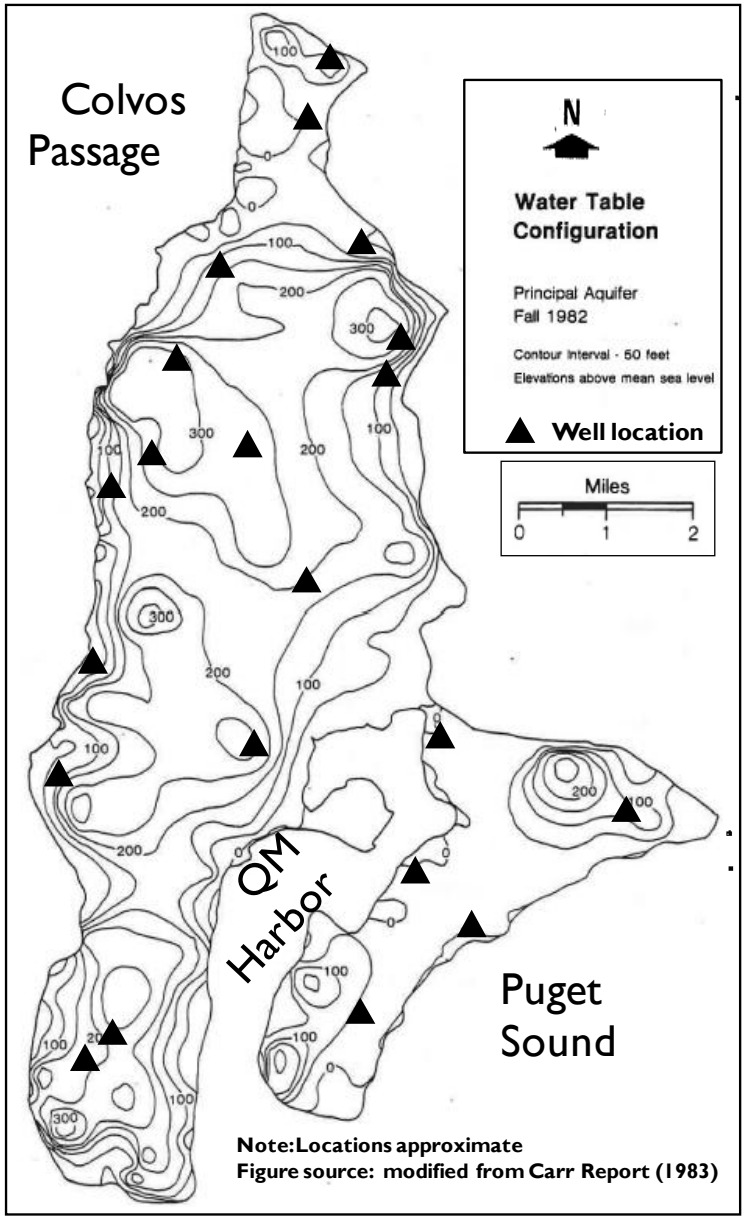


Figure 28. Water Table Elevation Map of GWMP Zone 1 for 1991.

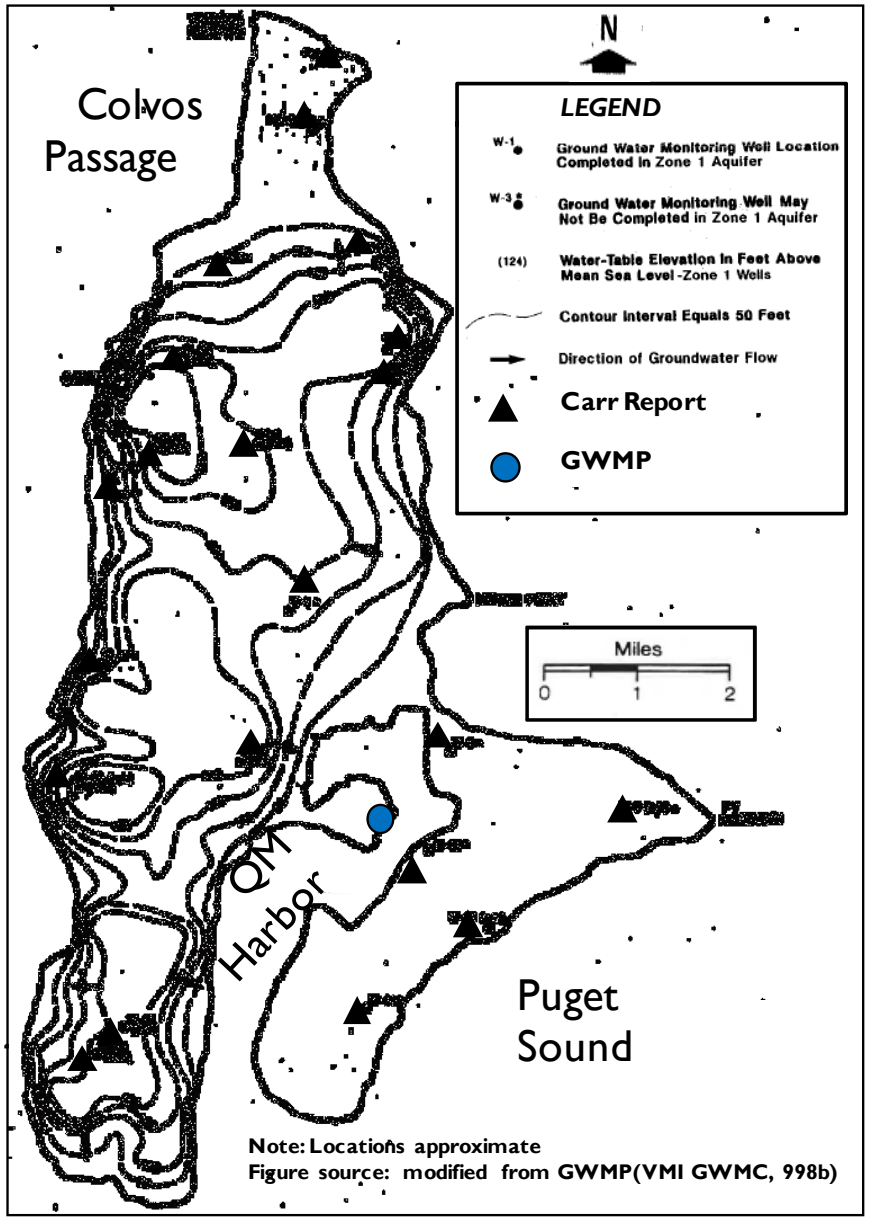
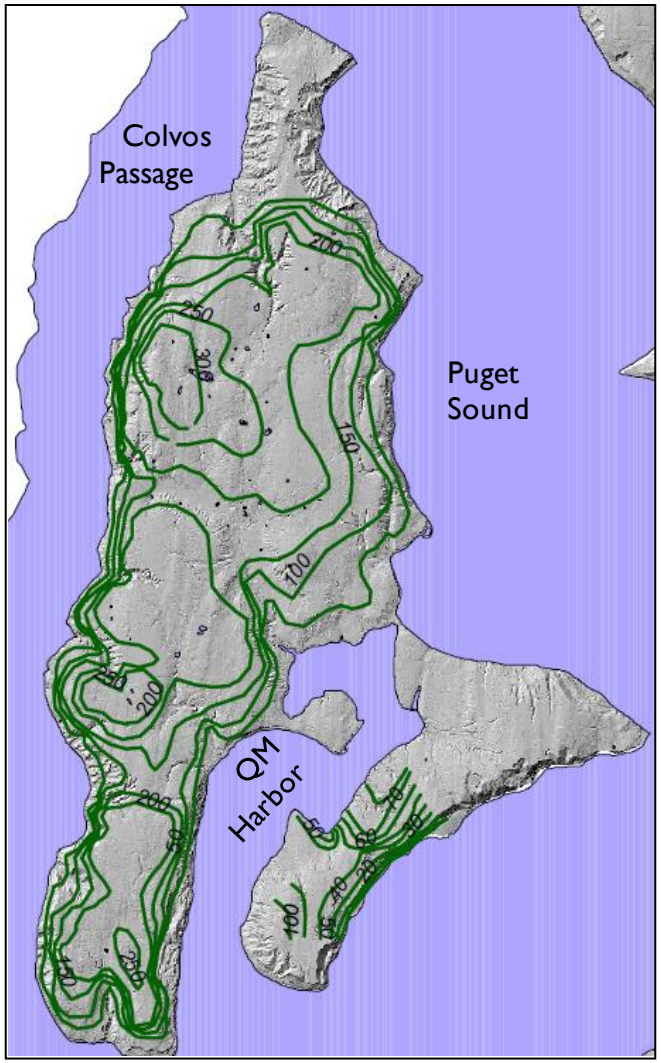
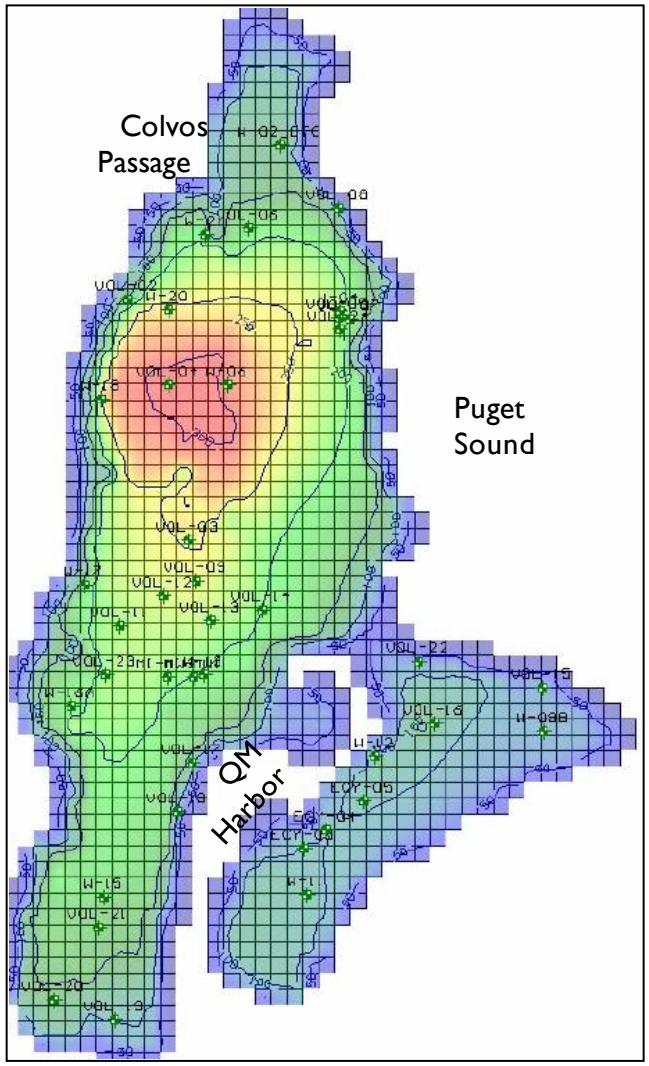


Figure 29. WRE Phase 1 Model Water Level Contour Input for Qva.



Note: Contours adapted from Carr/Assoc. (1983), VMI GWMC (1998b). Highest newer data (KC, 2003). Contour intervals = 50 feet, except on Maury Island.

Figure 30. WRE Phase 1 Model Water Level Contour Output for Qva.



Note: Produced using Visual MODFLOW (WHI, 2004). Qva water levels in red, lowest in blue. Contour intervals = 50 feet.

The WRE-Phase 1 modeling results also confirmed many previously documented aspects of groundwater flow on the Island (Figures 29 and 30). Many features included in previous interpretation showed up in the model output, such as steep groundwater gradients, particularly on the western edge of the Island. Groundwater gradients (and thus flows) were downward throughout the Island, although somewhat less along the coastline, where deep groundwater must flow up towards Puget Sound discharge locations (KC, 2005b).

Figure 31. Water Table Elevation Map of Qva aquifer for 2006.

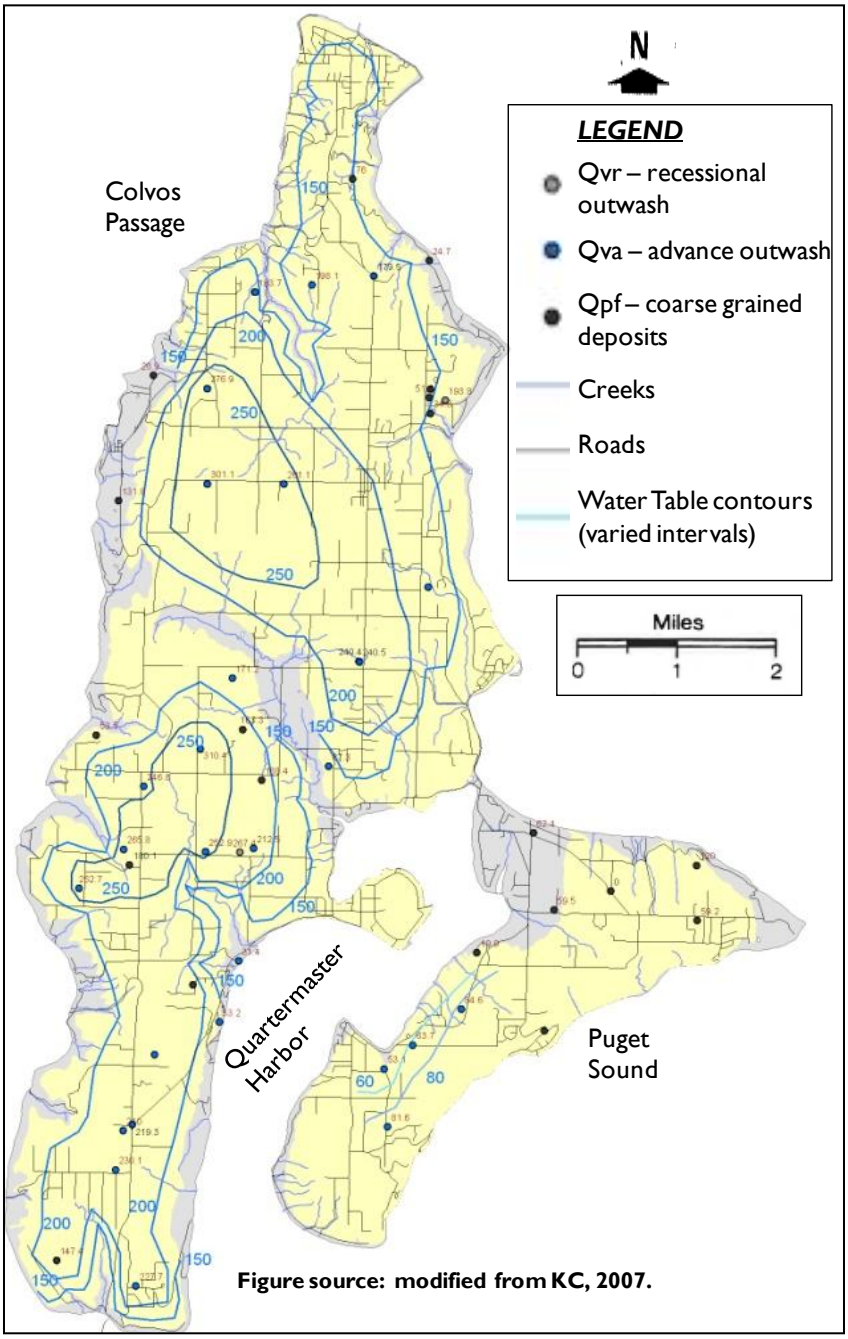


Figure source: modified from KC, 2007.

Water level contours mapped during the WRE indicated peak elevations trending north-south along the center of the Island, and dropped off steeply at its edge (Figure 31). The water table elevation maps in

Figures 27 through 31 show similar contour patterns and flow directions, illustrating that the Qva unit responds consistently over time and the patterns are consistent with our basic understanding of unconfined groundwater hydrology, where water level contours reflect overlying topography.

4.3 Island – Wide Hydrologic Water Budget

A water budget is a method to estimate water movement in the hydrologic system. In the simplest form, the water budget equation is inflow of water into the hydrologic system equaling the outflow of water from the hydrologic system. Inflow into this hydrologic system is local precipitation, as noted in the Carr Report (Carr/Assoc., 1983). As per the same report, the Vashon-Maury Island was reported to have no off island sources of recharge. Outflows of this hydrologic system included evapotranspiration, stream flow, and discharge to Puget Sound through the groundwater.

The Carr Report conducted additional analyses of recharge and water availability based on the water resource monitoring. The recharge potential of the Island was assessed by compiling slope, soil type, vegetation, and permeability datasets into a derivative map. Areas of recharge potential were designated 'high', 'medium' or 'low' recharge potential based on this map. Using the water resource data, an island-wide water budget/balance was generated. The importance of this water balance was further supported by the understanding that the Island has no off island sources of recharge. Analytical model results of island-wide averages in the Carr Report were as follows:

- 40 inches of average annual precipitation;
- Roughly 20 inches (50 percent) of precipitation evaporates; and
- Roughly 20 inches (50 percent) of precipitation either runs off or infiltrates through the soil.

In areas of high recharge potential, about seven inches infiltrates to the Principal aquifer; 11 inches are runoff. The remaining two inches may be available to recharge the deep aquifer system. Island-wide, about 15 inches of runoff; four inches of the surplus infiltrates to the Principal aquifer and one inch recharges the deep aquifer (Carr/Assoc., 1983). The Carr Report concluded that precipitation is the only source of recharge to the Island aquifers. In addition, the report summarized a water budget for the Island based on measured precipitation and stream flows.

The GWMP built upon the Carr Report and generated a new water budget that concluded there were 12,895 acre feet per year (AFY) available to recharge the aquifers, more water than previously understood. This estimate was significantly higher than that reported in the Carr Report (1,976 AFY) in part with more rainfall, less evapotranspiration and less runoff assumed (Table 9). The potential amount of annual groundwater recharge assessed on the Island was reported as significantly different values of about 9,800 to 33,700 AFY by the Carr Report and the GWMP, respectively. These earlier monitoring efforts (Carr Report and GWMP) used an analytical method to estimate the island-wide water budget, while the more recent WRE determined the water budget using computer models (Table 9).

The WRE attempted to resolve the differing estimates of groundwater availability calculated from the analytical water budgets prepared in the Carr Report and the GWMP. The WRE established a more accurate water budget for the Island with the development of two modeling efforts (WRE-Phase I and II). These models utilized the new monitoring along with all other necessary data to better assess the Island's overall water balance (KC, 2009b).

Table 9. Water Budget Estimates for Vashon-Maury Island.

	Carr / Assoc				GWMP				WRE-Phase I				WRE-Phase II *			
	1983				1998				2005				2009			
	gpm	AFY	in/yr	%	gpm	AFY	in/yr	%	gpm	AFY	in/yr	%	gpm	AFY	in/yr	%
Inflows																
+ Precipitation	48,851	78,856	40	100%	56,500	91,130	44.1	100%	49,584	79,830	38.7	100%	52,007	83,950	43.8	100%
- Evapotranspiration	24,425	39,427	20	50%	22,370	36,170	17.5	40%	21,410	34,470	16.7	43%	23,628	38,141	19.9	45%
- Runoff	18,319	29,571	15	37.5%	13,170	21,285	10.3	23%	11,719	18,868	9.2	24%	13,180	21,275	11.1	25%
Irrigation	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	520	840	0.3	1%
Septic Return Flow	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	0.3	NI	520	840	0.4	1%
TOTAL Groundwater recharge	6,107	9,858	5	13%	20,960	33,675	16.4	37%	16,455	26,493	12.8	33%	14,159	22,855	13.5	31%
Outflows																
Puget sound	1,224	1,976	1	2.5%	8,110	12,895	6.3	14%	13,501	21737	10.5	27%	9,855	15,908	7.6	17%
Streams	4,882	7,881	4	10%	12,850	20,780	10	23%	1,841	2964	1.4	4%	5,105	8,241	4.3	10%
Wells	NI	NI	NI	NI	NI	NI	NI	NI	753	1212	0.6	2%	712	1,150	0.6	1%
Springs	NI	NI	NI	NI	NI	NI	NI	NI	360	580	0.3	1%	356	575	0.3	1%
TOTAL Discharge	6,106	9,856	5	13%	20,960	33,675	16.3	37%	16,455	26,493	12.8	34%	16,029	28,876	13	29%
Data Sources:																
Carr Report			x	x												
GWMP					x	x										
WRE PHASE I report	x			x	x			x	x			x				
WRE PHASE II report			xx	xx			x	x			x	xx			x	x
Conversions	x	x		xx	x	x		x		x		x	x	x		xx

Notes:

** = Difference in total groundwater recharge and total outflow is due to change in storage of 2 percent.*

x = Indicates values reported in document listed in left column.

xx = Indicates values reported in documents were different than in original report.

NI = not included in budget

AFY = acre feet per year

in/yr = inches per years

% = percent

gpm = gallons per minute

The WRE-Phase I groundwater model (KC, 2005a) showed that many features that had been observed previously about the Island's groundwater could be replicated. The overall water budget in this model was similar to previous estimates of total flows in the various components. Figure 32 shows the hydrologic interconnections between the hydrostratigraphic units and the inflows and outflows of the WRE-Phase I model. The estimated percent of discharge to Puget Sound is larger in the WRE-Phase I model than in previous studies: 21,737 AFY compared to 12,895 AFY estimated in the GWMP and 1,976 AFY in the Carr Report (Table 9; VMI GWMC, 1998b; Carr/Assoc., 1983). The WRE-Phase I and II models yielded similar groundwater inflow (recharge) estimates that were less than that of the GWMP while being twice the amount calculated by the initial work in the Carr Report (Table 9).

Another difference between the results of the WRE Phase I and II modeling and GWMP budgets is the amount of water creating a freshwater lens beneath the Island. Resulting budgets of the GWMP and the Carr Report estimated the majority of the groundwater inflow going to the streams and not infiltrating into deeper zones before discharging to Puget Sound. The WRE-Phase I and II models reported greater volumes of water infiltrating (Puget Sound outflow) into these deeper zones (Table 9; Figure 32).

Figure 32. Water Balance Flow Details of WRE-Phase 1 Modeling Results.

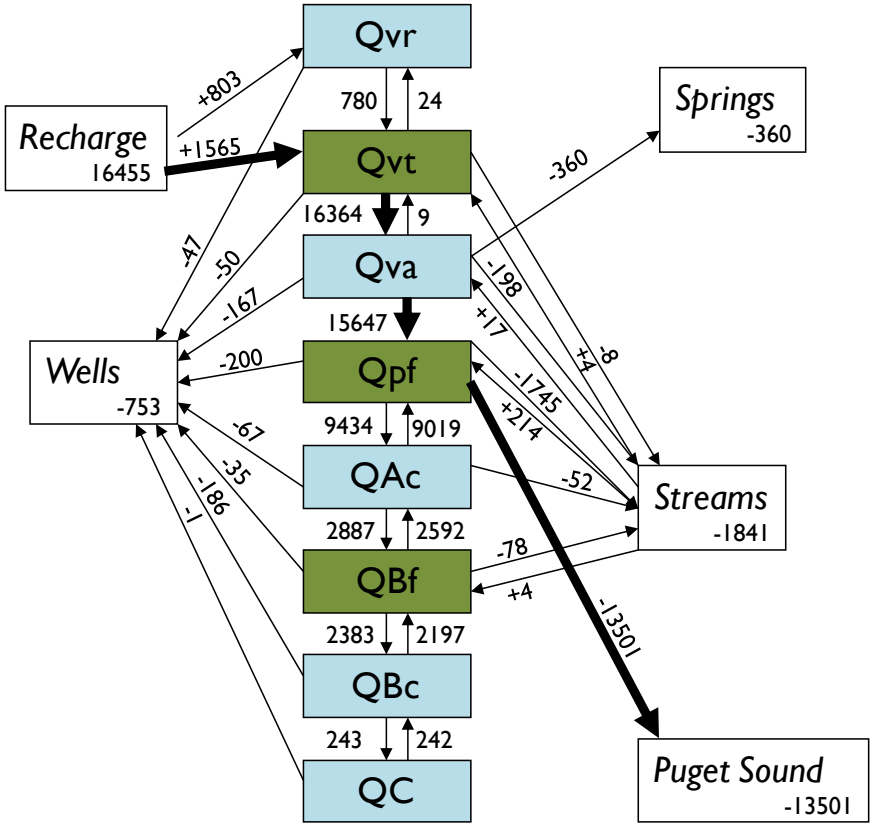


Figure source: modified from KC, 2005b

LEGEND
Flow is presented in gallons per minute (GPM)

Greater flows are shown with thicker arrows.

Aquifer unit

Aquitard unit

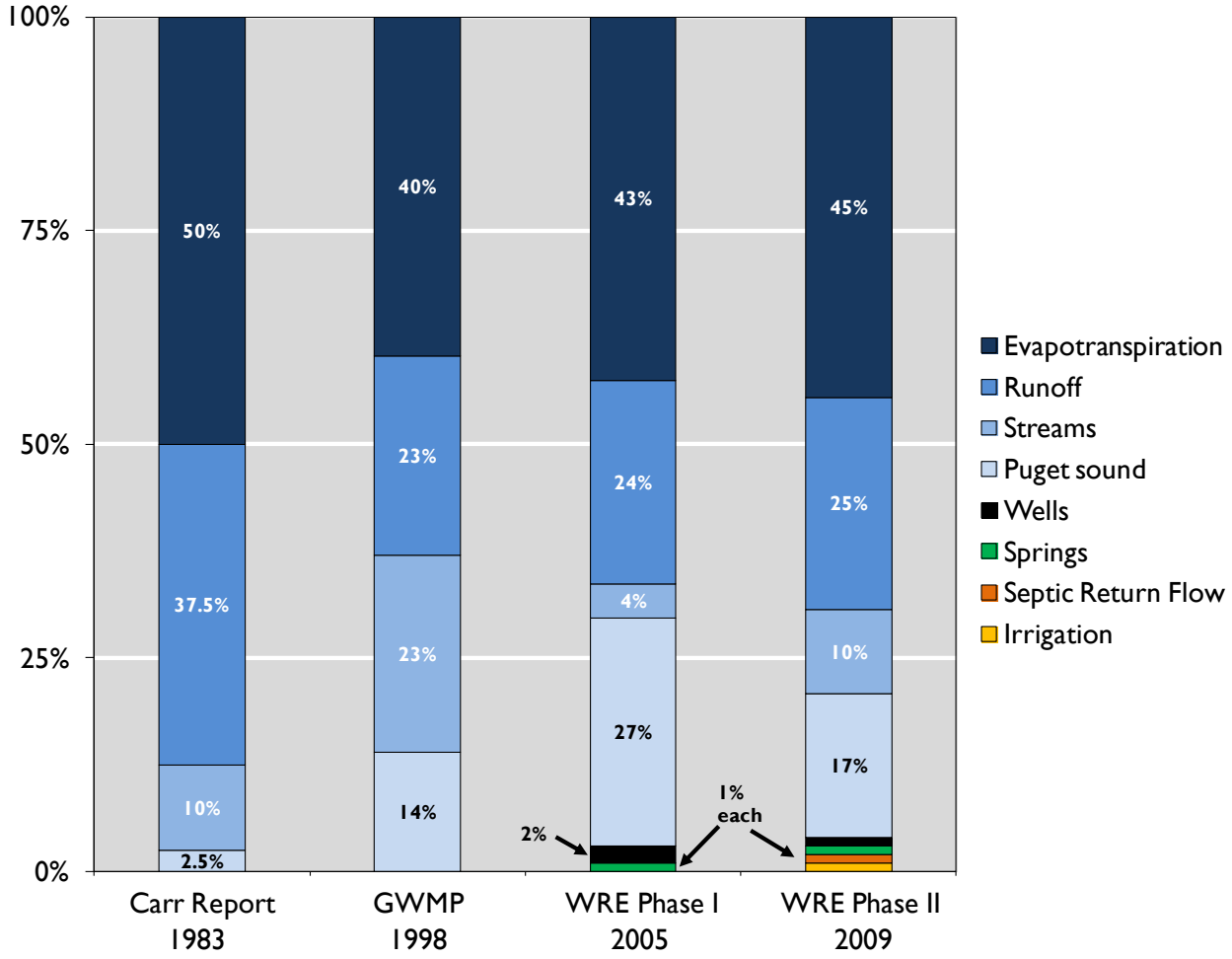
Note: Flow is presented in gallons per minute (gpm). Greater flows are shown with thicker arrows. Units without boxes at right of figure indicate flows out (negative) and into (positive) aquifer unit, to and from streams (adjacent arrows).

Not all of the recharge water is available for pumping as a result of aquifer retention and recovery factors. Recent work of the VMI Sustainability Monitoring project has been collecting water usage data from a variety of water users. Water consumption is calculated from four water users – Group A public water systems, Group B public water systems, individuals and agricultural water users. In 2010, the total island-wide water use was estimated to be 489 MGY. In converting the data presented in Table 9 to similar units the range of recharge is from 3,200 to over 10,900 MGY. The 2010 water use estimate of 489 MGY is 4 to 15 percent of this recharge range.

In summary, Vashon-Maury Island is reported to have no off island sources of recharge. Outflows of this hydrologic system included evapotranspiration, stream flow, and discharge to Puget Sound through the groundwater. Four water budgets were proposed since the 1980s, each using more data, detailed analysis and complex modeling techniques. Estimates varied based on differing assumptions of inflows and outflows, as per mode available data and improved modeling techniques. The more recent and more

accurate models were able to replicate previous observations and incorporate recharge due to irrigation and septic flow and discharges due to wells and springs. Figure 33 shows a more simplified graphic of percentages of the variables included in the models where precipitation represents 100 percent of the recharge to the system in all budgets.

Figure 33. Percent of Variables for Water Budgets of Vashon-Maury Island.



4.4 Water Quality on Vashon-Maury Island

WA Ecology administers the state's surface water quality standards (WAC 173-201A) and the WA Department of Health administers the state's public drinking water supply system monitoring requirements (WAC 246). These regulations establish minimum requirements for the quality of water that must be maintained in lakes, rivers, streams, groundwater and marine waters to ensure that all the beneficial uses associated with these waterbodies are protected. Examples of protected beneficial uses include: drinking water, aquatic life and wildlife habitat, fishing, and shellfish collection.

Monitoring and protecting the water quality of the surface water and groundwater is key for maintaining healthy ecosystems and sustainable water sources. Adequate protection includes protecting surface water supplies and protecting both from potential sources for water quality impairment, such as

household and land management practices, urban runoff, landfill and wastewater treatment facilities, failing and functional septic systems and in some areas seawater intrusion. For example, marine water quality is degraded from water carrying nutrients from septic systems or fertilizers, and contaminants from motor vehicle oil and exhaust.

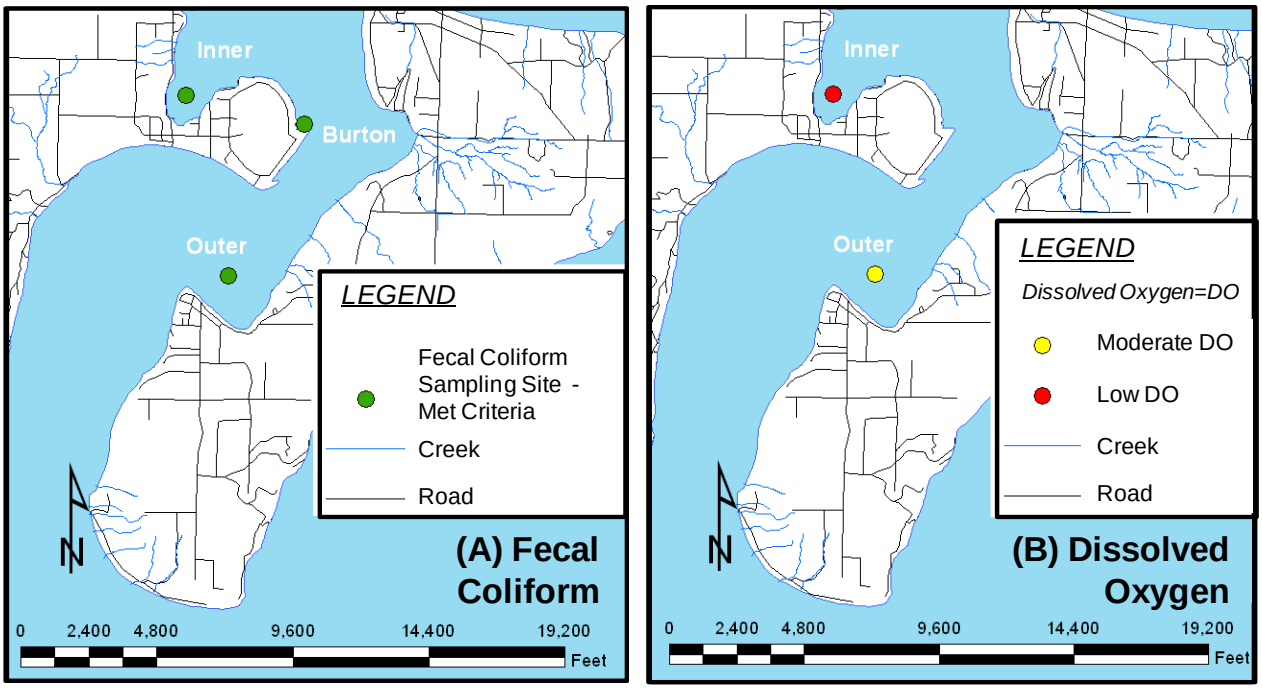
Within this section, the following are discussed in more detail:

- Marine water quality
- Freshwater surface water quality
- Groundwater water quality

4.4.1 Marine Water Quality in Quartermaster Harbor

King County has been conducting monthly sampling for fecal coliform at the inner and outer harbor since 2006 for both fecal coliform bacteria and dissolved oxygen. Sampling at a third station in Quartermaster Harbor (Burton Acres County Park) began in 2007 and the data is used for the assessment of fecal coliform bacteria only (Figure 34a; KC, 2013b).

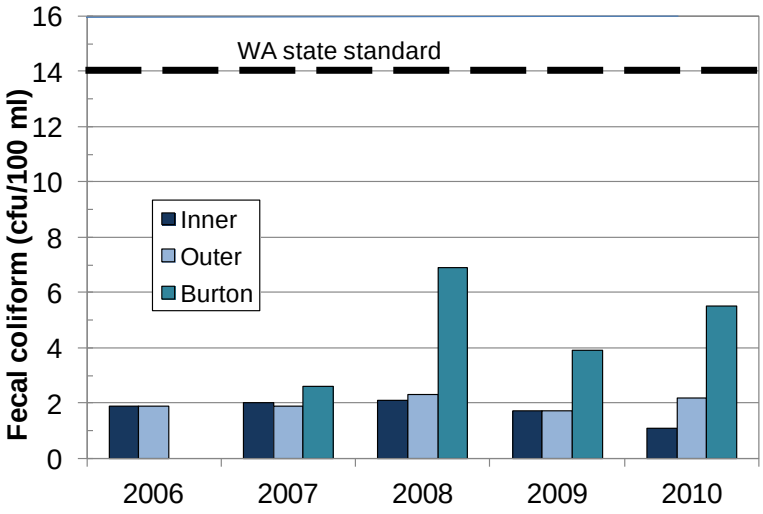
Figure 34. Sampling locations within Quartermaster Harbor for Fecal Coliform Bacteria (A) and Dissolved Oxygen (B) for 2010.



For data collected since 2006, all three locations sampled met state water quality criteria for fecal coliform bacteria (geomean value of 14 colony forming units per 100 milliliters of sample (cfu/100ml) for marine water) and the 2006-2010 average is 100 percent for locations meeting the state water quality criteria. All samples were well below 14 cfu/100ml, the WA standard for fecal coliform bacteria in marine waters (Figure 34; KC, 2013b). In addition, WA DOH collected marine water quality samples

along Quartermaster Harbor for fecal coliform analysis. There also were no exceedances of the criteria based on this dataset.

Figure 35. Fecal Coliform Bacteria Shown as Geometric Mean for Stations within Quartermaster Harbor.



Dissolved oxygen levels below the WA water quality standard (extraordinary criteria of 7 mg/L) have been observed in Quartermaster Harbor over the last seven years by both King County and UWT (KC, 2010c and 2013f). Table 10 shows the percentages of samples taken from the bottom of the water column that were below the WA water quality standard (extraordinary criteria of 7 mg/L) for each year sampled since 2006 (Figure 36). The inner harbor sampling location was assigned a low dissolved oxygen rating since 55 percent of the samples tested were below the extraordinary criteria of 7 mg/L (Figure 34b). In contrast, the outer harbor sample was assigned a moderate dissolved oxygen rating since 45 percent of the samples tested were below the extraordinary criteria of 7 mg/L (Figure 34b). More detail on these results is in Appendix A.

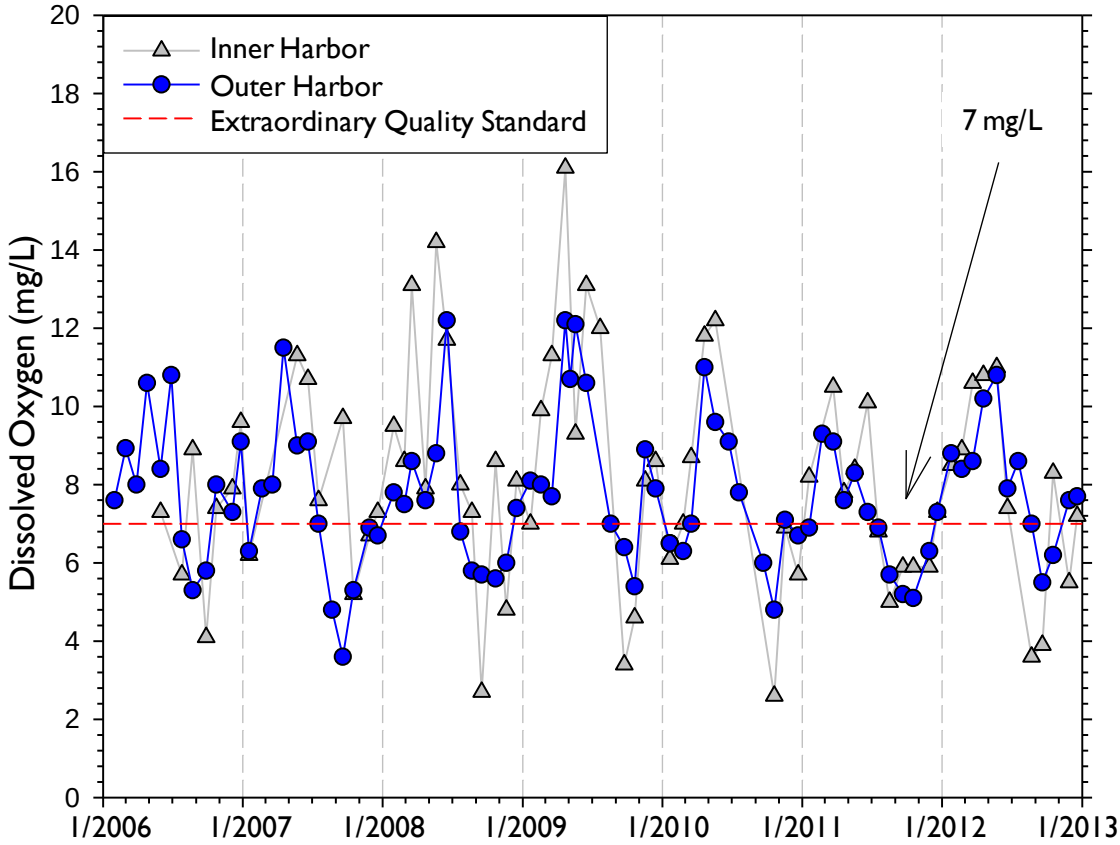
Table 10. Dissolved Oxygen in Quartermaster Harbor.

Inner Quartermaster Harbor Station					
	2006	2007	2008	2009	2010
Total Number	9	12	12	12	11
Percentage of samples below criteria	22%	25%	17%	25%	55%

Outer Quartermaster Harbor Station					
	2006	2007	2008	2009	2010
Total Number	12	12	12	12	11
Percentage of samples below criteria	25%	50%	42%	17%	45%

Notes: WA state water quality standard (extraordinary criteria of 7 mg/L) (KC, 2013b). Samples taken from bottom of water column.

Figure 36. Dissolved Oxygen in Quartermaster Harbor.



Note: WA state water quality standard (extraordinary criteria of 7 mg/L) (KC, 2013b). Samples taken from bottom of water column.

More information related to marine water quality in Quartermaster Harbor is presented in the documents related to the Quartermaster Harbor Nitrogen Management Study on the King County website (KC, 2013e) and more is to be presented in a forthcoming report on this study. The following are other ongoing projects studying influences on Quartermaster Harbor marine water quality:

- Public Health - Seattle & King County's Vashon-Maury Island Marine Recovery Area to correct failing on-site sewage systems in outer Quartermaster Harbor (Public Health, 2013).
- Puget Sound Restoration Fund's Quartermaster Harbor Nutrient Mitigation Project to test effects of growing mussels on water quality in Quartermaster Harbor (PSRF, 2013).
- WA Department of Health's Shellfish Program to monitor, classify water quality and manage shellfish harvest in Quartermaster Harbor (WA DOH, 2013b).
- WA Department of Natural Resources' Maury Island Aquatic Reserve management plan for Quartermaster Harbor (WA DNR, 2013).

4.4.2 Freshwater Surface Water Quality

The Carr Report presented selected water quality analysis of locations on McCormick, Shinglemill, Judd, Ellis, Beal, and Tahlequah Creeks (Carr/Assoc., 1983). Chlorides were reported as somewhat higher in springs and streams than in the wells, ranging between 3 and 18 mg/L.

The GWMP presents surface water quality data from eight creeks (Beal, Fisher, Green Valley, Judd, Shinglemill, Mileta, Paradise Cove, and Tahlequah Creeks) in 1991 and 1992 (VMI GWMC, 1998b). In addition, spring water quality data were collected from six locations between 1989-1990 for fecal coliforms, metals, sulfate, fluoride, and total dissolved solids. With the exception of elevated fecal coliform levels, high levels of contaminants were not observed at these locations (VMI GWMC, 1998b).

As part of the WRE, in late 2006, stream water quality sampling began as an island-wide assessment of the surface water quality since the last study completed in 1992. This effort included surface water sampling at seven locations across the Island. These locations were chosen to represent a wide range of conditions.

Within this section, the following are discussed in more detail:

- Stream water quality index
- Fecal coliform bacteria in streams
- Nitrogen in streams
- Stream temperatures
- Stream benthic invertebrate index

4.4.2.1 Stream Water Quality Index

The Water Quality Index (WQI) integrates key factors into a single number that can be compared over time and across locations. This index compares monthly data of temperature, pH, fecal coliform bacteria, dissolved oxygen, turbidity, total suspended solids, and nutrients (phosphorus and nitrogen) relative to state standards and guidelines. The WQI is a measure created by Ecology that generates a number ranging from 1 to 100 for a stream location. Higher numbers reflect better water quality. The multiple water quality parameters are combined and results aggregated over the water year to produce a single score for each sample station. In general, stations scoring 80 and above meet expectations and are of "low concern" with good water quality, scores 40 to 80 indicate "moderate concern and water quality", and stations with scores below 40 do not meet expectations and are of "high concern" with poor water quality.

Samples were collected at various locations on the Island (Figure 3). Time series plots of the key components of the WQI for Fisher, Judd and Mileta Creeks are depicted in Figures 37, 38 and 39.

After the 14 month assessment period of the WRE, surface water monitoring continued due in part to reported lower WQI values for Fisher, Tahlequah and Judd Creeks (Table 11). The WQI values for Fisher, Judd, Mileta and Shinglemill Creeks were mostly moderate concern with Fisher Creek being of high concern for WY 2007 as compared to WY 2011 moderate to low concern scores over 70 for all creeks sampled.

The water quality index for each location varied year to year (Table 11 and Figure 40). Overall for 2007 through 2011, scores have varied up and down, with an insufficient number of years of data to assess upward to downward trends. However, conditions appear to be improving.

Figure 37. Fisher Creek Water Quality Graphs for 2006 through 2012.

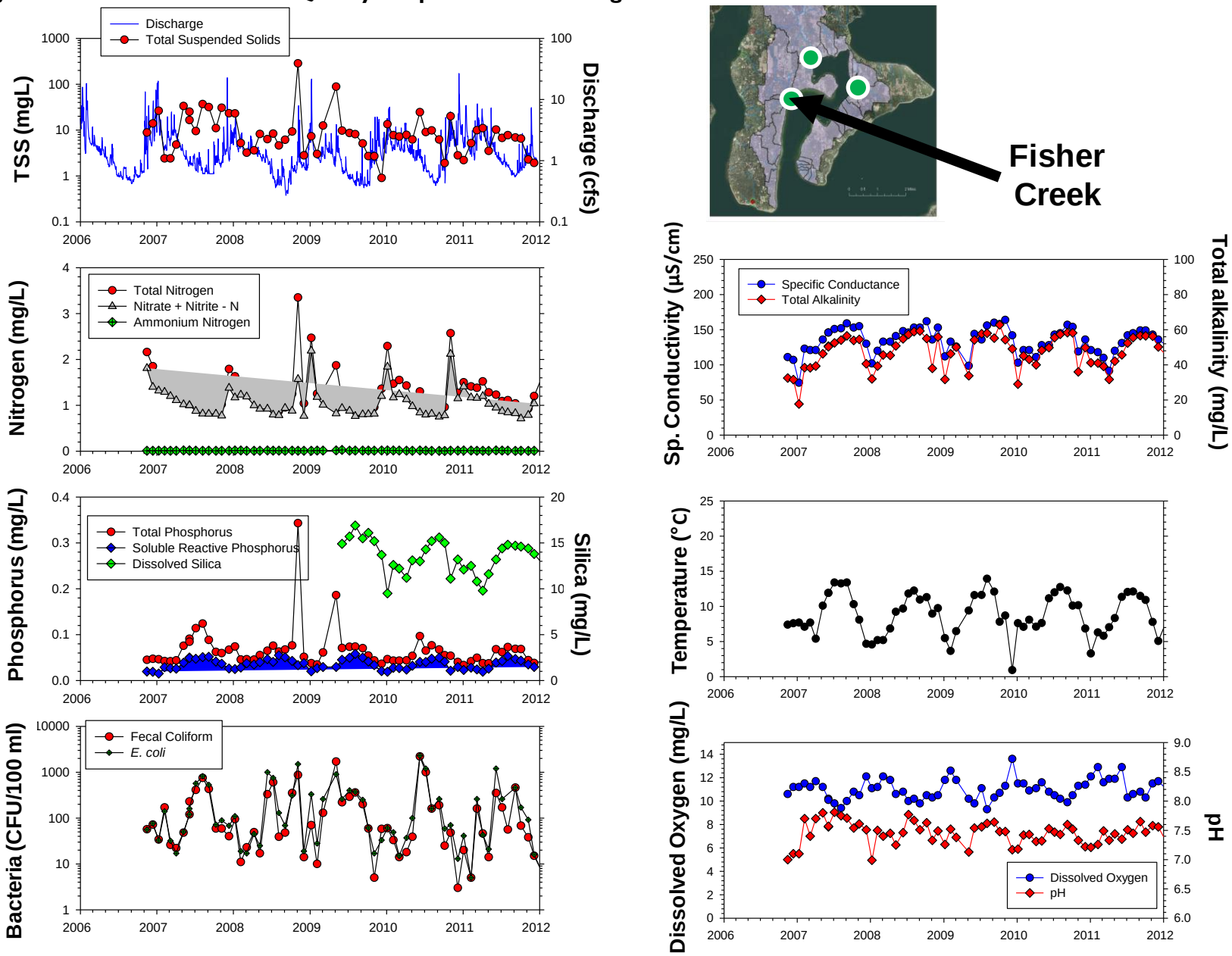


Figure 38. Judd Creek Water Quality Graphs for 2006 through 2012.

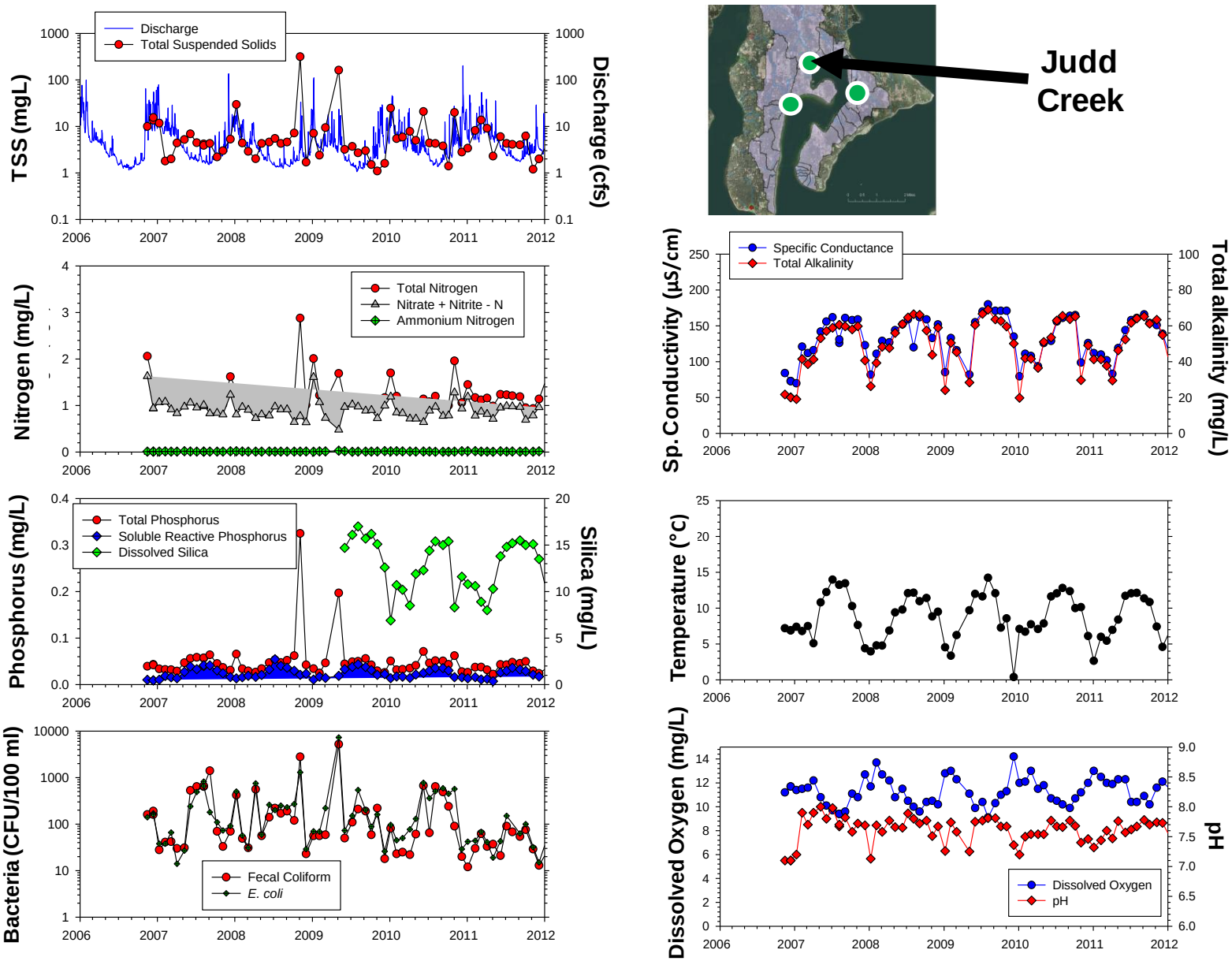


Figure 39. Mileta Creek Water Quality Graphs for 2006 through 2012.

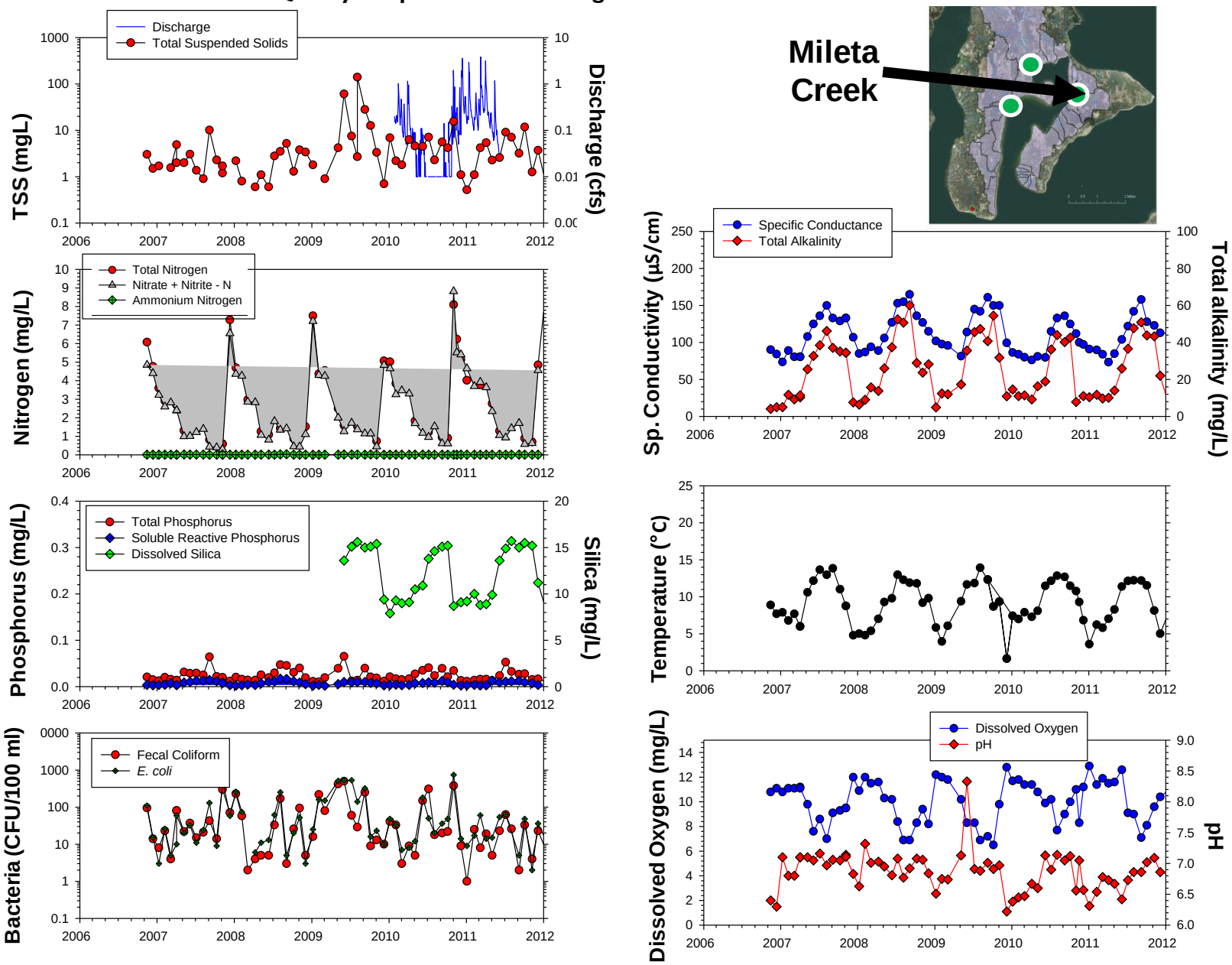


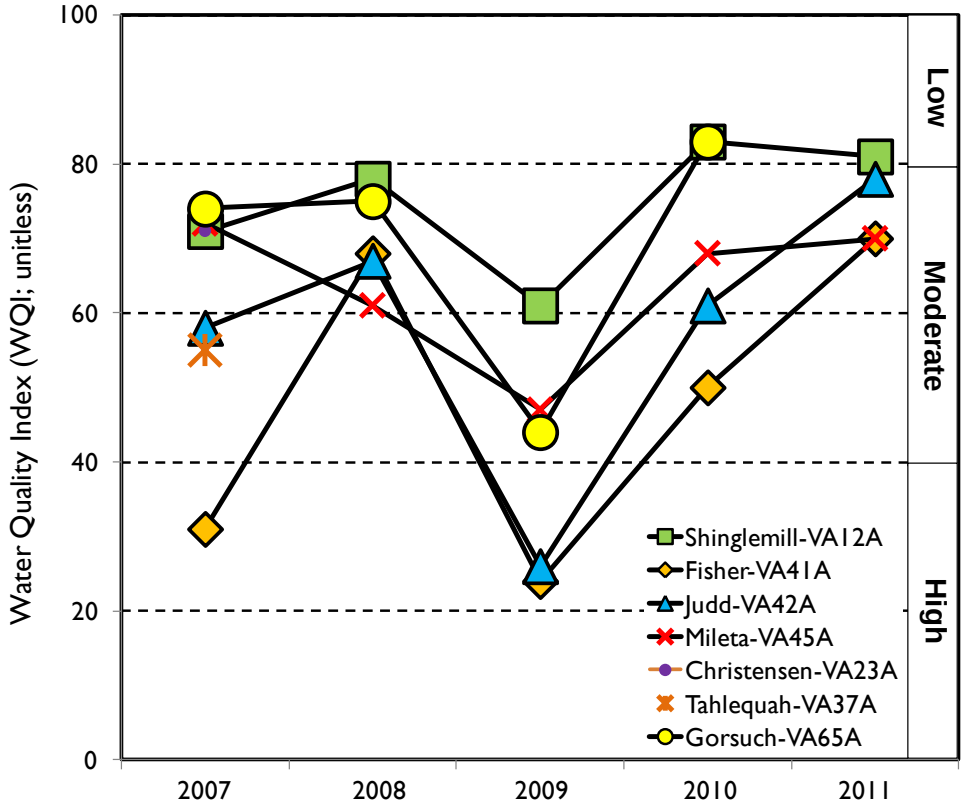
Table 11. Water Quality Index Scores for Selected Vashon-Maury Island Streams.

		Water Years				
Creek Name	**Site Name**	**2007**	**2008**	**2009**	**2010**	**2011**
Christensen	VA23A	71				
Fisher	VA41A	31	68	24	50	70
Gorsuch	VA65A	74	75	44	83*	
Judd	VA42A	58	67	26	61	78
Mileta	VA45A	72	61	47	68	70
Shinglemill	VA12A	71	78	61	83	81
Tahlequah	VA37A	55				
Total Low Concern		0	0	0	1	1
Total Moderate Concern		6	5	3	3	3
Total High Concern		1	0	2	0	0
Total Streams		7	5	5	4	4

Note: Colors are for VMI indicators and are not 'typical' for reporting WQI scores.
"" = Gorsuch Creek only has 6 samples (Oct-Mar) in Water Year 2010*

Score	*Explanation*
>80	*Low concern - good water quality*
80-40	*Moderate concern with a mix of good and poor water quality*
<40	*High concern – poor water quality*

Figure 40. Water Quality Index Scores for the Island Creeks by Water Year.



Note: Side bar blocks (low, moderate and high) are ratings for the VMI Sustainability Indicator program ratings and are not 'typical' for reporting WQI scores.

4.4.2.2 Fecal Coliform Bacteria in Streams

Water carrying nutrients from septic systems and overland flow of surface water capturing bacteria from animal wastes from pets and wildlife can degrade drinking water quality and can reduce oxygen levels for the animals that live and depend on Puget Sound habitats. Fecal coliform bacteria data were collected as part of the monthly stream water quality and is one of the ten parameters used to calculate WQI scores. This parameter also has a "state extraordinary criteria" where fecal coliform bacteria levels must not be higher than the geometric mean of 50 colony forming units (cfu)/100 mL.

Judd, Fisher, Mileta and Christensen Creeks had exceedances of the state extraordinary criteria for at least one year (Table 12). Exceedances of the criteria occurred repeatedly for the time period 2007 2010 on Fisher and Judd Creeks. Cattle and horse manure, septic systems, and farming practices are all potential sources of fecal coliform bacteria in the shallow aquifer (CDM, 2007).

Table 12. Geometric mean Fecal Coliform concentrations (cfu/100 mL) for Selected Vashon-Maury Island Creeks.

		Water Years				
Creek Name	**Site Identification**	**2007**	**2008**	**2009**	**2010**	**2011**
Christensen	VA23A	**54**	NS	NS	NS	NS
Fisher	VA41A	**107**	**56**	**168**	**73**	44
Gorsuch	VA65A	41	13	47	9*	NS
Judd	VA42A	**160**	**110**	**159**	**87**	46
Mileta	VA45A	25	28	**73**	20	15
Shinglemill	VA12A	34	22	43	12	17
Tahlequah	VA37A	31	NS	NS	NS	NS

Notes:
VMI streams have the extraordinary criteria of 50 CFU/100ml.
The stream results exceed the criteria, inferring poor water quality.
"" = refers to sites with missing data – incomplete water year dataset.*
cfu/100ml = standard unit of measure for bacteria data; colony forming units per 100 milliliters.
NS = Not sampled in this year.

4.4.2.3 Nitrogen in Streams

Water carrying nutrients from septic systems, cattle and horse manure, fertilizer applications, leaching of nitrate from nitrate-fixing alder trees, and leaching of decomposing organic matter are all potential sources of nitrate in the sensitive Principal aquifer (CDM, 2007).

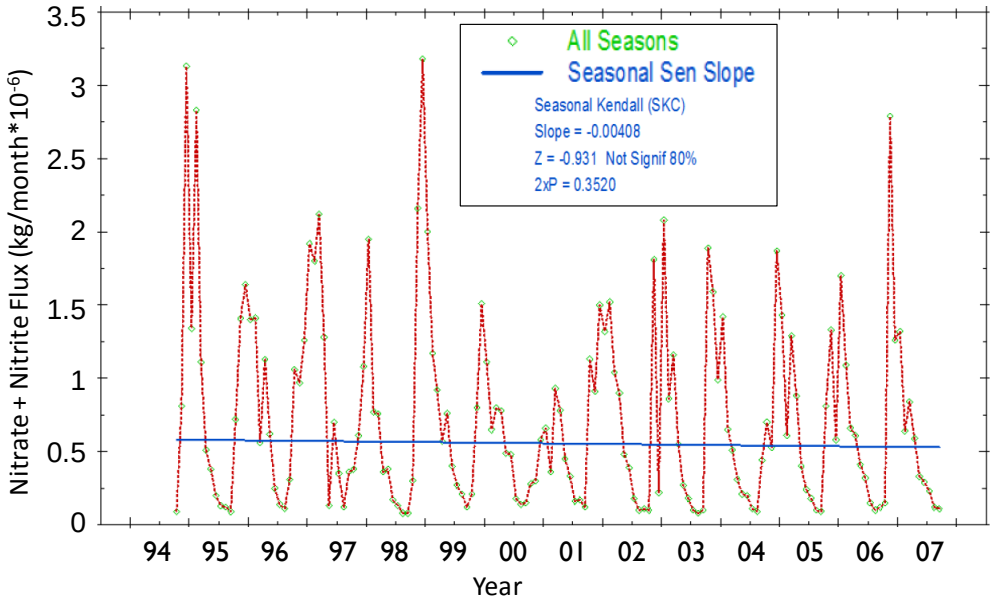
Nitrogen is an important plant nutrient. Vegetation along streams can be effective at taking up nutrients for storage and plant growth from the soil adjacent to a stream and directly from a stream. Natural sources of nitrogen include plant decomposition. Forest ecosystems adjacent to streams provide organic matter that contains nitrogen. Leaves and other organic matter fall directly into the stream channel. These plants determine the quantity, quality, and timing of nitrogen delivered to the soil and stream channel (Naiman et al, 1997). A majority of the plant material input from deciduous riparian forests typically are leaves high in nutrients are delivered to the stream over a six to eight week period during

autumn. These materials are processed by organisms that break down wood, leaves and other debris into smaller pieces (May, 2003).

Agricultural activities such as farming and animal grazing can also significantly increase nitrogen levels. Based on monitoring in small streams, runoff from residential and agricultural areas carries higher levels of nitrogen and other pollutants than runoff from natural land covers (Adelsman, 2013). In general, research has indicated that use of best management practices, such as limiting grazing access to a stream and riparian area using fencing, as well as maintenance of vegetative buffers along the riparian corridor can significantly reduce the impacts of agricultural activities (May, 2003). High levels of nitrogen to a stream can lead to uncontrolled plant and algae growth. Excessive aquatic plant growth, due to excessive nitrogen, can also lead to oxygen depletion in both freshwater and marine water systems.

Ecology reported that nitrate plus nitrite flux entering the Puget Sound was highly seasonal; highest in the winter, especially November through January, and lowest in the summer. There were no seasonal components to the trends and no significant trend in the nitrate plus nitrite flux from all major rivers entering Puget Sound (Figure 41; Hallock, 2009). These low nitrogen concentrations in the summer coincide with lower stream flows and lowering of water levels in shallow water bearing geologic zones. The low stream flows in the summer are mostly a result of groundwater inflow.

Figure 41. Nitrate + Nitrite Flux entering Puget Sound from Thirteen Largest Rivers.



Note: Modified from Hallock, 2009.

After the 14 month assessment period of the WRE, surface water monitoring continued due to reported lower water quality index values for Fisher, Talequah and Judd Creeks (Table 12) plus nitrate concentrations of over 6 mg/L during winter months in Mileta Creek (Figure 42). As part of the Quartermaster Harbor Nitrogen Management Study, the Nearshore Freshwater Inflows Assessment was conducted to identify small previously unmonitored streams draining to Quartermaster Harbor that might have relatively high nitrate concentrations. This study was conducted on October 2010 at 21 locations along the perimeter of the harbor (Figure 43; KC, 2012d).

In general, it appears that the range in nitrate concentrations measured in October 2010 in small freshwater inflows to Quartermaster Harbor was larger than that observed since 2006 in monthly grab samples collected in three of the largest tributaries to the harbor (Fisher, Judd and Mileta Creeks).

Figure 42. Nitrate + Nitrite Concentrations for Selected Vashon-Maury Island Creeks.

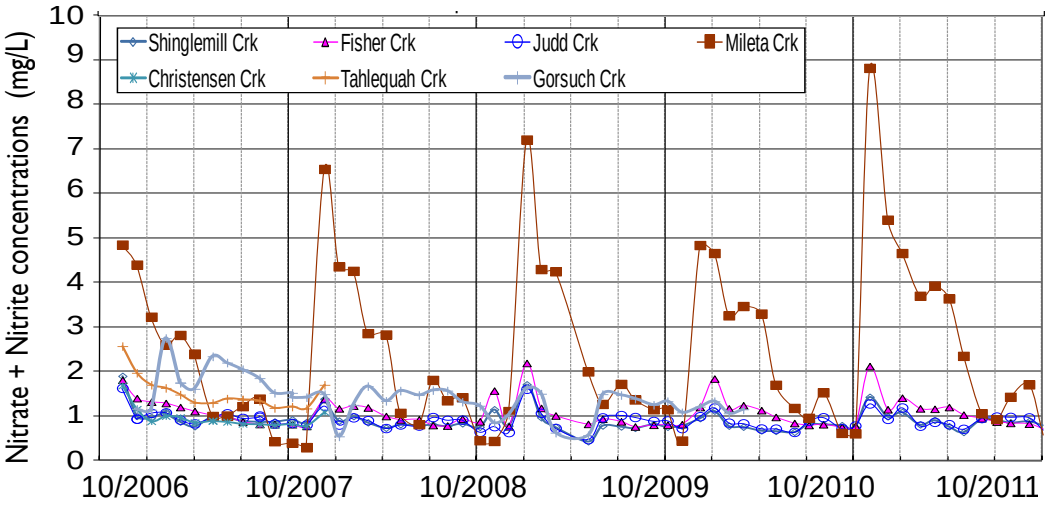
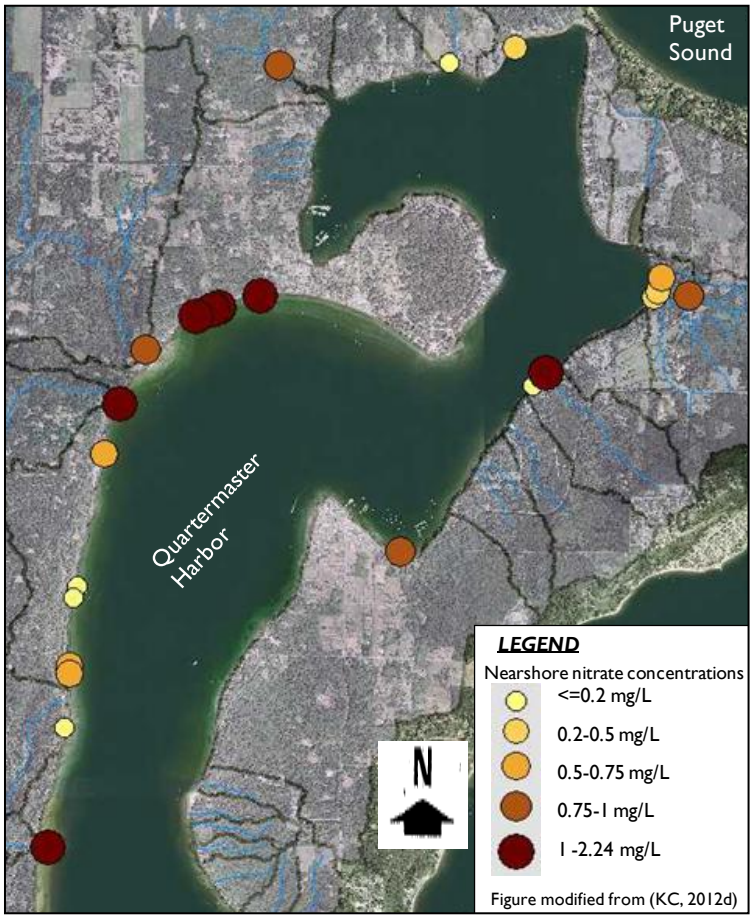
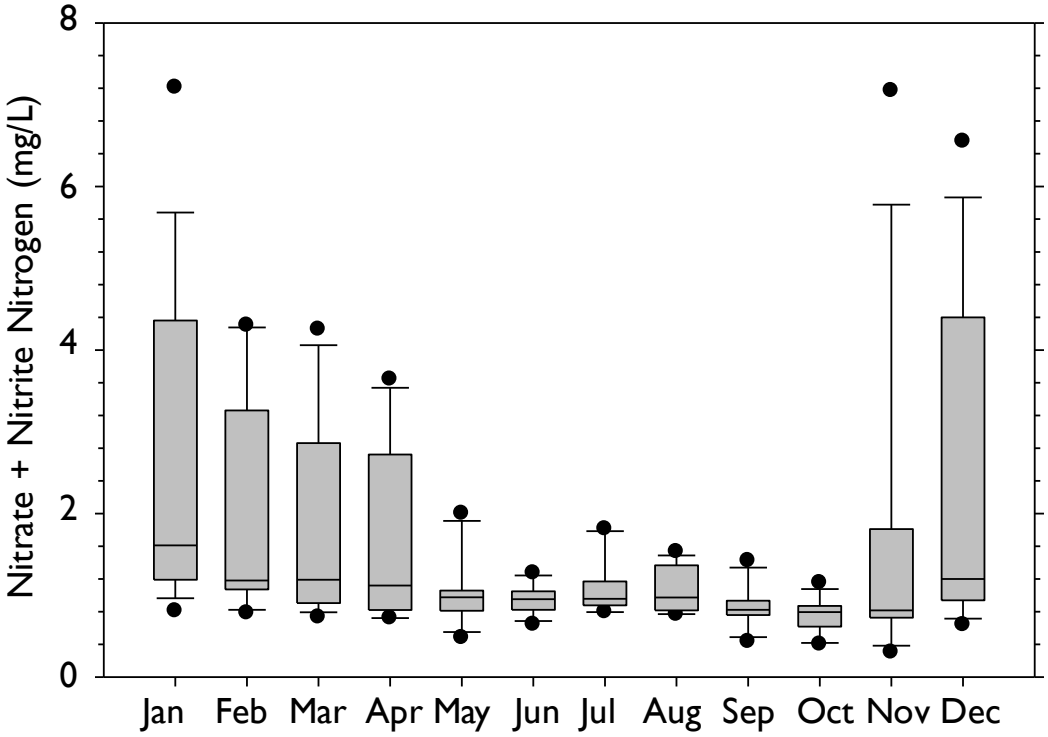


Figure 43. Range of Nitrate + Nitrite Nitrogen at Sampling Locations for the Nearshore Freshwater Inputs Assessment Study in 2010.



Routine monthly samples taken from Fisher, Judd and Mileta Creek showed a seasonal trend of lower concentrations of nitrate + nitrite nitrogen in summer months (May through October) and higher concentrations of nitrate + nitrite nitrogen in winter months (November through April) (Figure 42 and Figure 44). This pattern is typical of rural lowland streams, highest concentrations occur during winter when plant uptake is lowest and rain flushes nitrates from surface soils into nearby streams and lowest concentrations occur during summer when plant uptake is greatest and soils are general dry and accumulating nitrate.

Figure 44. Monthly Nitrate + Nitrite Nitrogen from Routine Monthly Samples from Fisher, Judd and Mileta Creeks.

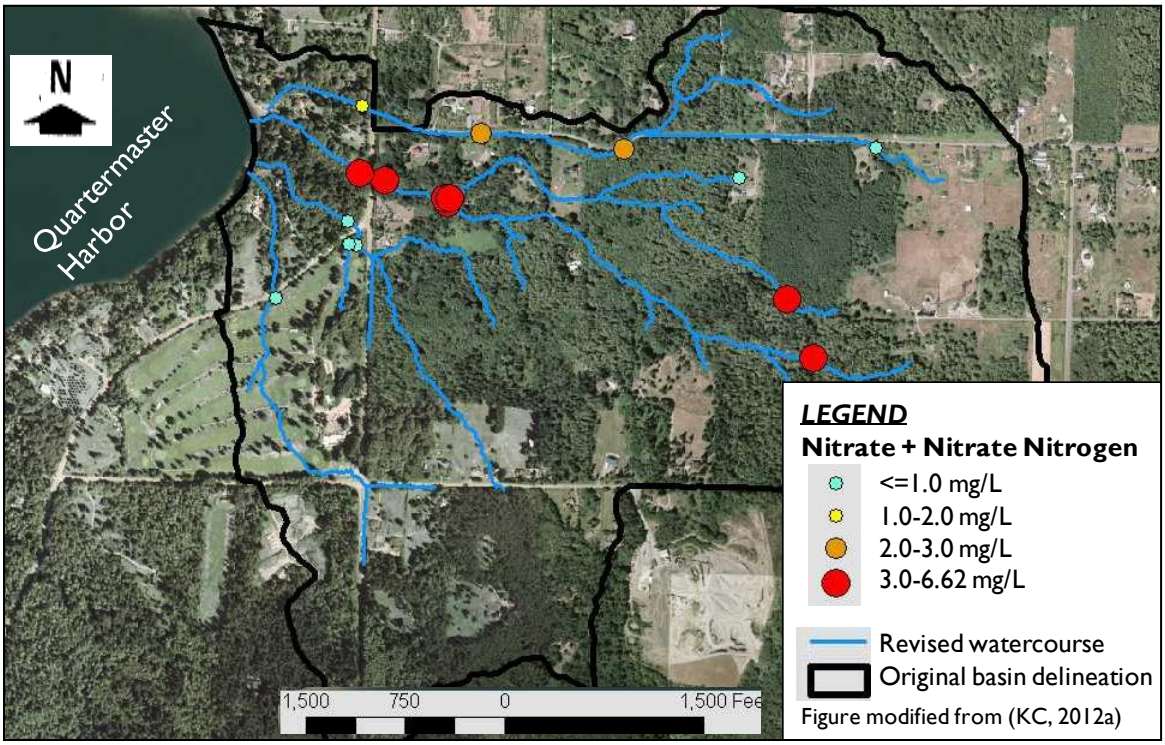


Note: Measurements for November 2006 through December 2010. Gray boxes define the median and lower and upper quartiles, while the whiskers denote the upper and lower 95th percentiles of the data for a particular month. The black circles identify the observed concentrations that are higher or lower than the 95th percentile. (KC, 2012d).

Although there were increases in nitrate in all streams during the winter months, the nitrate results from the sampling locations in Mileta Creek were reported as elevated and several times higher in concentration than in Judd and Fisher Creeks in the Quartermaster Harbor area during the winter months (Figure 42). Mileta Creek is a relatively small tributary to Quartermaster Harbor and it is the only tributary routinely monitored on the Maury portion of the Island. The Mileta Creek Nitrogen Source Tracking Study (part of the Quartermaster Harbor Nitrogen Management Study) was then conducted to identify locations on Mileta Creek where nitrate concentrations are elevated during winter months and to evaluate possible sources. The study was conducted in November 2010 at 16 locations in the drainage area representing Mileta Creek and associated smaller tributaries (Figure 45; KC, 2012a).

The source tracking study eliminated two potential sources (a golf course and some abandoned chicken barns) as the cause of elevated winter nitrate concentrations observed in Mileta Creek. The actual source remains unknown, but has been isolated to the reaches upstream of the main stem of Mileta Creek (KC, 2012a).

Figure 45. Locations of Nitrate + Nitrite Nitrogen Concentrations Measured during the Mileta Creek Nitrogen Source Tracking Study in 2010.

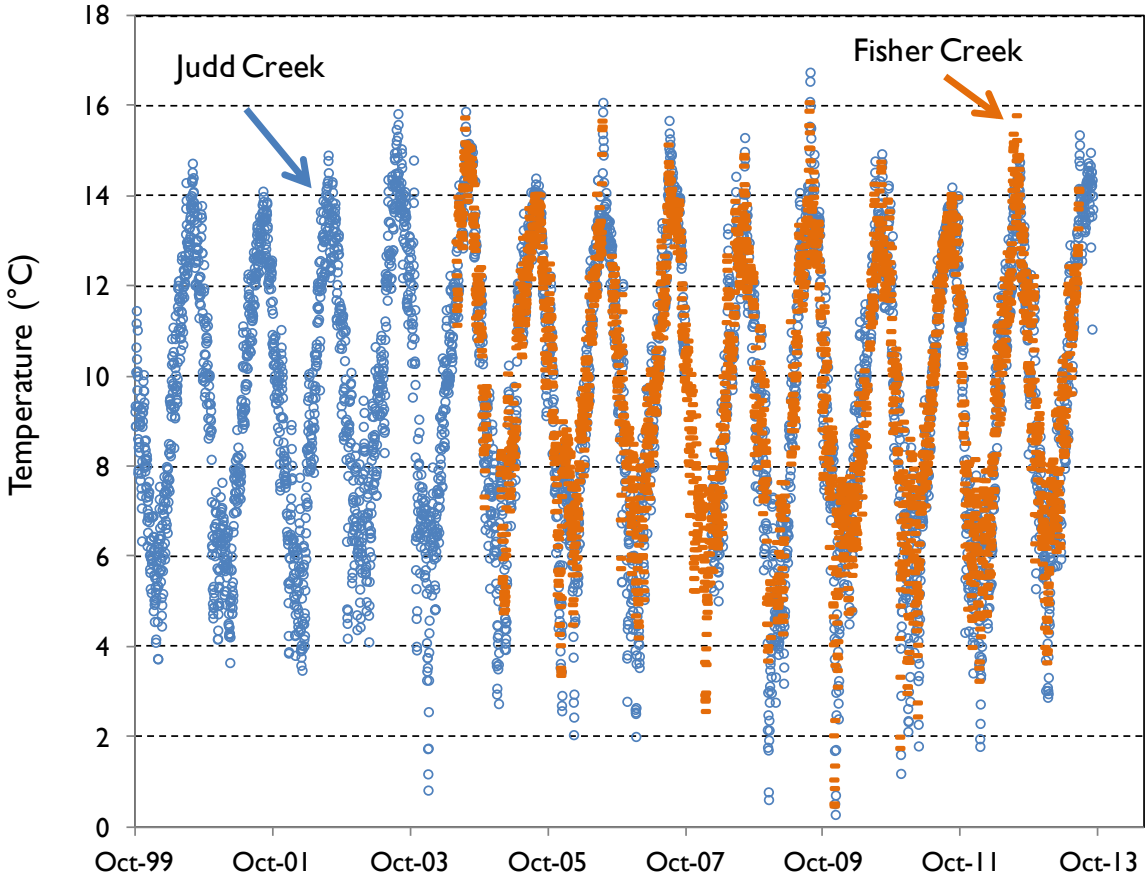


4.4.2.4 Stream Temperatures

Extensive development can substantially alter the extent of riparian shade that moderates daily peak stream temperatures. Development induced increases in high flows combined with the loss of riparian tree cover can also cause the stream to become wider and shallower, which also contributes to higher peak stream temperatures. Climate change, particularly predicted increases in air temperature are expected to result in warmer stream conditions without substantial investment in restoring riparian shade and summer flow conditions (KC, 2013d).

Stream temperatures for the Island creeks are typically below the state criteria of 16 degrees Centigrade (C) Seven-day Average of the Daily Maximum (7DADMax) for all locations (Figure 46). Being below the criteria indicates good water quality with respect to temperature. Judd and Fisher Creeks did have a few days over the criteria. For Judd Creek, a total of 23 days are over the 16 degrees C criteria for a13 water year period (WY2000-2011). These warmer periods occurred in mid/late July of 2003, 2004, 2006, 2007 and 2009. Fisher Creek has a total of five days for seven water years (2005-2011) all of which occurred in July/August of 2009. For Shinglemill (WY1999-2011) and Tahlequah (WY2005-2011) Creeks, stream temperature data are below the criteria for these periods, indicating good water quality with respect to stream temperature.

Figure 46. Seven-Day Average of the Daily Maximum Stream Temperatures for Judd and Fisher Creeks.



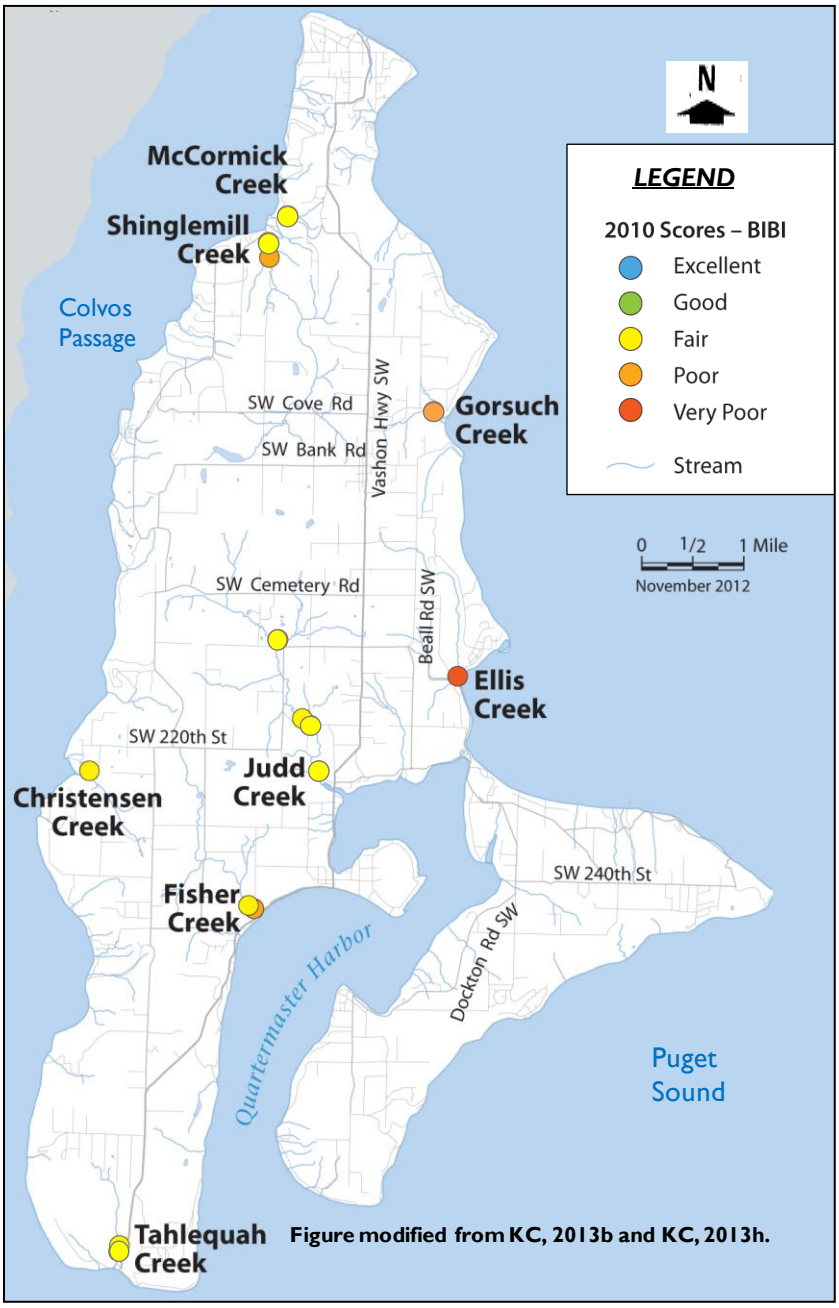
Note: The criteria for the Island creeks is 16°C.

4.4.2.5 Stream (or Benthic) Invertebrate Index

The Benthic Index of Biological Integrity (B-IBI) is another assessment of stream health that provides a "report card" for measuring the health of the benthic invertebrate community and for the stream ecosystem. The B-IBI scores are based on what stream invertebrate types (typically insect larva) and numbers are living in the stream. By using this scoring system, very different streams can be compared to each other and their ecological health ranked. On the Island, B-IBI data has been collected from a few stations since 2005 with increased monitoring at 14 locations representing eight different stream basins in 2010. The eight monitored stream basins are McCormick; Shinglemill, Christenson, Tahlequah, Fisher, Judd, Ellis, and Gorsuch (Figure 47). As a result of budget limitations, the sample collection program on the Island was reduced to six locations in 2011 and is currently included in the VMI Sustainability Indicators program as a Stream Benthic Macroinvertebrate Monitoring metric (KC, 2013b).

In 2012, King County updated the Puget Sound Stream Benthos database to reflect a more current best available science for calibrating the B-IBI scores (KC, 2013h). The scores shown in Table 13 and Figure 47 reflect the updated methodology. B-IBI Scores shown in Appendix A reflect the former calibration method.

Figure 47. Benthic Index of Biologic Integrity Sampling Locations on Vashon-Maury Island in 2010.



Most samples from the streams scored between "Very Poor" and "Fair" rankings. These rankings appear to be low for rural streams having low development. Six samples scored a "Good" ranking and were widely distributed across years and streams. One location, Ellis Creek, has maintained a "Very Poor" ranking for the period of 2005 through 2010. After further review, the sampling location appeared to be within the tidally affected zone of the creek. The tidal affect is likely to have a negative impact on the diversity and type of insect communities present in this portion of the creek. Assessments of other locations are ongoing to evaluate the possible cause/reason for their respective B-IBI scores. Overall, the Island's B-IBI scores vary with a few locations increasing overall and others decreasing over time. There are currently insufficient data to conduct statistical trend analysis.

Table 13. Benthic Index of Biologic Integrity Ranking and Scores for Selected the Island Creeks.

		Calendar Years							
Creek Name	**Site Identification**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Christenson	VashChris	34	36	36	32	38	36	30	36
Ellis	E1223	14	14	14	14	14	12	—	—
Fisher	65B	—	—	—	30	31.3	32	26.7	20.7
	E1227	26	38	36	38	36	20	—	—
Gorsuch	P847	24	20	24	18	26	20	—	—
Judd	28A	—	—	—	26	25.3	31.3	29.3	26
	VashJudd	30	30	34	—	32	28	36	38
	E1231/1232	28	30	32	42	22	28	—	—
	E2770	24	28	30	38	36	36	—	—
McCormick	E1219	36	32	32	34	26	28	—	—
Shinglemill	VashShing	28	32	24	30	14	20	16	24
	E1236	18	28	22	30	26	30	—	—
Tahlequah	65A	—	—	—	32.7	34.7	36	32.7	26
	E2887	28	36	40	36	36	28	—	—

Rank	*Score*
Excellent	*46-50*
Good	*38-45*
Fair	*28-37*
Poor	*18-27*
Very Poor	*10-17*

Modified from *http://pugetsoundstreambenthos.org*

Using Fore, Wisseman (2012)

4.4.3 Vashon-Maury Island's Groundwater Quality

Groundwater water quality impacts may occur naturally or as a result of human activity. Runoff, or water flowing over the land surface, may pick up pollutants from wildlife and soils. Wells having water levels close to the ground surface are at most risk. The groundwater and surface water provide all of the water used on the Island. The majority of the residents obtain their water from shallow water sources, which are more vulnerable to contamination (VMI GWMC, 1998a and KC, 2005c).

The USEPA posits the following as examples of impacts to groundwater quality (USEPA, 2013):

- Bacteria and other microorganisms in the soil.
- Underground rocks and soils may contain metals such as arsenic.
- Fertilizers used to promote growth on farms, private lawns and golf courses.
- Chemicals used to treat homes and lawns to reduce insect damage.
- Improper disposal of many common products in households and faulty septic systems can pollute ground water. Pollutants can include cleaning solvents, used motor oil, or paint thinners. Even soaps and detergents can harm drinking water.
- Heavy metals releases can occur by mining and construction into nearby ground water sources. Some older fruit orchards may contain high levels of arsenic, once used as a pesticide.

- Spills and improper disposal of harmful chemicals used in commercial businesses can threaten ground water supplies.
- Petroleum products and wastes stored in underground storage tanks and pipes may end up in the ground water.
- Older landfills or unmanaged dump sites may have a wide variety of pollutants that can seep into ground water.

Within this section, the following freshwater groundwater quality topics are discussed in more detail:

- Arsenic
- Chloride
- Nitrate
- Other parameters

4.4.3.1 Arsenic in Groundwater

Arsenic is a metal common in the groundwater in this region and is one of three parameters selected as an indicator metric for the VMI Sustainability Indicators program (KC, 2013b) due largely to its potential carcinogenic effects. Arsenic enters water supplies either from natural deposits in the earth or from industrial and/or agricultural pollution. Arsenic is a parameter of concern as identified by the WA DOH requirement to have all active sources monitored annually for arsenic and the GWP Committee's focus on environmental indicators (nitrate, arsenic and chloride). The USEPA drinking water standard for arsenic is a maximum contaminant level (MCL) of10 micrograms per liter (µg/L) (USEPA, 2009).

A county-wide study, entitled Ambient Groundwater Monitoring Study - 2001-2004 Results, was implemented by King County WLRD. This study reported that arsenic was reported as consistently having exceeded the MCL (KC, 2005a). King County has monitored 30 locations for arsenic since about 2001 which represents about 3 percent of the over 1,000 wells on the Island. WA DOH reported arsenic data from 71 public water sources which are 35 percent of the Island's 200 public water sources (KC, 2013b). Data from multiple sources including the Island water purveyors, the King County's Groundwater Protection Program, Public Health's Drinking Water Program, and WA DOH Office of Drinking Water, was used to evaluate an overall condition of arsenic concentrations (Figure 48).

Only arsenic exceeded the MCL for USEPA Drinking Water Standards during King County sampling events. Arsenic was found at higher concentrations above the MCL in samples from a few wells around the Island. These wells have deep water sources in older geologic units/aquifers that appear to have naturally occurring arsenic. The shallower Principal aquifers (younger geologic units) have little to no arsenic present in the samples of drinking water.

Eleven of the 95 locations sampled had arsenic levels above the MCL, indicating poor conditions (Figures 48 and 49; KC, 2013b). Twenty three locations had sample values between 5 to 10 µg/L. The remaining 61 locations had values below 5 µg/L (KC, 2013b). There was no apparent change in concentration at wells monitored on a regular basis, although this conclusion was not based on statistical trend testing (KC, 2013b).

Figure 48. Maximum Arsenic Concentrations (µg/L) in Groundwater Samples (1990 to 2010).

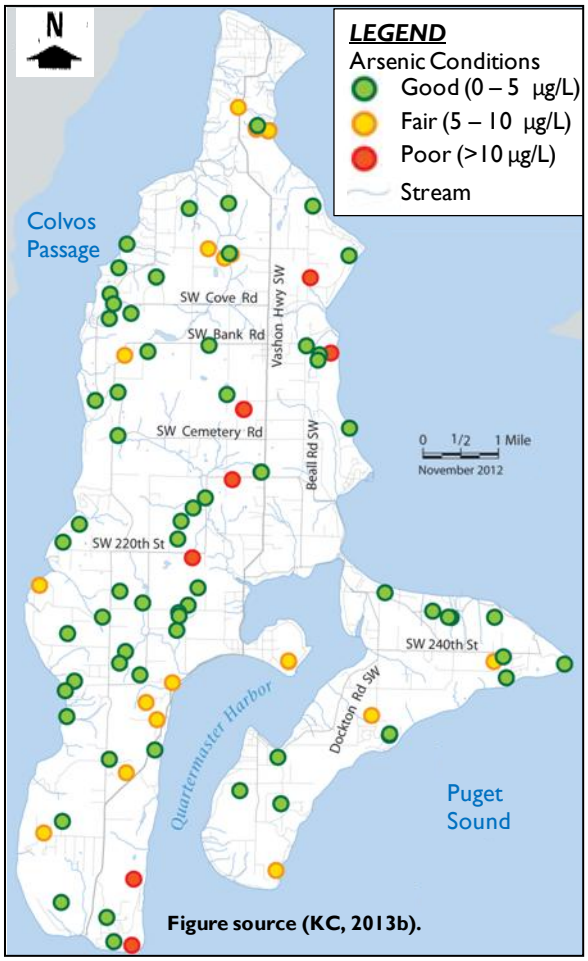
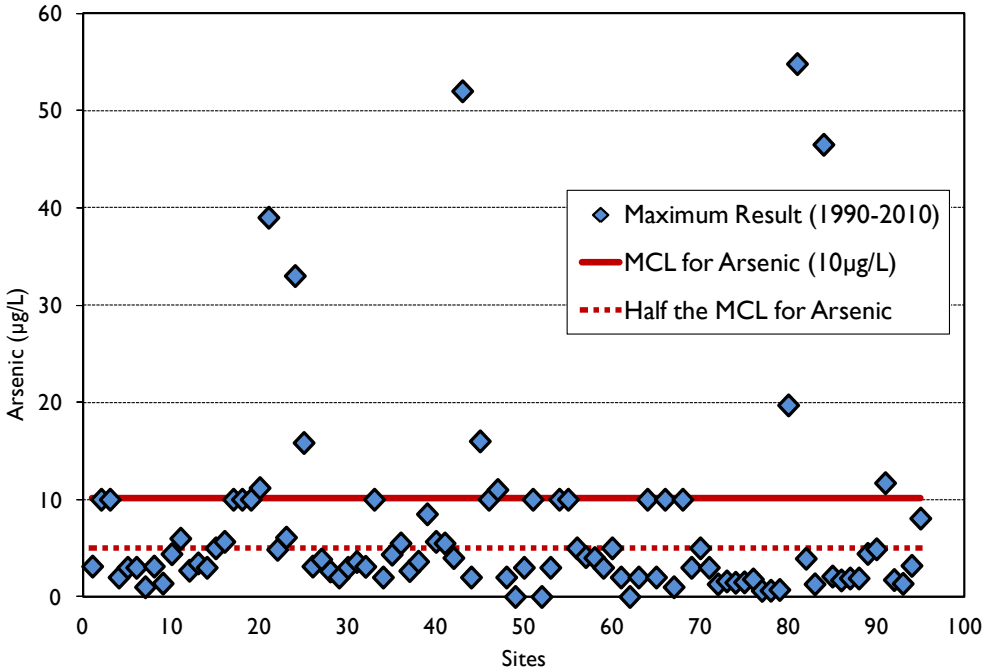


Figure 49. Maximum Arsenic Levels in Groundwater at Sampling Wells between 1990 and 2010.



The WRE conducted a special study of arsenic at selected monitoring wells by evaluating the arsenic speciation. Dissolved arsenic in groundwater is typically in two different states: (1) Arsenite As(III) – H3AsO3 or (2) Arsenate As(V) –H2AsO4 (KC, 2007). Fourteen wells were sampled for arsenic speciation (Table 14).

In eight wells sampled, the predominant form of arsenic found was arsenite, As(III). The remaining five wells were found to have mostly arsenate, As(V). Three of the 14 wells had arsenic concentrations over the MCL (10 µg/L) (KC, 2012e). For public water systems that may have had elevated arsenic concentrations in the system's source water, these public water systems treat the water in a variety of ways such that the water delivered to the user does not exceed the MCL standard for arsenic. All large public water systems test the system's water after treatment to ensure compliance at the point of delivery (KC, 2007).

Table 14. Arsenic Speciation Details at Groundwater Sampling Wells.

Well Name	Aquifer Zone	Arsenic (total) (µg/L)	Arsenite As(iii) (µg/L)	Arsenate As(v) (µg/L)	Percent Arsenite As(iii) (%)	Percent Arsenate As(v) (%)	Depth to bottom of well (feet below ground surface)	Bottom of well elevation (feet above MSL)	pH	Dissolved Oxygen (mg/L)
W-52	Zone 1 - Qva	0.67	0.01	0.67	1.30	99.60	80	190	6.87	7.01
W-21		1.66	0.92	0.74	55.50	44.60	133	166	7.90	2.17
W-56		1.85	1.66	0.19	89.70	10.10	139	146	7.49	0.12
W-57		1.89	0.09	1.80	4.80	95.20	160	60	7.81	1.24
W-58		1.67	0.12	1.55	7.30	92.80	180	80	7.60	2.21
W-68	Zone 2 - Qac OR Zone 2 - Qpf	1.24	0.12	1.12	9.30	90.30	132	119	7.73	8.46
W-02A		5.24	0.04	5.20	0.70	99.20	177	83	7.36	3.90
W-66		43.10	36.00	7.17	83.50	16.60	204	96	8.18	0.06
W-67	Zone 3 - QAc	1.41	0.26	1.15	18.20	81.60	160	-30	7.64	0.28
W-54	Zone 3 - QBc	5.69	3.95	1.74	69.40	30.60	185	-125	7.72	2.01
W-07	Zone 3 - QAc	11.80	11.70	0.40	99.20	0.80	297	-37	8.31	3.96
W-04	Zone 3 - QBc	20.10	17.50	2.66	87.10	13.20	305	-107	8.28	0.94
W-09A	Zone 3 - QAc	5.03	4.50	0.53	89.50	11.10	450	-39	7.60	0.77
W-12	Zone 3 - QBc	4.86	5.50	0.04	113.20	0.80	473	-363	8.19	1.13

Notes: Colors assigned to show range of values. Darker colors, higher values.

<2	*µg/L or %*	*<100*	*feet below ground surface*
<10	*µg/L or %*	*100-200*	*feet below ground surface*
>10	*µg/L or %*	*>200*	*feet below ground surface*

MSL = mean sea level

4.4.3.2 Chloride in Groundwater

Chloride in groundwater can affect potability and may act as a conservative tracer of human activities. Pumping wells in aquifers that are hydraulically connected to Puget Sound can cause salt water intrusion into the aquifer. Chloride is also concentrated in animal urine and concentrations of animals (human or

otherwise) have the potential to elevate the chloride levels in groundwater (KC, 2013b). The USEPA drinking water standard for chloride is 250 mg/L (USEPA, 2009).

The Carr Report reported that wells in the Principal aquifer had specific conductance levels (a surrogate for chloride levels) at 100 to150 micromhos per centimeter (µmhos/cm), whereas conductance in the Deep aquifer is about 300 µmhos/cm. The lowest chloride levels were found along the west side of Vashon Island with levels gradually increasing to the east and north. Isolated areas of higher chloride levels were also present in some wells along the margins of the Island at about 500 µmhos/cm. Chloride levels were also reported to have increased in some deep wells over the same time period.

King County has monitored 35 locations for chloride since about 2001 and representing about 4 percent of the over 1,000 wells on the Island. WA DOH reported chloride data from 55 public water sources which are 28 percent of the Island's 200 public water sources (KC, 2013b). Data from multiple sources including the Island water purveyors, the King County's Groundwater Protection Program, Public Health's Drinking Water Program, and WA DOH Office of Drinking Water, were used to evaluate an overall condition and trend of chloride concentrations.

Figure 50. Maximum Chloride Levels in Groundwater Wells (1990 to 2010).

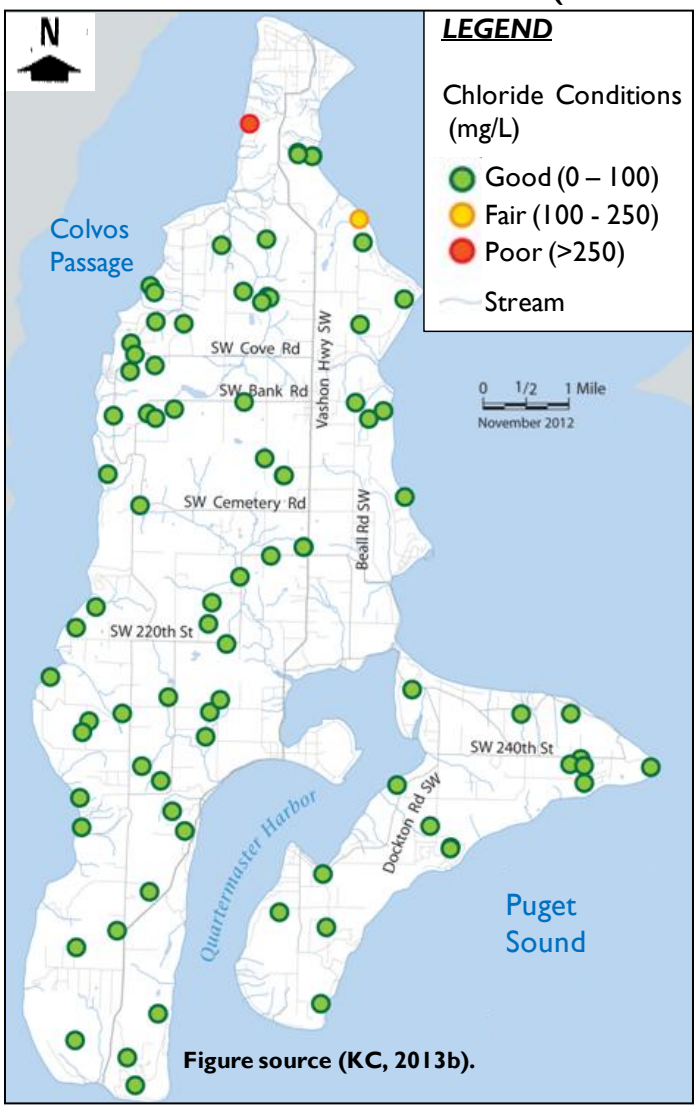
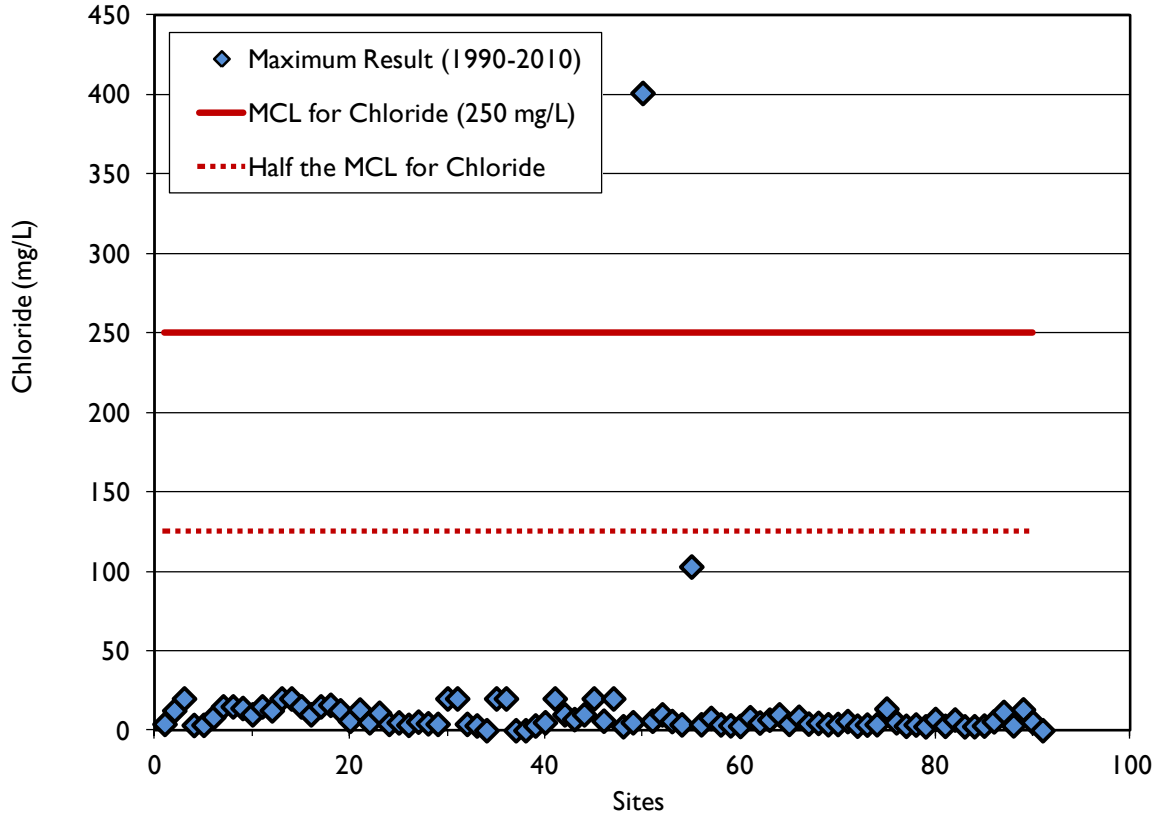


Figure source (KC, 2013b).

One of the 90 locations had results above the drinking water standard, indicating that most wells had good to fair water quality with respect to chloride (**Error! Reference source not found.** 50; KC, 013b). Results of the maximum chloride levels from the 90 wells (55 public water sources and 35 long-term monitoring wells) from 1990 to 2010 are presented in Figure 50 and Figure 51) The two wells categorized as Poor and Fair with respect to chloride levels are in close proximity to the shoreline and most susceptible to seawater intrusion. There was no apparent change in concentration at wells monitored on a regular basis, although this conclusion was not based on statistical trend testing (KC, 2013b).

Figure 51. Maximum Chloride Levels in Groundwater at Sampling Wells between 1990 and 2010.



4.4.3.3 Nitrate in Groundwater

Nitrate can track changes in water quality caused by human activities. Leaching from septic systems, fertilizer or manure and nitrogen fixing vegetation such as alder trees are some examples of how human activities can influence the measured concentration of nitrate in groundwater. High levels of nitrate in drinking water, undergoing a conversion to nitrite in the body, is the common cause of methaemoglobinemia (blue baby syndrome) in bottle-fed infants (WHO, 2013). Nitrate is a parameter of concern as identified by the WRE, WA DOH requirement to have all active sources monitored annually for nitrate and the GWP Committee's focus on nitrate, arsenic and chloride as indicators (KC, 2013b). The USEPA drinking water standard for nitrate is 10 milligrams per liter (mg/L) (USEPA, 2009).

The Carr Report indicated that relatively high nitrate as nitrogen levels were found in the northern and eastern areas of Vashon Island and the northern and southern ends of Maury Island. King County has been monitoring nitrate concentrations annually on Vashon-Maury Island since 2001 and has monitored 35 locations for nitrate which represents about 4 percent of the over 1000 wells on the Island. In addition, Public Health and WA DOH require annual nitrate testing of public water system sources. The overall condition and trend of nitrate concentrations was evaluated using data from multiple sources including the Island water purveyors, the King County's Groundwater Protection Program, Public Health's Drinking Water Program, and WA DOH Office of Drinking Water (KC, 2013b).

Maximum nitrate as nitrogen levels collected at 190 wells (155 public water systems and 35 long-term monitoring locations) from 1990 to 2010 indicate that most (186) wells had good conditions (below 5 mg/L) with respect to nitrate with a few (4) sampling locations having fair conditions (between 5 and 10 mg/L) (Figure 52). None were above the USEPA drinking water standard for nitrate (10 mg/L).

Figure 52. Maximum Nitrate Levels in Groundwater Wells (1990 - 2010).

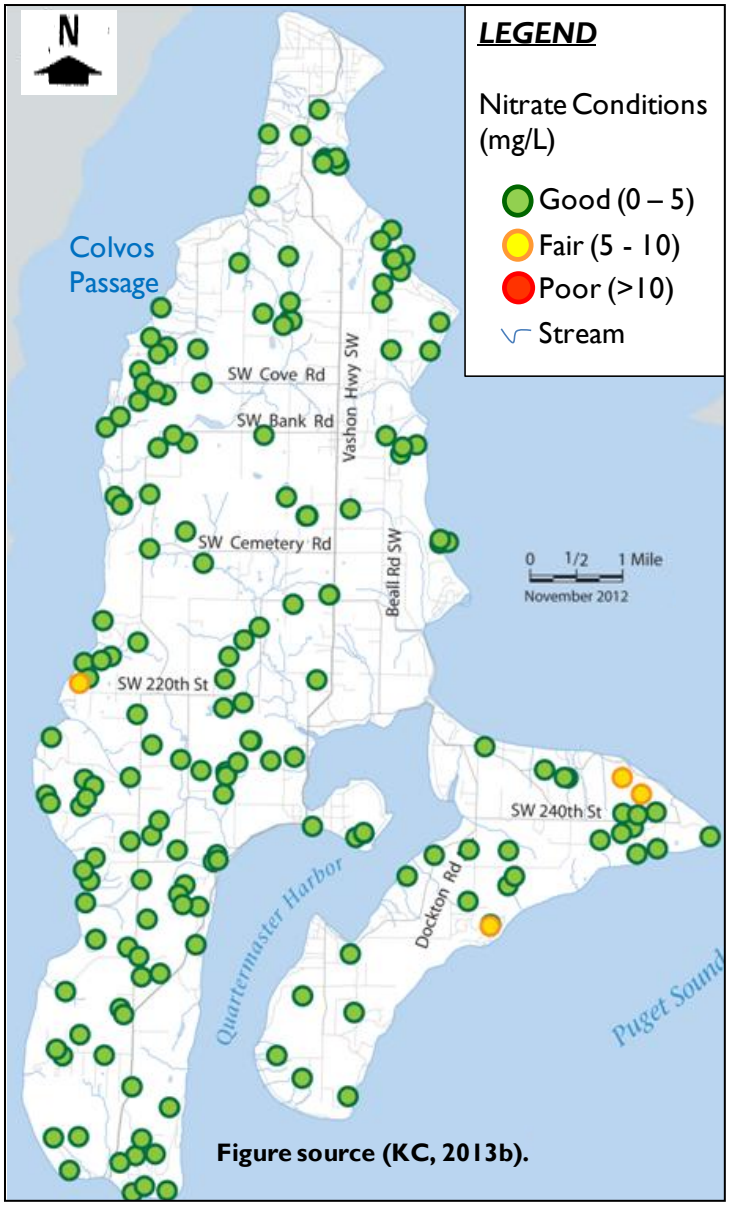
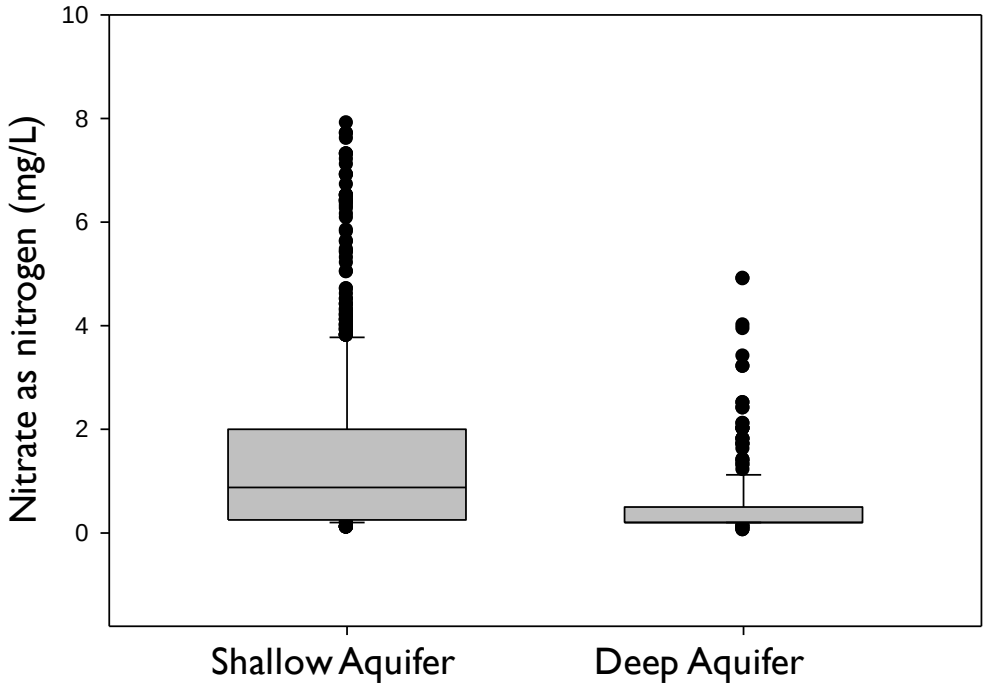


Figure source (KC, 2013b).

Nitrate levels in shallow Principal and Deep aquifer wells supplying public water systems for the time period between 1990 and 2013 are shown in Figure 53. Median nitrate levels in Principal aquifer public water system wells were typically higher than those in public water system wells completed in deeper aquifers. The average for nitrate in shallow Principal aquifer public water system wells was almost three times more than the average for public water systems supplied from Deep aquifers. These results support that the susceptibility to impacts is greater in shallow groundwater systems than in the deeper groundwater systems.

Figure 53. Nitrate from Shallow and Deep Aquifer Public Water System Groundwater Samples (1990 – 2013).



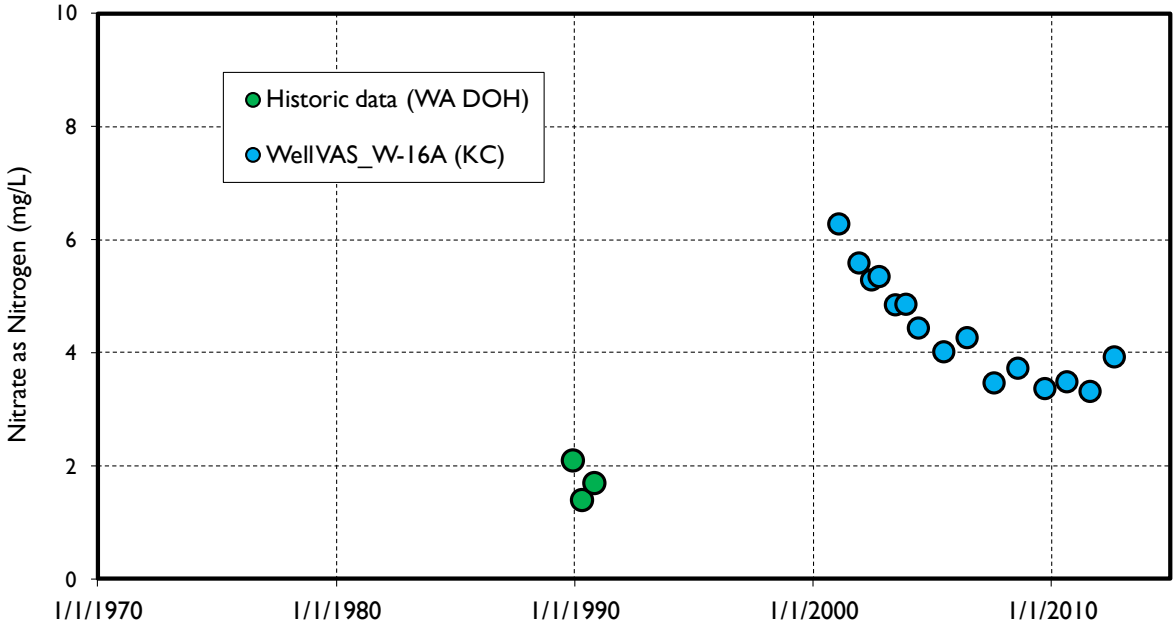
Note: The box plot graph was created by first ranking and plotting values smallest to largest as points without regard to which PWS or date each value came from. The ends of the box define the 25th and 75th percentile. The line in the box is the median and the whisker bars indicate the 10th and 90th percentile.

To illustrate the susceptibility of the shallow groundwater on the Island, Figure 53 and the following are three examples of negative nitrate impacts to groundwater from human and land use activities on groundwater water quality.

Example 1- Fertilizer usage of manure in the vicinity of a shallow well

Excessive use of raw (uncomposted) manure occurred in garden areas in the vicinity of a shallow (67 feet deep) well in the Vashon advance deposits (Qva). Reportedly high concentrations (3 - 7 mg/L) in the 2000s were compared to historical data (1 - 3 mg/L). After educating the homeowner about improved practices near wells the homeowner stopped the activity after sampling restarted in 2001. Since then, nitrate concentration have been decreasing from greater than 6 mg/L down to 3.3 mg/L in 2011 (Figure 54).

Figure 54. Response of Nitrate in Groundwater in a Shallow Well (W-16A) to Excessive Manure Application.

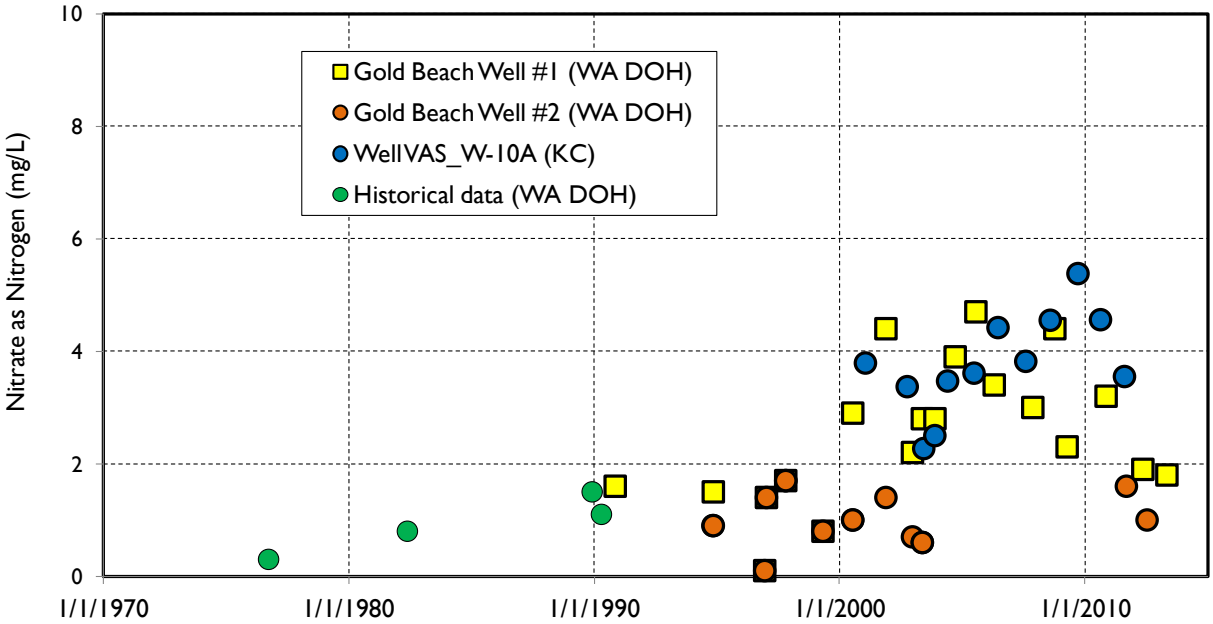


Note: Data sources in parenthesis of legends.

Example 2 - An onsite septic system drain field stopped functioning

An onsite septic system (OSS) failure occurred in the Gold Beach area when a drain field stopped functioning. Elevated nitrate concentrations relative to historic (about 3 to 1 mg/L) were detected in groundwater from the Vashon advance deposits (Qva). After the OSS was fixed and or replaced in 2005 nitrate concentrations remained near 4 mg/L until 2012 when the most recent reported value was 1.9 mg/L. (Figure 55).

Figure 55. Response of Nitrate in Groundwater in Shallow Wells to Septic System Failure.



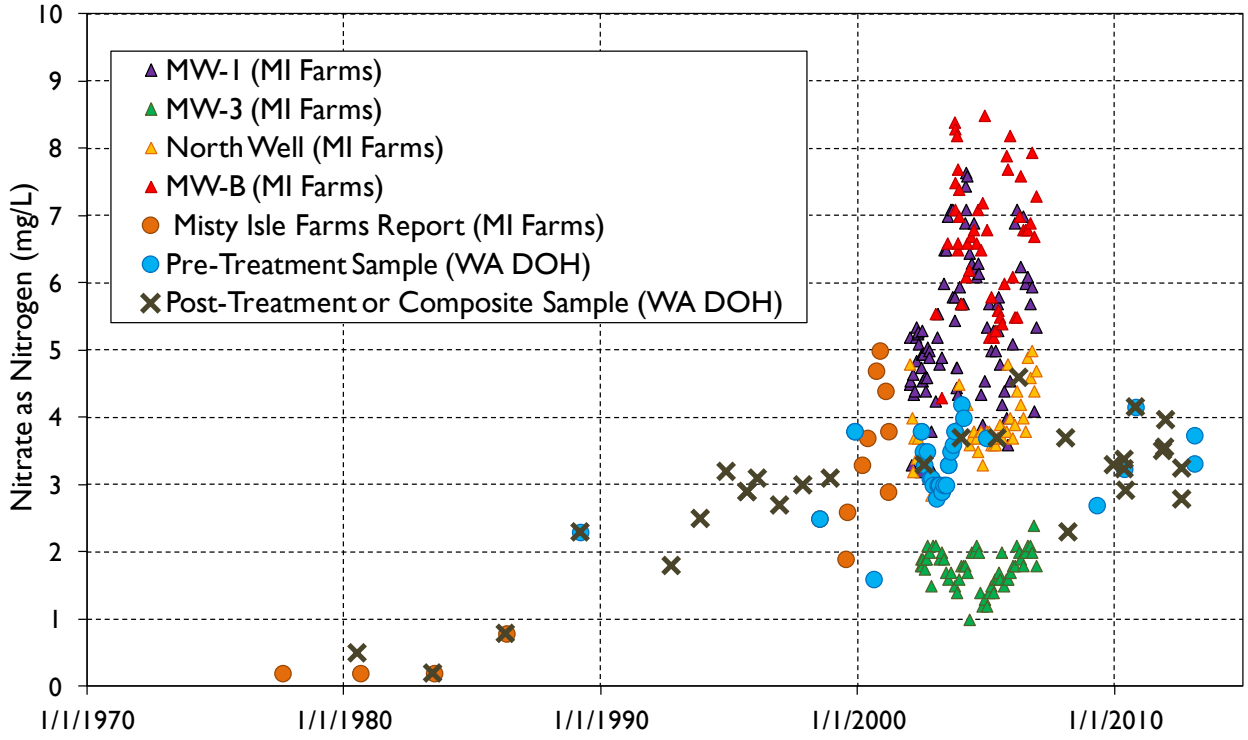
Note: Data sources in parenthesis of legends.

Example 3 - Land clearing and livestock management practices

A 2007 report prepared by CDM (CDM, 2007) documented a review of five years of livestock and farm management activities, groundwater, and soil nitrate concentrations on Misty Isle Farms and suggested that prior to 1990s land clearing and tree removal practices on several parcels on the Island contributed to elevated nitrate concentrations in local groundwater and in the nearby Burton public water system. An analysis of the stable isotopes for nitrogen and oxygen was conducted to determine the predominant source of nitrate at the levels found in the shallow groundwater and compared with that of the fertilizer used by Misty Isle Farms. CDM applied the results to plots by published reports (Panno et al., 2001; Kendall and McDonnell, 1998) and stated that the nitrate in groundwater is associated with naturally present soil organic nitrogen and that the two forms of nitrogen in the fertilizer are within the isotopic ranges for mineralized and synthetic fertilizer. These results also support that the nitrate present in groundwater is not from the fertilizer sampled by CDM (CDM, 2007). However, high concentrations of livestock and excessive pasture fertilization cannot be ruled out as a contributor to the elevated groundwater nitrate concentrations. In more recent years, the Misty Isle Farms no longer stocks cattle.

Reported nitrate concentrations for pre-treatment, post-treatment and composite samples are shown in Figure 56 for several wells at Misty Isle Farms and the nearby Burton public water system. These wells receive water from the Vashon recessional deposits (Qvr) and typically range between 3 and 5 mg/L. None of the groundwater well samples showed nitrate levels above the USEPA drinking water standard for nitrate (10 mg/L).

Figure 56. Response of Nitrate in Groundwater in Shallow Wells to Upland Land Clearing and Agricultural Activities.



Note: Pre-treatment, composite and post-treatment sample designation set by public water system. For example, treatment may include chlorination.

4.4.3.4 Other Groundwater Parameters

The Carr Report presented iron levels up to 16.6 mg/L and that the Deep aquifer generally showed slightly higher iron levels than the Principal aquifer. Relatively high nitrate as nitrogen levels were found as well as having gradually increasing concentrations.

As in the Carr Report, the GWMP reported that fecal coliforms were detected above regulatory levels in some wells; some wells showing increasing trends. Iron and manganese were detected in several wells, as had been in the Carr Report. Levels of mercury and zinc were reported as having a possible increase from 1989 to 1990 data (VMI GWMC, 1998b).

The Ambient Study reported metal parameters such as arsenic, iron and manganese most frequently exceeding the MCL (KC, 2005a). These metals are all common in the groundwater in this region. Sodium levels were elevated in some samples, up to about 58.6 mg/L (KC, 2005a). Iron results were stable, as expected due to being naturally derived from dissolution of geologic material.

Groundwater samples collected in 2001 and 2002 for the Ambient Study (KC, 2005a) had no detections of volatile and synthetic organic compounds. In addition, samples tested during the WRE study (KC, 2006 and 2006b) in 2005 and 2007, had no detections for selected organic compounds, such as pesticides, herbicides and endocrine disrupting compounds.

5.0. SUMMARY OF SCIENTIFIC FINDINGS

Climate and water resources conditions on Vashon-Maury Island were presented in Sections 3.0 (Island-wide Climate Conditions) and 4.0 (Island-wide Water Resources). The following subjects were discussed in detail and the highlights of the findings are summarized in this section:

- Climatic conditions
    - Air Temperature
    - Precipitation
    - Stream Flows
- Hydrologic Water Budget
- Island-Wide Water Resources
    - Water Usage
    - Groundwater Quantity
    - Marine Water Quality
    - Freshwater Surface Water Quality
    - Groundwater Quality

5.1 Findings for Climatic Conditions

The climatic conditions for Vashon-Maury Island are summarized as:

- The mean monthly average air temperature for the first half of the last century ranged between 38.7 to 62.9 degrees Fahrenheit. There has not been much work done to develop a more current understanding of air temperatures and the spatial pattern of temperatures across the Island.
- Average annual temperatures rose in the Pacific Northwest on average about 1.5 degrees Fahrenheit in the last century. A warming temperature trend is occurring in this region and is present in local and regional data. The long-term rise in global surface land and seawater temperatures and ocean heat anomalies appears to have stalled in the recent decade. This change in the warming rates since the 1990's is also present in local data. The pause is likely due to several factors.
- Precipitation data collection has been sporadic and sparsely located across the Island. A spatial pattern is present with precipitation rates increasing from the east to the west, between about 35 and 50 inches per year.
- Recent studies show that since 2005, the Island receives between -4 to 15 percent of the precipitation observed at the Seattle-Tacoma International Airport and that this difference occurs only about 4.5 miles southwest of the airport.
- The creeks in the 75 drainage basins on the Island originate from a series of upland seeps and springs and flow down steep and incised ravines into the Puget Sound and Colvos Passage. Seasonally varying spring discharges emerge in valleys or on hillsides, making spring discharge difficult to quantify.
- Peak flows occur during winter months in response to increased precipitation and uniform low flows occur through the summer months from late May through August. Annual stream flow data indicated responses were as expected with increases in discharge during wet years and decreases during drier periods.

- There does not appear to be a systematic trend in stream flow flashiness. Additional data is required to determine if any changes are occurring beyond the variability induced by interannual variation in precipitation.
- The 7-day moving average low-flows were maintained or improved from 2001 to 2010. The Baseflow Index (ratio of baseflow or groundwater inflow to total stream flow) for Shinglemill, Judd, Fisher and Tahlequah Creeks had values of 70, 69, 79 and 74 percent, respectively. Groundwater contribution to the total annual stream flow was between 69 to 79 percent. Relative baseflow contributions during summer were higher by about 17 to 25 percent. Results suggest that reductions in groundwater discharge to streams during this period, as a result of increased groundwater withdrawals for example, could impact the instream flows needed to sustain fish and maintain water quality.

5.2 Findings of the Island-wide Hydrologic Budget

Highlights of the island-wide hydrologic budgets completed for Vashon-Maury Island are:

- Analytical methods to assess the island-wide water budget concluded that the Island had only precipitation as the source of recharge and that outflow from the hydrologic system included evapotranspiration, stream flow, and discharge to Puget Sound through the groundwater.
- Four water budgets (Carr Report, GWMP, and WRE Phases I and II) were proposed since the 1980s, each using more data, detailed analysis and both analytical and computer modeling techniques. Estimates varied based on differing assumptions of inflows and outflows, using more available data and improved modeling techniques.
- The more recent and more accurate computer models (WRE-Phase I and II) were able to replicate previous observations and incorporate recharge due to irrigation and septic flow and discharges due to wells and springs. In addition, more recent monitoring data and geologic mapping efforts were used to better refine the assumptions and showed that many features that had been observed previously about the Island's groundwater could be replicated.
- The estimated amount of discharge to Puget Sound is larger in the WRE-Phase I model than in previous studies. The WRE-Phase I and II models yielded similar groundwater inflow (recharge) estimates that were less than that of the GWMP while being twice the amount calculated by the initial work in the Carr Report.
- A difference between the results of the WRE Phase I and II modeling and GWMP budgets is the amount of water creating a freshwater lens beneath the Island. Resulting budgets of the GWMP and the Carr Report estimated the majority of the groundwater inflow going to the streams and not infiltrating into deeper zones before discharging to Puget Sound. The WRE-Phase I and II models reported greater volumes of water infiltrating (Puget Sound outflow) into these deeper zones.

5.3 Findings for Island-Wide Water Resources

5.3.1 Water Usage

Highlights of island-wide water usage on Vashon-Maury Island are:

- The population of the Island is growing steadily, historically at about two percent per year, and will likely continue to grow at a rate of 100 people per year, currently 1percent of the population.

- Estimated average water use has been measured at between about 100 and 120 gallons per person per day. Municipal and domestic water demand on the Island was calculated to be approximately 375 million gallons per year in 2010. Out of the at least 1,000 permit exempt wells on the Island, eight self-metered wells showed a range of usage patterns.
- Group A public water system water providers have a range of average daily usage of 100 to 200 gallons per day per connection. Increased usage occurs during May through October with 60 to 75 percent of the total annual use during this period, similar to some exempt well users.
- Water use peaks in the summer by a factor of 1.8 based on an island-wide average, whereas, the summer water use peaking factors ranged from 1.2 to 2 at selected Group A public water systems.
- The 10 year (2001-2010) average of total island-wide water consumption is 515 million gallons per year. The annual total consumption ranged from 496 to 535 million gallons per year during this period. The overall per capita water consumption during the time period 2001 through 2010 was 83 gallons per day. Typically, consumption increased during periods with lower rainfall totals and decreased during periods with higher rainfall totals.
- Modeling results yielded noticeable drawdown in the vicinity of some Group A public water system wells, though generally very small numerically, and it also showed slightly higher shallow groundwater levels in many other areas of the Island, where increased septic system returns were modeled.

5.3.2 Groundwater Quantity

The groundwater quantity findings for Vashon-Maury Island can be summarized as:

- The three main groundwater bearing geologic units of interest on the Island are Zone 1 - shallow Vashon recessional outwash deposits (Qvr) and Principal/ Main Vashon advance outwash deposits (Qva) ; Zone 2 – Deep 1 Pre Fraser coarse grained deposits (Qpfc); and Zone 3 - Deep 2 Olympia coarse grained deposits (Qpoc) and deeper units.
- Groundwater contour maps indicate that slopes are steeper on the west than on the east and steeper in the spring than the fall. Vertical groundwater gradients (and thus flows) were downward throughout the Island, although somewhat less along the coastline, where deep groundwater must flow up towards Puget Sound discharge locations.
- Water table contour maps of the Qva/Principal aquifer have not changed substantially over time (1982-2010) illustrating that the Qva/Principal aquifer unit responds consistently over time and the patterns are consistent with our basic understanding of unconfined groundwater hydrology, where water level contours reflect overlying topography.
- Measured groundwater levels in wells showed responses to seasonal and long-term recharge variations, tidal and barometric influences and pumping. The largest responses were observed in the recharge areas of the Principal/Main Qva aquifer.
- Water level fluctuations showed different patterns in the Principal/Main Qva aquifer from those in the deeper aquifers. These fluctuations tended to correlate with rainfall (with lags of time up to four months), with seasonal highs in during summer months and lows during fall months. Some wells showed little to no seasonal influence, indicating the wells were not screened in units directly recharged by rainfall.
- The GWMP reported that long-term (1989-1992) trends indicated that the hydrostratigraphic zones were generally stable and had not been affected by ground water withdrawals. Overall, data from 2001 through 2012 indicated that levels were generally stable with no significant declines.

5.3.3 Marine Water Quality

The marine water quality conditions for the Vashon-Maury Island can be summarized as:

- Dissolved oxygen levels below the Washington State water quality standard (extraordinary criteria of 7 mg/L) have been observed in Quartermaster Harbor over the last seven years (KC, 2010c and 2013f).
- For data collected since 2006, all marine water sampled met state water quality criteria for fecal coliform bacteria. All samples were well below the WA standard for fecal coliform bacteria in marine waters. In addition, there also were no exceedances of the criteria of marine water quality samples collected by WA DOH along Quartermaster Harbor for fecal coliform analysis.

5.3.4 Freshwater Surface Water Quality

The freshwater surface water quality conditions for Vashon-Maury Island can be summarized as:

- The water quality index for each location varied year to year. Overall for 2007 through 2011, WQI scores varied from one year to the next and data are currently not sufficient (of adequate length) to conduct statistical trend analysis. However, conditions appear to be improving.
- Fecal coliform bacteria levels in Judd, Fisher, Mileta and Christensen Creeks from 2007 through 2011 had exceedances of the state extraordinary criteria for at least one year. Exceedances of the criteria occurred repeatedly for the time period on Fisher and Judd Creeks. Cattle and horse manure, septic systems, and farming practices are all potential sources of fecal coliform bacteria to these streams.
- The Nearshore Freshwater Inflows Assessment reported that the range in nitrate concentrations measured in October 2010 in small freshwater inflows to Quartermaster Harbor were larger than that observed since 2006 in monthly grab samples collected in three of the largest tributaries to the harbor (Fisher, Judd and Mileta Creeks).
- Routine monthly samples taken from Fisher, Judd and Mileta Creek showed a seasonal trend of lower concentrations of nitrate plus nitrite nitrogen in summer months (May through October) and higher concentrations of nitrate plus nitrite nitrogen in winter months (November through April). This pattern is typical of rural lowland streams, highest concentrations occur during winter when plant uptake is lowest and rain flushes nitrates from surface soils into nearby streams and lowest concentrations occur during summer when plant uptake is greatest and soils are general dry and accumulating nitrate.
- Although there were increases in nitrate in all streams during the winter months, the nitrate results from the sampling locations in Mileta Creek were reported as elevated and several times higher in concentration than in Judd and Fisher Creeks in the Quartermaster Harbor area during the winter months. The Mileta Creek Nitrogen Source Tracking Study (part of the Quartermaster Harbor Nitrogen Management Study) was then conducted to identify locations on Mileta Creek where nitrate concentrations are elevated during winter months and to evaluate possible sources. The actual source for elevated winter nitrate concentrations observed in Mileta Creek remains unknown, but has been isolated to the reaches upstream of the main stem of Mileta Creek.
- With the exception of a few temperature exceedances on Judd and Fisher Creeks, overall stream temperatures for the Island creeks are typically below the state criteria of 16 degrees C, indicating good water quality with respect to stream temperature during water years 2000 to about 2011. As expected, the exceedances on Judd and Fisher Creeks occurred during the months of July or August.
- Overall, the Benthic Index of Biological Integrity scores of samples from the streams scored between “Very Poor” and “Fair” rankings. These rankings appear to be low for rural streams

having low development. Overall, the Island's B-IBI scores vary with a few locations increasing overall and others decreasing improving and a few locations worsening in recent years over time. There are currently insufficient data to conduct statistical trend analysis..

5.3.5 Groundwater Quality

The groundwater water quality conditions for Vashon-Maury Island can be summarized as:

- Arsenic is common in the deeper groundwater in this region and was measured consistently at higher than the USEPA drinking water standard, indicating poor conditions in wells drawing water from Deep aquifers.
- There was no apparent change in arsenic at wells monitored on a regular basis and there were not enough samples collected to evaluate if a trend exists.
- In the past 15 years, only one well had chloride above the drinking water standard, indicating that most wells had good to fair water quality with respect to chloride. There was no apparent change in concentration at wells monitored on a regular basis.
- Recent studies showed maximum nitrate as nitrogen levels collected at 190 wells from 1990 to 2010 indicate that most wells had good conditions (below 5 mg/L) with respect to nitrate with a few sampling locations having fair conditions (between 5 and 10 mg/L). None were above the USEPA drinking water standard for nitrate (10 mg/L).
- Since 1990, median nitrate levels in shallow public water system wells were typically higher than those in deep public water system wells. The average for nitrate in shallow public water system wells was almost three times more than the average for deep public water systems. These results support that the susceptibility to impacts is greater in shallow groundwater systems than in the deeper groundwater systems.
- With the exception of arsenic, no samples exceeded the MCL for USEPA Drinking Water Standards during King County sampling events including selected organics (pesticides/fertilizers/Endocrine Disrupting Compounds). The WA DOH dataset of public water systems on the Island show similar results as the King County monitoring data with no reported exceedances.

6.0. MOVING FORWARD

6.1 Future Sustainability Monitoring

In 2010, the GWP Committee generated a list of eleven sustainability indicators for the Island's water resources (Table 3). These indicators, divided into four main groups of water quality, water quantity, ecosystem health and water use/management measure progress in approaching or meeting the target goals set to preserve the water resources quality and quantity on the Island. Ongoing monitoring and project work on the Island is aligned with these sustainability indicators. More detail about the VMI Sustainability Indicators is presented in Appendix A.

6.2 Key Challenges

6.2.1 Continuing to Engage and Educate Islanders

A variety of activities such as engaging stakeholders, managing volunteer well owners and salmon watchers, and holding public meetings have occurred on the Island. Various efforts to educate residents on groundwater, surface water, wastewater treatment and conservation were also completed. A recent example is the *Protecting our Liquid Assets* (KC, 2012b) series of informational pages developed to encourage Islanders to work together to educate Islanders about their water resources. The *Protecting our Liquid Assets* series of mailers sent to residents was a collaboration of the GWP Committee and KC WLRD. The series subjects were:

- Island Stories
- Watch Out for that Ditch!
- What's Your Watershed Address?
- Going Under Ground - Geology of "The Rock"
- Setting the Water Table
- Sipping Sand Slurpies
- Experienced Water, Where Does It All GO?
- Doing Our Business

While these efforts have been useful for educational purposes and involved many residents, the number of volunteers for the Salmon Watchers and the Groundwater Well Self-Monitoring Program have declined. As a result, the Salmon Watcher program is no longer active on the Island and only four private well owners remain in the Groundwater Well Self-Monitoring Program.

An education and outreach program was included as part of the Quartermaster Harbor Nitrogen Management Study. The Phase 1 Findings were presented at a public meeting on Vashon Island on October 6, 2010 to introduce to the Islanders the background, tasks, and outputs of the study (KC, 2010c). An update was given to the residents on October 12, 2011 using technical posters and presentations on all aspects of the study, including water monitoring, special studies, model development, and policy recommendations (KC, 2011a). In addition, a project overview and technical presentations were given at the Salish Sea Ecosystem Conference in Vancouver, British Columbia, Canada on October 25-27, 2011(KC, 2011b).

Quarterly updates on all aspects of water resources work are given to the GWP Committee during the year and will continue, as requested by the GWP Committee, in the future.

6.2.2 Implications of the Earth Justice Challenge

Earth Justice is a non-profit public interest law firm dedicated to protecting natural resources and wildlife, and to defending the right of people to a healthy environment. The organization currently has presented a legal challenge concerning permit exempt well management in closed stream basins (Washington Administrative Code (WAC) 173-507-030; WAC 173-508-040; WAC 173-509-040; WAC 173-510-040; and WAC 173-515-040) and relationship to salmon listings under the Endangered Species Act. The result of this challenge may have implications for quantifying water availability and for tracking water rights more closely.

6.2.3 Adapting to a Changing Climate

Ecology reports that:

> "Many of these challenges created by changing climate and environmental conditions are similar to those we have been wrestling with for decades – water supply and quality, ecosystem health, air quality, and shoreline and habitat protection and restoration. But the rate and severity of the changes we are likely to witness in the coming years will be unlike anything Washingtonians have ever experienced." (WA Ecology, 2012)

Statewide trends of worsening conditions are evident and projections follow a similar trend. In addition, Washington State reports that "climate-influenced conditions and events such as temperatures, sea levels, and storms can no longer be expected to remain within their historical ranges, and these trends are likely to continue well beyond the end of the 21st century." (WA Ecology, 2012).

Human health and economic impacts are also showing worsening trends. Some examples of these impacts are increased coastal and storm damage costs, increased energy-related costs (reduced hydropower production and increased demand), increased wildfire costs, increased health-related costs, and costs associated with reduced water availability. The state is "already experiencing challenging economic conditions. The risks of not taking action to address climate change impacts now will only compound these economic challenges." (WA Ecology, 2012).

The Watershed Plan (KC, 2005c) posed climate change could impact the Island could be in several ways, such as seawater intrusion, increased water usage, and/or reduced recharge. Recharge to the groundwater system of the Island will be affected by changes to precipitation patterns. Less total annual rainfall would lead to less groundwater recharge while increased rainfall may lead to more surface water discharge than groundwater recharge Any assessment of future water needs for the Island needs to include some consideration of potential climate change impacts and leave a margin of safety to help address the uncertainty that remains (KC, 2005c).

Continuing to collect or analyze available scientific indicator data related to these impacts will assist in planning for adaptations to these changing environmental conditions and to reduce the impact of worsening conditions.

6.2.4 Uncertainties Affecting Water Resources

6.2.4.1 Water Availability

In 1998, the Vashon-Maury Island Ground Water Management Plan noted that during the 1990s several public water systems were experiencing shortages (Water District 19, Heights, Burton and Westside) (VMI GWMC, 1998a). Since that time, Dockton Water has been able to keep a constant average daily consumption (Dockton Water, 2013). Heights Water members have greatly reduced their consumption through conservation methods (Heights Water, 2011 and 2013).

In the 2007 Water System Plan for Vashon-Maury Island's Water District 19 (the "District"), the District reported that although the water rights are sufficient to meet the current and anticipated needs of the District, the District does not have enough source capacity to meet WA DOH recommendations during summertime peak usage (District 19, 2008). Water supply is limited by the inability of the existing sources of supply to keep up with historic peak water system demands. This is the limiting system factor prohibiting the addition of new connections to the system (District 19, 2008). Alternatives were identified and recommended for further analysis. In 2012, ending a 15 year moratorium on new water shares was lifted, in part due to conservation by customers and from a new well. The District released 30 shares to those on its lengthy wait list (VMI Beachcomber, 2011 and 2013).

All of these purveyors are working to reduce their system loss (Burton Water, 2013; Dockton Water, 2013; Heights Water, 2011 and 2013; and District 19, 2013) and at the present time these purveyors are considered adequate for existing uses and adding new service connections up to the number of approved service connections (WA DOH, 2013a). These water purveyors have been able to meet demand through increased conservation methods and improving infrastructure issues causing leakage. Changing climate conditions and aging infrastructure may have an impact on the water availability in the future.

6.2.4.2 How Much Water Are We Really Using?

There is no current requirement for recording the volume of water pumped at exempt wells, nor for enforcing allowable amounts. As a result, it is unknown exactly how much water is consumed and used on the Island from these types of wells. A few exempt well owners on the Island have volunteered and self-monitored their well usage. This has assisted in collecting some information on this subject. Due to the wide range of uses of the wells (irrigation, seasonal or year-round garden use, grass watering, farm animal water, etc), conditions of the pumps, and the large number of exempt wells on the Island, it is unlikely that these values reasonably represent actual island-wide usage.

A more extensive and longer program would refine the knowledge island-wide and improve the understanding of the Island's wider use of exempt wells.

6.2.4.3 Institutional Funding for Water Resources Monitoring

The ending of capital funding in recent years for the County's Groundwater Protection Program reduced the budget by about $200,000 per year for monitoring and outreach activities on the Island. The reduction of financial resources may have had a negative impact on volunteerism. As a result, water

resources data that may help with understanding the impacts on where water is available and where water is impacted are not being collected.

In mid-2012, it was reported to the GWP Committee that the King County code authorizing the GWP Committee will sunset at the end of December 2013 if reauthorization legislation is not enacted by the King County Council. King County advised that the GWP Committee could pursue one of three broad legislative options: (1) dissolve the GWP Committee at the end of 2013, (2) seek an extension with the same "groundwater protection" mandate currently outlined in King County Code, or (3) seek an extension with a new "watershed and groundwater protection" mandate (KC, 2012f).

King County offered a recommendation that the GWP Committee seek a legislative extension with a new "watershed and groundwater protection" mandate to reflect their broader interest for water resources, beyond groundwater. The basis for this recommendation was cited as the preparation of the Vashon-Maury Island Watershed Plan in 2005, the multiple watershed management recommendations submitted by the GWP Committee for consideration in the 2012 King County Comprehensive Plan amendment and the GWP Committee's strong interest in watershed sustainability (KC, 2012f).

The funding for future water resource efforts on the Island is uncertain. At the time of this report, the GWP Committee has decided to request authorization from the King County Council and has voted to continue as a "groundwater protection" committee but still want to do a variety of watershed activities. The GWP Committee also wants additional services to be done, likely requiring more funding. The focus would be on VMI Sustainability Monitoring, described in Appendix A.

7.0. REFERENCES

Adelsman, Hedia. 2013. Initial Recommendations for Local Source Reduction. WA Department of Ecology. Presentation.

Baker, D.B., P. Richards, T.L. Loftus, and J.W. Kramer (Baker et al). 2004. A New Flashiness Index: Characteristics and Applications to Midwestern Rivers and Streams. Journal of the American Water Resources Association 40(2):503 – 522. http://chagrin.epa.state.oh.us/dsw/nps/NPSMP/docs/JAWRA_03095_Baker.pdf

Berryman & Henigar, Inc. and Udaloy Environmental Associates (B&H/UES). 2004. Vashon Island Landfill Hydrogeologic Report Update. Prepared for King County Department of Natural Resources, Solid Waste Division. December.

Booth, D. B. 1991. Geologic Map of Vashon and Maury Islands, King County, Washington. U.S. Geological Survey Miscellaneous Field Studies Map: 2161. http://pubs.usgs.gov/mf/1991/2161/report.pdf

Burton Water Company (Burton Water). 2013. Water Use Efficiency Annual Performance Report – 2012. June 14. https://fortress.wa.gov/doh/eh/portal/odw/si/SingleSystemViews/RptViewSingleSys.aspx?rptName=wue&orgnum=09800&RptYear=2012

Carr/Associates (Carr/Assoc.). 1983. Vashon/Maury Island Water Resources Study. Submitted to the King County Department of Planning and Community Development. December 1, 1983.

CDM. 2007. Conditional Permit Summary Report (2002 – 2006); Development Services of America, Misty Isle Farms, Vashon Island, Washington. March 6, 2007.

DeGasperi, Curtis L., Hans B. Berge, Kelly R. Whiting, Jeff J. Burkey, Jan L. Cassin, and Robert R. Fuerstenberg (DeGasperi et al). 2009. Linking Hydrologic Alteration to Biological Impairment in Urbanizing Streams of the Puget Lowland, Washington, USA. Journal of the American Water Resources Association (JAWRA) 45(2):512-533. DOI: 10.1111/j.1752-1688.2009.00306.x http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.2009.00306.x/pdf

Dockton Water Association (Dockton Water). 2013. Water Use Efficiency Report – 2012. July 26. https://fortress.wa.gov/doh/eh/portal/odw/si/SingleSystemViews/RptViewSingleSys.aspx?rptName=wue&orgnum=19550&RptYear=2012

The Economist. 2013a. Apocalypse perhaps a little later: Climate change may be happening more slowly than scientists thought. But the world still needs to deal with it. Print Edition. March 30. http://www.economist.com/news/leaders/21574490-climate-change-may-be-happening-more-slowly-scientists-thought-world-still-needs

The Economist. 2013b. A sensitive matter: The climate may be heating up less in response to greenhouse-gas emissions than was once thought. But that does not mean the problem is going away. Print Edition. March 30. http://www.economist.com/news/leaders/21574490-climate-change-may-be-happening-more-slowly-scientists-thought-world-still-needs

Garling, M.E., D. Molenaar, et al (Garling et al). 1965. Water Resources and Geology of the Kitsap Peninsula and Certain Adjacent Islands. Washington Division of Water Resources, Water Supply Bulletin No. 18. With contributions by the US Geological Survey. http://www.ecy.wa.gov/programs/eap/wsb/wsb_Hydrologic-Systems.html

Guemas, Virginia, F. J. Doblas-Reyes, I. Andreu-Burillo and M. Asif (Guemas et al). 2013. Retrospective prediction of the global warming slowdown in the past decade. Nature Climate Change. Volume 3. Pages 649–653. April 07. http://www.nature.com/nclimate/journal/v3/n7/full/nclimate1863.html

Hallock, D. 2009. River and Stream Water Quality Monitoring Report, Water Year 2008. Washington State Department of Ecology Freshwater Monitoring Unit, Environmental Assessment Program. Publication No. 09-03-041. August. https://fortress.wa.gov/ecy/publications/summarypages/0903041.html

Heights Water. 2011. Water Use Efficiency Program. May 24. http://www.heightswater.org/

Heights Water. 2013. Water Use Efficiency Annual Performance Report – 2012. May 21. https://fortress.wa.gov/doh/eh/portal/odw/si/SingleSystemViews/RptViewSingleSys.aspx?rptName=wue&orgnum=32300&RptYear=2012

Kendall, C and J.J. McDonnell. 1998. Isotope Tracers in Catchment Hydrology. Elsevier Science B.V. pp. 519-576.

King County (KC). 2003. King County Groundwater Program – 2002 Annual Report. April 1.

King County (KC). 2004a. Vashon-Maury Island Water Resources Evaluation Work Plan. Prepared by King County Department of Natural Resources and Parks, Water and Land Resources Division, Seattle, Washington. http://your.kingcounty.gov/dnrp/library/archive-documents/wlr/wq/vashon-island/pdf/Vashon-Maury-Island-plan.pdf

King County (KC). 2004b. Vashon-Maury Island Rapid Rural Reconnaissance Report. Prepared by King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://www.kingcounty.gov/environment/watersheds/central-puget-sound/vashon-maury-island/recon-report.aspx

King County (KC). 2005a. Ambient Groundwater Monitoring -- 2001-2004 Results. Prepared by Anchor Environmental and King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://www.kingcounty.gov/environment/waterandland/groundwater/maps-reports/ambient-monitoring01-04.aspx

King County (KC). 2005b. Vashon-Maury Island Phase I Groundwater Model – A Part of the Vashon-Maury Island Water Resources Evaluation. Prepared by the King County Department of Natural Resources and Parks, Water and Land Resources Division. http://your.kingcounty.gov/dnrp/library/2005/kcr1895.pdf

King County (KC). 2005c. Vashon-Maury Island Watershed Plan. Prepared by King County Department of Natural Resources and Parks, Water and Land Resources Division. June 6. http://www.kingcounty.gov/environment/watersheds/central-puget-sound/vashon-maury-island/watershed-plan.aspx

King County (KC). 2006. Vashon-Maury Island 2005 Water Resources Data Report. Prepared by Eric W. Ferguson, King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://your.kingcounty.gov/dnrp/library/2006/kcr2106_2005.pdf

King County (KC). 2007. Vashon-Maury Island 2006 Water Resources Data Report. Prepared by Eric W. Ferguson, King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://your.kingcounty.gov/dnrp/library/2007/kcr2106_2006.pdf

King County (KC). 2008a. Areas Susceptible to Groundwater Contamination in King County. Prepared and maintained by the King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, WA. http://www5.kingcounty.gov/sdc/Metadata.aspx?Layer=asgwc

King County (KC). 2008b. Vashon-Maury Island 2007 Water Resources Data Report. Prepared by Eric W. Ferguson, King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://your.kingcounty.gov/dnrp/library/2008/kcr2106_2007.pdf

King County (KC). 2009a. Vashon-Maury Island 2008 Water Resources Data Report. Prepared by Eric W. Ferguson, King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://your.kingcounty.gov/dnrp/library/2009/kcr2106_2008.pdf

King County (KC). 2009b. Vashon-Maury Island Hydrologic Modeling – Technical Report. Prepared by DHI Water & Environment for King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/vashon-island/WRE-Phase2-modeling-report.aspx

King County (KC). 2010a. Initial Assessment of Nutrient Loading to Quartermaster Harbor. Prepared by Curtis DeGasperi, King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://your.kingcounty.gov/dnrp/library/2010/kcr2119.pdf

King County (KC). 2010b. Vashon-Maury Island 2009 Water Resources Data Report. Prepared by Eric W. Ferguson, King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/vashon-island/WRE-data-report.aspx

King County (KC). 2010c. Quartermaster Harbor Nitrogen Management Study Public Workshop. Prepared by King County Department of Natural Resources and Parks, Water and Land Resources Division in cooperation with University of Washington Tacoma and Washington State Department of Ecology. Public Presentation at Vashon Island High School. October 6. http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/central-puget-sound/vashon-maury-island/QMH_VashonHighSchool_101006.pdf and http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/central-puget-sound/vashon-maury-island/QMH_VHS_UWT_20101006.pdf

King County (KC). 2011a. Quartermaster Harbor Nitrogen Loading Study: Phase One Findings. Prepared by King County Department of Natural Resources and Parks, Water and Land Resources Division in cooperation with University of Washington Tacoma and Washington State Department of Ecology. Public Presentation at Vashon Island High School. October 12. http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/central-puget-sound/vashon-maury-island/QMH_VashonHighSchool_101006.pdf and http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/central-puget-sound/vashon-maury-island/QMH_VHS_UWT_20101006.pdf

King County (KC). 2011b. Quartermaster Harbor Nitrogen Management Study: Project Overview and Preliminary Nitrogen Loading Estimates to the Harbor. Prepared by King County Department of Natural Resources and Parks, Water and Land Resources Division in cooperation with University of Washington Tacoma and Washington State Department of Ecology. Public Presentation at Salish Sea Ecosystem Conference, Vancouver, BC, Canada. October 25. http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/central-puget-sound/vashon-maury-island/QMH_Salish-Sea-2011.pdf

King County (KC). 2012a. Mileta Creek Nitrogen Source Tracking Study. Prepared by Curtis DeGasperi and Eric Ferguson, King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://your.kingcounty.gov/dnrp/library/2012/kcr2309.pdf

King County (KC). 2012b. Protecting Our Liquid Assets: Water Resource Information for Vashon-Maury Island. Includes "Island Stories", "Watch Out for that Ditch!!", "What's Your Watershed Address?", "Going Under Ground - Geology of "The Rock"", "Setting the Water Table", "Sipping Sand Slurpies", "Experienced Water, Where Does It Go?", and "Doing Our Business". http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/liquid-assets.aspx

King County (KC). 2012c. Quartermaster Harbor Benthic Flux Study. Prepared by Curtis DeGasperi, King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://your.kingcounty.gov/dnrp/library/2012/kcr2320.pdf

King County (KC). 2012d. Quartermaster Harbor Nearshore Freshwater Inflows Assessment. Prepared by Curtis DeGasperi and Eric Ferguson, King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. http://your.kingcounty.gov/dnrp/library/2012/kcr2319.pdf

King County (KC). 2012e. Vashon-Maury Island Water Resources Assessment Report *(not published)*. Prepared by Eric Ferguson, King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington.

King County (KC). 2012f. Vashon-Maury Island Groundwater Protection Committee Meeting Notes, July 25, 2012. Prepared by King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington.

King County (KC). 2013a. Assessing Our Liquid Assets: A Report Card to the Community http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/Assess-assets.aspx

King County (KC). 2013b. Sustainability Indicators. http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/Assess-assets.aspx

King County (KC). 2013c. King County Groundwater Well Data Website Database. http://green.kingcounty.gov/groundwater/default.aspx

King County (KC). 2013d. KingStat Environmental Indicators. King County Department of Natural Resources and Parks. Seattle, Washington. http://your.kingcounty.gov/dnrp/measures/indicators/

King County (KC). 2013e. Quartermaster Harbor Nitrogen Management Study. King County Department of Natural Resources and Parks. Seattle, Washington. http://www.kingcounty.gov/environment/watersheds/central-puget-sound/vashon-maury-island/quartermaster-nitrogen-study.aspx

King County. (KC). 2013f. Quartermaster Harbor Marine Water Quality Report. Prepared by Kimberle Stark (Water and Land Resources Division), Cheryl Greengrove, and Nick Schlafer (University of Washington-Tacoma). Submitted by King County Department of Natural Resources and Parks, Seattle, Washington. DRAFT. August

King County (KC). 2013h. Puget Sound Stream Benthos website. http://pugetsoundstreambenthos.org

Lyman, John. M., S. A. Good, V. V. Gouretski, M. Ishii, G. C. Johnson, M. D. Palmer, D. M. Smith and J. K. Willis (Lyman et al) 2010. Robust warming of the global upper ocean. Nature. Volume 465, Pages 334–337. May 20. http://www.nature.com/nature/journal/v465/n7296/full/nature09043.html

May, Christopher W. 2003. Stream-Riparian Ecosystems In the Puget Sound Lowland Eco-Region; A Review of Best Available Science. Watershed Ecology LLC. 76 p. http://www.kitsapgov.com/dcd/lu_env/cao/bas/fw/Riparian_BAS_Rpt_May.pdf

Mote, P. W. 2003. Trends in Temperature and Precipitation in the Pacific Northwest During the Twentieth Century. Northwest Science V. ol.77. No. 4. https://research.wsulibs.wsu.edu:8443/xmlui/bitstream/handle/2376/1032/v77%20p271%20Mote.PDF?sequence=1

Naiman, R.J. and H. Decamps. (Naiman et al).1997. The ecology of interfaces: riparian zones. Annual Review of Ecological Systems 28:621-658. http://micssrv22.epfl.ch/images/6/64/RECORD_Naiman_1997.pdf

Pacific Groundwater Group (PGG). 2000. Maury Island Gravel Mine Hydrogeologic Impact Assessment. Prepared for Washington State Department of Ecology. WA Ecology Publication 00-10-026. May. https://fortress.wa.gov/ecy/publications/publications/0010026.pdf

Pacific Marine Environmental Laboratory (PMEL). 2013. Upper Ocean Heat Content Anomaly. http://oceans.pmel.noaa.gov/index.html

Panno, S.V., K.C. Hackley, H.H. Hwang, W.R. Kelley (Panno et al). 2001. Determination of the Sources of Nitrate Contamination in Karst Springs using Isotopic and Chemical Indicators. Chemical Geology 179 (2001) 113-128.

Public Health-Seattle-King County (Public Health). 2007. King County On-Site Septic System Management Plan. Prepared by Community Environmental Health Program. July. http://www.kingcounty.gov/healthservices/MRA/~/media/health/publichealth/documents/mra/KingCountyOSSManagementPlanJuly2007.ashx

Public Health-Seattle-King County (Public Health). 2013. Vashon-Maury Island Marine Recovery Area. http://www.kingcounty.gov/healthservices/MRA/~/media/health/publichealth/documents/mra/KingCountyOSSManagementPlanJuly2007.ashx

Puget Sound Restoration Fund (PSRF). 2013. Nutrient Mitigation Study. http://www.restorationfund.org/projects/mitigation

Rosenthal, Y., B. K. Linsley, and D. W. Oppo (Rosenthal et al). 2013. Pacific Ocean Heat Content During the Past 10,000 Years. Science. Vol. 342 no 6158 pp. 617-621. November. http://www.sciencemag.org/content/342/6158/617

Sinclair, K.A., and Pitz, C.F.. 1999. Estimated base-flow characteristics of selected Washington rivers and streams: Washington State Department of Ecology Water Supply Bulletin No. 60 (pub. No. 99-327), 24 p. https://fortress.wa.gov/ecy/publications/summarypages/99327.html

Stockton, L and E. Ferguson. 2009. Managing Water Resources for Sustainability on Vashon-Maury Island, King County, Washington. Sea Grant Law and Policy Journal, Vol. 2, No. 1. June. http://nsglc.olemiss.edu/SGLPJ/Vol2No1/Stockton.pdf

Tung, K. K. and J. Zhou. 2013. Using Data to Attribute Episodes of Warming and Cooling in Instrumental Records. Proceedings of National Academy of Sciences. Edition 110. http://depts.washington.edu/amath/research/articles/Tung/journals/Tung_and_Zhou_2013_PNAS.pdf

United Kingdom National Weather Service. (UK NWS). 2013. The recent pause in global warming (2): What are the potential causes? Prepared by the MetOffice Hadley Centre. July. http://www.metoffice.gov.uk/media/pdf/q/0/Paper2_recent_pause_in_global_warming.PDF

U. S. Census Bureau. 2013a. King County, Washington QuickLinks- Website. http://quickfacts.census.gov/qfd/states/53/53033.html

U. S. Census Bureau. 2013b. Vashon CDP, Washington QuickLinks- Website. http://quickfacts.census.gov/qfd/states/53/5374305.html

U.S. Environmental Protection Agency (USEPA). 2009. National Primary Drinking Water Regulations. EPA 816-F-09-004 May. http://water.epa.gov/drink/contaminants/upload/mcl-2.pdf http://water.epa.gov/drink/contaminants/index.cfm

U.S. Environmental Protection Agency (USEPA). 2013. *Human Health.* http://water.epa.gov/drink/info/well/health.cfm

Vashon-Maury Island Beachcomber (VMI Beachcomber). 2011. "Water District 19 to issue new shares, ending its 15-year moratorium". December 21. http://www.vashonbeachcomber.com/news/135957073.html

Vashon-Maury Island Beachcomber (VMI Beachcomber). 2013. "Candidates Address Vashon's Water Future". October 29. http://www.vashonbeachcomber.com/news/228823061.html

Vashon-Maury Island Groundwater Management Committee (VMI GWMC). 1998a. Vashon-Maury Island Ground Water Management Plan-Management Strategies. Prepared by King County of Natural Resources and Parks and Seattle-King County Department of Public Health. Final, submitted December 1998. http://www.kingcounty.gov/environment/waterandland/groundwater/maps-reports/management-plans.aspx

Vashon-Maury Island Groundwater Management Committee (VMI GWMC). 1998b. Vashon-Maury Island Ground Water Management Plan-Supplement 1 – Area Characterization. Prepared by King County of Natural Resources and Parks and Seattle-King County Department of Public Health. Final, submitted December 1998. http://www.kingcounty.gov/environment/waterandland/groundwater/maps-reports/management-plans.aspx

Washington State (WA). Department of Ecology; Washington Administrative Code 173 (WAC 173) http://apps.leg.wa.gov/WAC/default.aspx?cite=173

Washington State (WA). Department of Health; Washington Administrative Code 246 (WAC 246) http://apps.leg.wa.gov/WAC/default.aspx?cite=246

Washington State (WA). Growth management - planning by selected counties and cities (Growth Management Act (GMA)); Revised Code of Washington (RCW Section 36.70A). http://apps.leg.wa.gov/rcw/default.aspx?cite=36.70A

Washington State (WA). Groundwater Management Areas and Programs; Washington Administrative Code 173-100 (WAC 173-100) http://apps.leg.wa.gov/WAC/default.aspx?cite=173-100

Washington State (WA). Guidelines to classify agriculture, forest, and mineral lands and critical areas; Revised Code of Washington (RCW Section 36.70A.050). http://apps.leg.wa.gov/rcw/default.aspx?cite=36.70A.050

Washington State (WA). Instream resources protection program—Cedar-Sammamish basin, water resource inventory area (WRIA) 8; Washington Administrative Code 173-508 (WAC 173-508). http://apps.leg.wa.gov/wac/default.aspx?cite=173-508

Washington State (WA). Instream resources protection program—Green-Duwamish River basin, water resource inventory area (WRIA) 9; Washington Administrative Code 173-509 (WAC 173-509). http://apps.leg.wa.gov/wac/default.aspx?cite=173-509

Washington State (WA). Instream resources protection program—Kitsap water resource inventory area (WRIA) 15; Washington Administrative Code 173-515 (WAC 173-515). http://apps.leg.wa.gov/wac/default.aspx?cite=173-515

Washington State (WA). Instream resources protection program—Puyallup River basin, water resource inventory area (WRIA) 10; Washington Administrative Code 173-510 (WAC 173-510). http://apps.leg.wa.gov/wac/default.aspx?cite=173-510

Washington State (WA). Instream resources protection program—Snohomish River basin, water resource inventory area (WRIA) 7; Washington Administrative Code 173-507 (WAC 173-507). http://apps.leg.wa.gov/wac/default.aspx?cite=173-507

Washington State (WA). On-site Sewage Disposal Systems – Marine Recovery Areas; Revised Code of Washington (RCW Section 70.118A). http://apps.leg.wa.gov/rcw/default.aspx?cite=70.118A

Washington State (WA). Permit to Withdraw; Revised Code of Washington (RCW Section 90.44.050). http://apps.leg.wa.gov/rcw/default.aspx?cite=90.44.050 http://www.ecy.wa.gov/programs/wr/comp_enforce/gwpe.html

Washington State (WA). Regulation of Public Groundwaters; Revised Code of Washington (RCW Section 90.44). http://apps.leg.wa.gov/rcw/default.aspx?cite=90.44

Washington State (WA). Water Code; Revised Code of Washington (RCW Section 90.03). http://apps.leg.wa.gov/rcw/default.aspx?cite=90.03

Waterloo Hydrogeologic Inc. (WHI). 2004. Visual MODFLOW v.4.0 User's Manual/ Waterloo, Ontario.

Washington State Department of Ecology (WA Ecology). Water quality standards for surface waters of the state of Washington; Washington Administrative Code 173-201A (WAC 173-201A). http://apps.leg.wa.gov/wac/default.aspx?cite=173-201A

Washington State Department of Ecology (WA Ecology). 2002. Evaluating Standards for Protecting Aquatic Life in Washington's Surface Water Quality Standards: Temperature Criteria. *Discussion Paper and Literature Summary*. Prepared by Water Quality Program/Watershed Management Section. Publication Number 00-10-070. December. https://fortress.wa.gov/ecy/publications/publications/0010070.pdf

Washington State Department of Ecology (WA Ecology). 2012. Preparing for the Impacts of Climate Change: Washington State's Integrated Climate Response Strategy. Pub. No. 12-01-004. April. https://fortress.wa.gov/ecy/publications/publications/1201004b.pdf

Washington State Department of Health. (WA DOH). 2013a. Sentry Internet Database. https://fortress.wa.gov/doh/eh/portal/odw/si/Intro.aspx

Washington State Department of Health. (WA DOH). 2013b. Recreational Shellfish Program. http://www.doh.wa.gov/AboutUs/ProgramsandServices/EnvironmentalPublicHealth/ShellfishandWaterProtection/ShellfishProgram/RecreationalShellfish.aspx

Washington State Department of Natural Resources. (WA DNR). 2013. Maury Island Aquatic Reserve. http://www.ecy.wa.gov/puget_sound/dissolved_oxygen_study.html

Water District 19 (District 19). 2008. 2007 Water System Plan. http://water19.com/plan.html

Water District 19 (District 19). 2012. Water Use Efficiency Annual Performance Report – 2011. April 16. https://fortress.wa.gov/doh/eh/portal/odw/si/SingleSystemViews/RptViewSingleSys.aspx?rptName=wue&orgnum=38900&RptYear=2011

Western Regional Climate Center (WRCC). 2013. Air Temperature Summary Tables and Graphs for NCDC COOP Station Number 458802 (Vashon Island). http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wa8802

World Health Organization (WHO). 2013. Water-related diseases: Methaemoglobinemia. http://www.who.int/water_sanitation_health/diseases/methaemoglob/en/

APPENDIX A - SUSTAINABILITY INDICATORS

Vashon Maury Island Groundwater Protection Committee document about Sustainability Definition, Indicators and Measures

July 28, 2010

DEFINITION

Sustainable: Water use rate at which neither water quality nor available quantity is perceptibly diminished. (Appendix A - p.10 Vashon-Maury Island Watershed Plan, June 6, 2005)

BACKGROUND

While surface water currently meets a portion of Vashon-Maury Island water demand, ground water is expected to be the primary source of the Island's future water supply. Island streams, although tapped by a number of Islanders, are too small to sustain much use. Springs and shallow wells are used by many Island water systems. All of these – streams, springs, and aquifer – form an integral hydrologic system. We want to insure that our groundwater resource can provide a safe, sustainable source of supply to meet forecasted population growth and future water demand, while protecting the island's hydrologic system. (p. 4-7

Vashon-Maury Island Watershed Plan)
We recognize that:

- Island water sources are not replenished by off-island snow melt or aquifers, but only by island rain water.
- Surface and ground water resources are interrelated.
- Both water quality and quantity need to be maintained to provide water for present and future use.
- Preservation of our natural hydrology is directly related to preservation of our water supplies.

GOALS

The Watershed Plan discusses a range of issues related to the preservation of our water supply. In order to preserve the quality and quantity of our water resources, we will strive to achieve the following goals.

- An "early warning system" of sustainability indicators needs to be developed to identify any decline in water quality and quantity since once a decline is identified; it is very difficult to reverse.
- Maintain water quality at current levels.
- Maintain water quantity without decline.
- Use our water supply more efficiently.
- Protect and enhance groundwater recharge.
- Ensure water resource needs of all future inhabitants are not compromised.
- Use both preventive and adaptive strategies to maintain and enhance the integrity of the hydrologic system.
- Use the best available science in the decision-making process.

INDICATORS

Indicators are used to measure the status of water resources. These provide ways we can measure how well we are adhering to the goals described above, and are used to report progress. The Vashon-Maury Island Ground Water Protection Committee (GWPC) plans to use the sustainability indicators to measure progress in meeting their goals to preserve the quality and quantity of water resources as guided by the Vashon-Maury Island Watershed Plan. The GWPC will assess the indicators and monitor changing water resource conditions to identify trends. The GWPC will identify specific strategies in response to observed trends to achieve the sustainability goals.

Indicator		Method	Data Analysis	Target
Sustainable Water Quality				
Groundwater quality	1	Measure groundwater quality in Group A wells, Group B wells and the 19 long term monitoring wells. This indicator is implemented by annually obtaining reported test results for applicable water quality parameters from public health (DOH and PHSHC) and the KC WLRD monitoring.	Water quality results are compared to adopted drinking water standards	Groundwater quality meets or exceeds drinking water quality standards (test results are below the maximum contaminant level (MCL)) and there is no increase greater than 10% over baseline for any parameter over two years for nitrate or since prior test results for all other standards.
Stream water quality	2	This indicator is implemented by monthly measuring bacteria, nutrients, and conventional parameters in five streams.	Stream water quality results are compared to Washington State water quality standards	Stream water quality meets or exceeds surface water quality standards for the protection of aquatic life and there is no increase greater than 10% over baseline for any parameter over two years.
Quartermaster Harbor water quality	3	This indicator is implemented by conducting continuous and monthly oxygen monitoring and monthly bacteria monitoring in Quartermaster Harbor	Quartermaster Harbor water quality results are compared to Washington State water quality standards for marine waters	Quartermaster Harbor water quality meets or exceeds surface water quality standards for the protection of aquatic and shellfish harvesting and there is no increase in bacteria or decrease in oxygen greater than 10% over baseline for any parameter over two years.
Sustainable Water Quantity				
Seasonal groundwater levels	4	This indicator is measured by continuous monitoring in 10 KC WLRD monitoring wells and 2 private wells near the Glacier gravel mine, along with monthly monitoring in volunteer wells	Annual and seasonal groundwater levels are graphed and trends over time are analyzed	Groundwater levels are maintained or improved
Summer instream flows	5	This indicator is measured by using continuous flow data from 4 stream gages maintained by King County (Shinglemill, Judd, Tahlequah, and Fisher) and 1 stream gage maintained by Water District 19 (Beal)	The annual minimum 7-day average low flows are calculated and tracked from year-to-year	Summer low flows are maintained or increased over time
Stream flashiness	6	This indicator is measured by using gage data for the same 6 streams	The percent of time per year that each stream's flow exceeds its average flow for that year will be calculated and tracked from year-to-year. Decreases in percent of time exceeding the annual average are generally associated with increased development and impervious area.	The percent of time that flow exceeds the average flow is maintained or increased over time.

Indicator		**Method**	**Data Analysis**	**Target**
Healthy Ecosystem				
Stream benthic macroinvertebrate populations	7	This indicator is measured by conducting annual stream benthic macroinvertebrate monitoring at three locations by KC WLRD and eight locations by KC Roads	The Benthic Index of Biologic Integrity (BIBI) will be calculated for each site and tracked from year-to-year.	The BIBI scores are maintained or improved.
Salmon populations	8	This indicator is measured by using data from the Salmon Watcher Program that estimate the number of salmon returning to spawn on Vashon-Maury Island	The number of salmon returning to spawn will be estimated each year and compared from year-to-year.	The number of salmon returning to spawn in Vashon-Maury Island streams is maintained or increased.
Sustainable Water Resources Use and Management				
Annual total island-wide water consumption	9	This indicator is measured by obtaining annual withdrawal data from Group A water systems via DOH and withdrawal data from individual volunteer well owners as part of the Water Resources Evaluation. No Group B system data are currently available. Eight exempt well owners voluntarily provide usage data as part of an assessment of permit-exempt wells.	Annual total consumption calculated by estimating Group B and exempt well withdrawals and adding them to the Group A withdrawals. Total annual consumption is tracked from year-to-year.	
Per capita water consumption	10	This indicator is measured by using the same consumption data as above, along with population data from the assessor office.	Per capita consumption is calculated by dividing total annual consumption by total population and is tracked from year-to-year.	Per capita consumption does not increase.
Summer water use peaking factor	11	This indicator is measured using monthly withdrawal data, obtained from Larger Group A PWS and comparing to their Water System Plan peaking factor.	Monthly summer water withdrawals are divided by monthly winter water withdrawals to calculate the summer peaking factor. Peaking factor is tracked from year-to-year.	Summer water use peaking factors do not increase.
Vashon-Maury Island watershed plan implementation	12	This indicator is measured by tracking the number of GWPC priority implementation items that are accomplished each year.	The cumulative number of items accomplished is divided by the number of priority items in the plan to calculate the percent of priority items completed.	The percent of priority items completed increases year-to-year.

Other Possible Indicators to be Implemented Should Funding and/or Data Become Available

1. Land cover is maintained in a manner that allows for maintenance of a natural hydrologic cycle. This indicator is measured by comparing the percent of land cover classified as "impervious" and the percent classified as "forest" every two years by subbasin on Vashon-Maury Island. Impervious land cover targets for each subbasin are less than 10% and forested land cover targets for each subbasin are greater than 65%. (Note: Fine scale land cover data is available for 1995 and 2002 to provide a base line if measurement can be funded in the future)
2. Public attitudes and involvement demonstrate strong support for water resource stewardship. This indicator is measured by conducting a survey of public attitudes about water resources every 2 years, and tracking changes in attitudes over time.
3. Groundwater recharge and quality, and stream flows and water quality are protected and enhanced through aggressive implementation of Low Impact Development techniques. This indicator is measured by calculating the acres of land developed per year using Low Impact Development techniques, and tracking trends over time.
4. Groundwater and stream water quality are protected and enhanced through improved design, operation, and maintenance of on-site septic systems. This indicator is measured by determining the number of on-site septic systems that have been inspected each year and the number upgraded to meet code each year based on information from SKCPH, and tracking trends over time.
5. Groundwater and stream water quality are protected and enhanced by reducing the amount of pesticides applied to Vashon landscapes. This indicator is measured by obtaining the annual amount of different pesticides sold by island retailers and tracking trends over time.
6. Basins are opened or closed to water allocations based on better understanding of surface water / groundwater interaction and sustainability. This indicator is measured by identifying the number of basin reviews DOE completes where surface water/groundwater interaction and sustainability are substantially considered.

STRATEGIES FOR SUSTAINABILITY

The following strategies could be undertaken by the GWPC in the future to further implementation of the sustainability goals:

- Continue efforts to implement the recommendations contained in the VMI Watershed Plan. Near term identify policy recommendations to improve water resource management including nitrogen reduction for consideration in the 2012 amendment to the King County Comprehensive Plan.
- Revise the scope of the ongoing monitoring by KC WLRD to compile, evaluate, review and the report the findings on indicators 1-10 to the GWPC and other interested parties including the general public, on an annual basis. Develop strategies to fill data gaps for sustainability indicators 1-11.
- Identify and evaluate hydrologic management and sustainability techniques being developed in other island communities for application on VMI.
- Evaluate the potential benefits or liabilities and feasibility of modifying the WRIA designation for VMI

Summaries of the eleven indicators are presented in the following four main groups:

Water Quality Indicators:

- Groundwater
- Stream water
- Quartermaster Harbor (marine) water

The water quality of the island is assessed by three components – groundwater, surface water and marine (Quartermaster Harbor). The groundwater quality is very good. There are no reported violations of United States Environmental Protection Agency drinking water standards and Maximum MCLs for over 95 parameters during the last three (2008-2010) years. However, arsenic is one standard that can have high levels at the source then be blended with other sources to produce concentrations below the drinking water standard at the point of use. Surface water quality can and does vary by year with the most recent data being of low to moderate concern. Water quality data from Quartermaster Harbor shows low levels of fecal coliform bacteria but also has periods of low dissolved oxygen especially in the inner harbor area.

Water Quantity Indicators:

- Groundwater levels
- Surface water summer low flows
- Stream "flashiness"

The water quantity of the island is assessed by groundwater levels and stream flow indicators. Of the more than 1,000 wells on VMI, only 60 have multiple years of water level data from 2001 to 2010. Fifteen locations had sufficient data for a baseline assessment with one site showing a decline greater than one standard deviation and one site having an increase in water table elevations greater than one standard deviation. The other 13 sites have variations within one standard deviation indicating little to no change over this time period. Judd and Shinglemill Creek have 10 years of flow data while Fisher and Tahlequah creeks have been monitored since 2005. The stream flow data reflect changes in total amount of precipitation over the ten years of 2001-2010. The stream flow flashiness assessment as measured by the Richards-Baker index method appears to be maintaining uniform values; however, additional data is required to determine if any changes are more than indicators of variation in the total amount of precipitation. Ten years or more of continuing data is needed to assess longer term trends for these hydrologic indicators.

Ecosystem Health Indicators

- Stream benthic macro invertebrate
- Salmon populations

The indicators of ecosystem health for the island are unexpectedly poor. The data from stream benthic macroinvertebrate populations score in the "fair" to "very poor" categories which are lower than many other rural streams in King County. The island –wide average of all sites has been declining (worse) since 2005 when sampling began. The number of salmon reported per survey year has decreased since 2001 for several creeks. However, the number of volunteers reporting the data and the number of sites

surveyed has also decreased over the same period. At this point, there is insufficient data to conclude whether salmon populations are maintaining.

Water Use Indicators

- Annual total usage
- Per capita usage
- Summer peaking factor

The total water use for the island was estimated based on data from selected public water systems and individual volunteer. The total island-wide water consumption was estimated for by water user type including – Group A public water systems, Group B public water systems, self supply and agricultural water users. Total water use was estimated to be 495 Million gallons per year for 2010. Average per capita water usage was estimated to be 83 gallons per person, per day and water use peaks in the summer ranges from a factor 1.1 to 4.4 based on data from selected Group A public water systems.

The data were assessed over a ten year period from 2001-2010, when possible. However, most indicators, such as #2, 3, 5, 6, and 7, have shorter periods of record starting in 2005 or 2006 due to lack of data. Other indicators, such as #1, 4, 9, 10 & 11, will require additional data collection from public water systems around the island. This initial effort in assessing the Sustainability Indicators highlighted the need to fill in data gaps and re-assess indicators periodically when sufficient new data is available, typically every three years. This allows for additional data gathering and longer periods for analysis.

King County and the Groundwater Protection Committee placed an insert in the Beachcomber Assessing Our Liquid Assets to help Vashon Island residents learn about their water resources. Published November 2012.

A copy of the report card to the Community and the indicators were published via the King County Groundwater Management Area web pages and can be found at:

http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/Assess-assets.aspx

The following indicators are a collaboration of the VMI-GWPC and King County and are from a version of the Sustainability Indicators, dated December 2012.

Legend

2010 Finding

Poor Conditions: Reported data are above Maximum Contaminant Level (MCL) and/or fails to meet the state standard or criteria for a given indicator; needs improvement.

Fair Conditions: On average, data fell between the standard or criteria for "poor" and "good" and may be variable.

Good Conditions: Reported data are below MCL and/or meet the state standard or criteria for a given indicator.

No Annual Assessment

2001-2010 Status

Downward Trajectory: 2001-2010 data shows decreasing or worsening conditions

No Change: 2001-2010 data shows no change with time.

Upward Trajectory: 2001-2010 data indicate increasing or improving conditions

Insufficient Data: reported data has too few data points and/or too short a period

1A. Groundwater Quality — Nitrate

Target: Drinking Water below the Maximum Contaminant Level (MCL)

About this indicator: Nitrate is one of three parameters selected as an indicator of groundwater quality because it can track changes caused by human activities. High nitrate levels can cause methemoglobinemia (blue baby syndrome) especially in infants under six months. The MCL for nitrate is 10 milligrams per liter (mg/L).

Influencing factors: Leaching from septic systems, runoff from fertilizer or manure and nitrogen fixing vegetation such as alder trees can influence the measured concentration of nitrate in groundwater.

2010 Target: Groundwater quality meets drinking water quality standards (test results are below the MCL).

2010 Finding: No sites above MCL

2010 Status: No nitrate results were reported above the drinking water standard (MCL of 10 mg/L). Four sites have nitrate values between 5 to 10 mg/L (half of the MCL up to the MCL). The remaining 186 locations had result values below 5 mg/L.

Maximum result values for nitrate data collected at 190 locations (155 public water sources and 35 long-term monitoring sites) from 1990 to 2010 is presented in Figure 1.

Other Drinking Water Standards: The United States Environmental Protection Agency sets drinking water standards and MCL's for over 95 parameters including microorganisms, disinfectants & their byproducts, inorganic chemicals, organic chemicals and radionuclide's.

Review of the public drinking water source data for Group A water systems available from the Washington Department of Health Drinking Water Program from 2008 to 2010 found no value above the MCL for the other 92 regulated parameters.

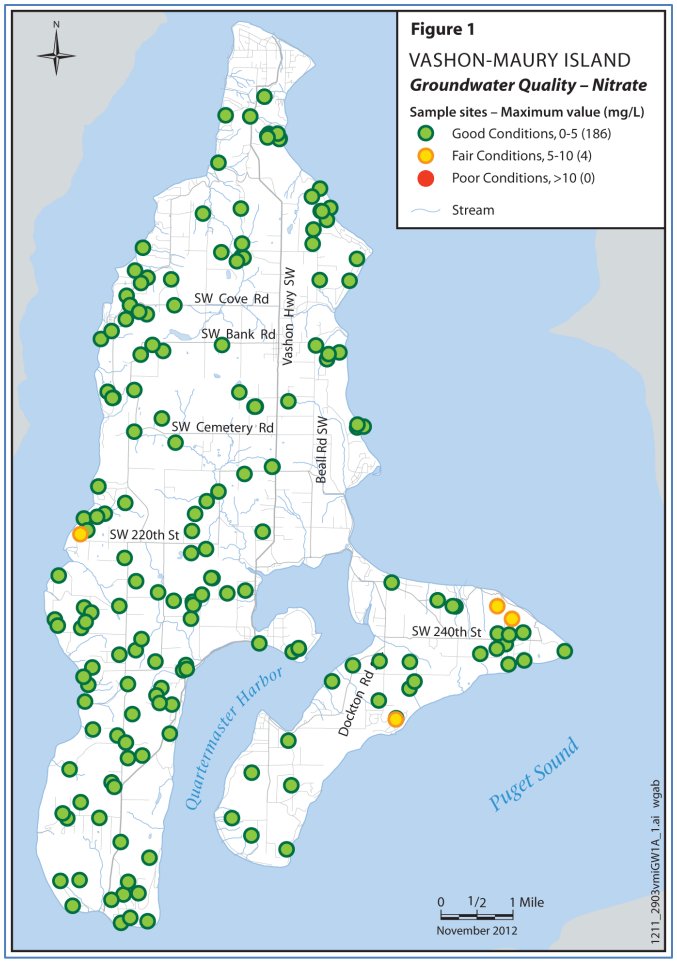
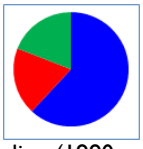


Figure 1. Maximum nitrate results from 1990 to 2010 for 190 locations. No sample results are above the MCL of 10 mg/L. Four sites have results between 5 – 10 mg/L while the remaining 186 sites have result values below 5 mg/L.

Trend Target: For locations with more than 10 years of water quality samples, new data will be compared to the baseline period to evaluate changes through time. Water quality changes that would trigger further evaluation were defined in the Vashon-Maury Island Ground Water Management Plan management strategies as follows:

- Any increase in the sampled contaminates level greater than 10% over the baseline for two or more years;
- Any trend that increases from zero to one quarter of the MCL or reaches one half the MCL limit.

Trend Finding:
21 sites; 4 increasing, 4 decreasing, 13 unchanged from 1990 to 2010



Trend Status Four of 21 sites had an increase when comparing averaged 2009-2010 data to their baseline (1990-2008), Figure 2. Four other sites had a decrease when comparing averaged 2009-2010 data to their baseline while the remaining 13 sites had no change between recent and baseline values.

Technical Notes: Nitrates in Groundwater

Data source: The data for this indicator comes from multiple sources including VMI water purveyors, King County WLRD Groundwater Protection Program, Public Health - Seattle & King County Drinking Water Program, and Washington State Department of Health Office of Drinking Water.

Collection frequency: King County has been monitoring nitrate concentrations annually on Vashon-Maury Island since 2001 and monitored 21 and 22 locations during 2009 and 2010, respectively. Department of Health – local and state require annual nitrate testing of public water system sources. Department of Health reported data from 31 and 43 public water sources in 2009 and 2010, respectively.

Methods for analysis: Each result is compared to the drinking water standard. Baseline assessment was completed for 21 public water sources that had at least 10 years from 1990 to 2008. Thirteen of these had no change, four sources had decreases and four had increases when comparing an averaged 2009 and 2010 data to their baseline.

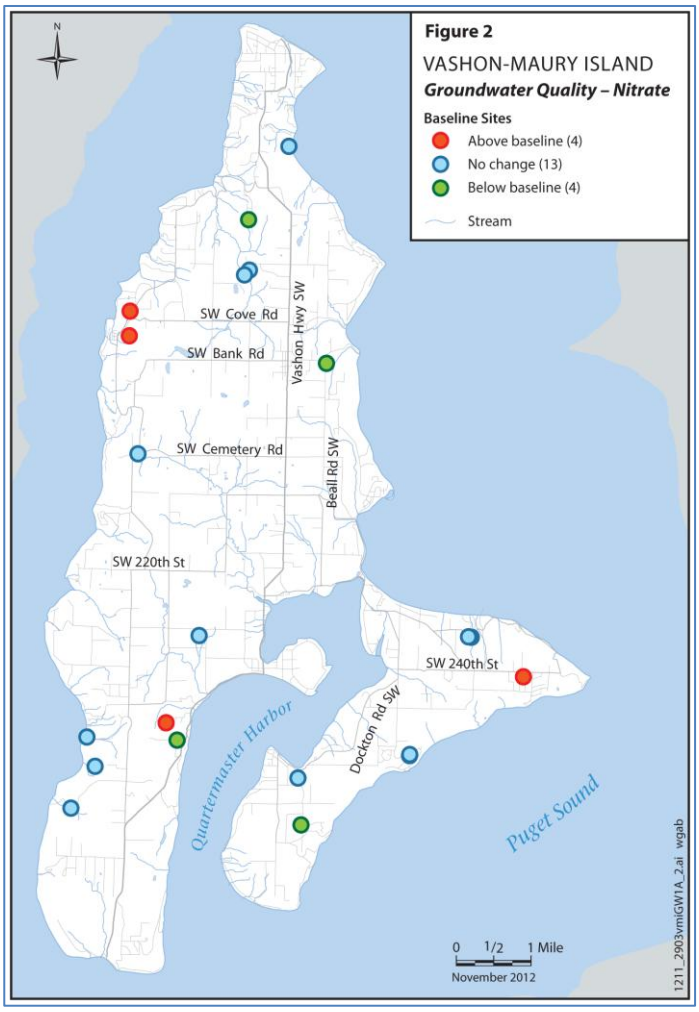


Figure 2. Baseline assessment locations. Twenty-one locations had sufficient data to assess the recent data (2009 & 2010) to a baseline (>10 year) average evaluating for change. Four sites had increases in recent data compared to baseline, four additional sites had lower values recently and the remaining 13 sites had no change comparing recent to baseline data.

Data Reliability and Quality: The data quality of this indicator is high based on the SAP/SOP of sample collection. The reliability is fair to good. Data reliability from the sources can and does vary. King County has monitored 35 locations for nitrate which is represents about 4% of the over 1000 wells on VMI. Department of Health reported arsenic data from 155 public water sources which is 78% of the island's 200 public water sources.

Data Gaps: Collection of historic monitoring data directly from the public water purveyors might expand the data set sufficiently to permit extended trend analysis for many of the 71 public water sources.

Data Reference:
King County - Water Resources Evaluation Project – Data Report 2005-2009.
http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/vashon-island.aspx

Washington State Department of Health – Sentry - database of public water systems (1990-2010).
https://fortress.wa.gov/doh/eh/portal/odw/si/Intro.aspx

Washington Administrative Code (WAC) — 173-200 Water quality standards for groundwater

Arsenic (1B) and Chloride (1C) were selected for the other groundwater quality indicator parameters.

1B. Groundwater Quality — Arsenic

Target: Drinking Water below the Maximum Contaminant Level (MCL)

About this indicator: Arsenic is one of three parameters selected as an indicator of groundwater quality due to its potential carcinogenic effects. The MCL for arsenic is 10 micrograms per liter (µg/L).

Influencing factors: Arsenic enters water supplies either from natural deposits in the earth or from industrial and/or agricultural pollution.

Target: Groundwater quality meets MCL drinking water quality standards (test results are below the MCL).

2010 Finding: 11 sites above MCL

Status: Eleven of the 95 sites sampled had arsenic levels above the drinking water standard (MCL of 10 µg/L). Twenty three sites had sample values between 5 to 10 µg/L. The remaining 61 locations had result values below 5 µg/L.

Maximum values for arsenic data collected for 95 (71 public water sources and 24 long-term monitoring sites) locations between 1990 and 2010 are represented in Figure 1. Maximum sample values for each site are shown in Figure 2.

Other Drinking Water Standards: The United States Environmental Protection Agency sets drinking water standards and MCL's for over 95 parameters including microorganisms, disinfectants & their byproducts, inorganic chemicals, organic chemicals and radionuclide's.

Review of the public drinking water source data for Group A water systems available from the Washington Department of Health Drinking Water Program from 2008 to 2010 found no value above the MCL for the other 92 regulated parameters.

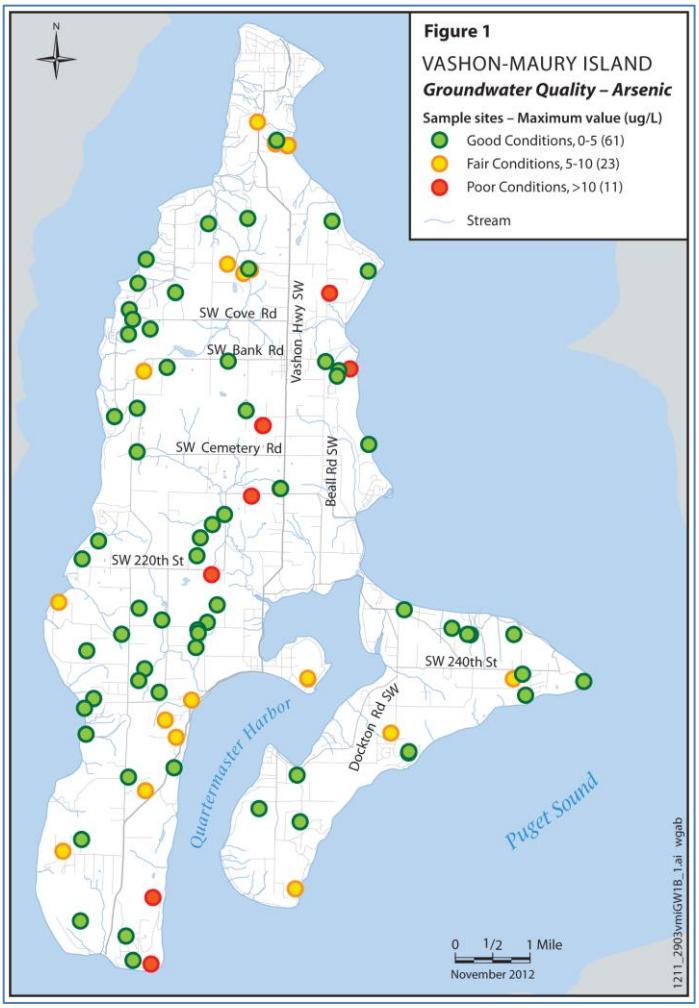
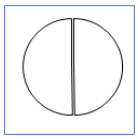


Figure 1. Maximum arsenic results from 1990 to 2010 for 95 locations. Eleven sample results are above the MCL of 10 µg/L. Twenty-three sites have results between 5 – 10 µg/L while the remaining 61 sites have result values below 5 µg/L.

Trend Target: For locations with more than 10 years of water quality samples, new data will be compared to the baseline period to evaluate changes through time. Water quality changes that would trigger further evaluation were defined in the Vashon-Maury Island Ground Water Management Plan management strategies as follows:

- Any increase in the sampled contaminates level greater than 10% over the baseline for two or more years;
- Any trend that increases from zero to one quarter of the MCL or reaches one half the MCL limit.

Trend Finding: Reported arsenic data has too short a period of record to complete an analysis;



Trend Status: Baseline assessment was not done due to insufficient data. No site has more than 10 years of arsenic data. Sixteen sites have 10 years and two additional sites have eight years of data.

Recent Status: No apparent recent change in concentration in sites monitored on a regular basis, Figure 3.

Technical Notes: Arsenic in Groundwater

Data source: The data for this indicator comes from multiple sources including VMI water purveyors, King County WLRD Groundwater Protection Program, Public Health - Seattle & King County Drinking Water Program, and Washington State Department of Health Office of Drinking Water.

Collection frequency: King County has been monitoring arsenic concentrations annually on Vashon-Maury Island since 2001. Department of Health – local and state require arsenic testing of public water system sources.

Methods for analysis: Each result is compared to the drinking water standard. Baseline assessment was not done due to insufficient data. No site has more than 10 years of arsenic data. Sixteen sites have 10 years and two additional sites have eight years of data.

Data Quality and Reliability: The quality of data for this indicator is high and reliability is considered to be good though data reliability from the sources can and does vary. King County has monitored 30 locations for arsenic which is represents about 3% of the over 1000 wells on VMI. Department of Health reported arsenic data from 71 public water sources which are 35% of the island's 200 public water sources.

Data Gaps: Collection of historic monitoring data directly from the public water purveyors might expand the data set sufficiently to permit trend analysis for many of the 71 public water sources.

Data Reference:

King County - Water Resources Evaluation Project – Data Report 2005-2009.
http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/vashon-island.aspx

Washington State Department of Health – Sentry - database of public water systems (1990-2010).
https://fortress.wa.gov/doh/eh/portal/odw/si/Intro.aspx

Washington Administrative Code (WAC) — 173-200 Water quality standards for groundwater

Nitrate (1A) and Chloride (1C) were selected for the other groundwater quality indicator parameters.

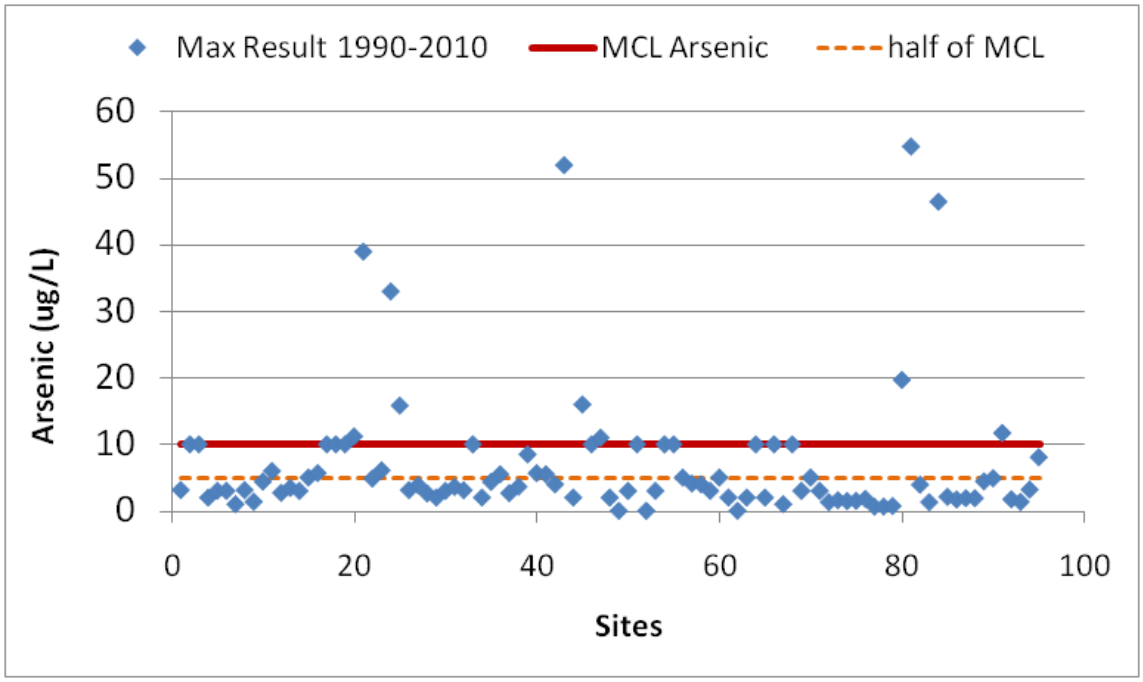


Figure 2. Maximum arsenic concentration for each site from 1990 to 2010. The maximum contaminant level (MCL) for arsenic is 10 µg/L. Eleven of 95 sites have maximum results over the MCL (above the solid red line). Twenty-three sites have data between the dashed line and solid line; sites shown as yellow circles in Figure 1.

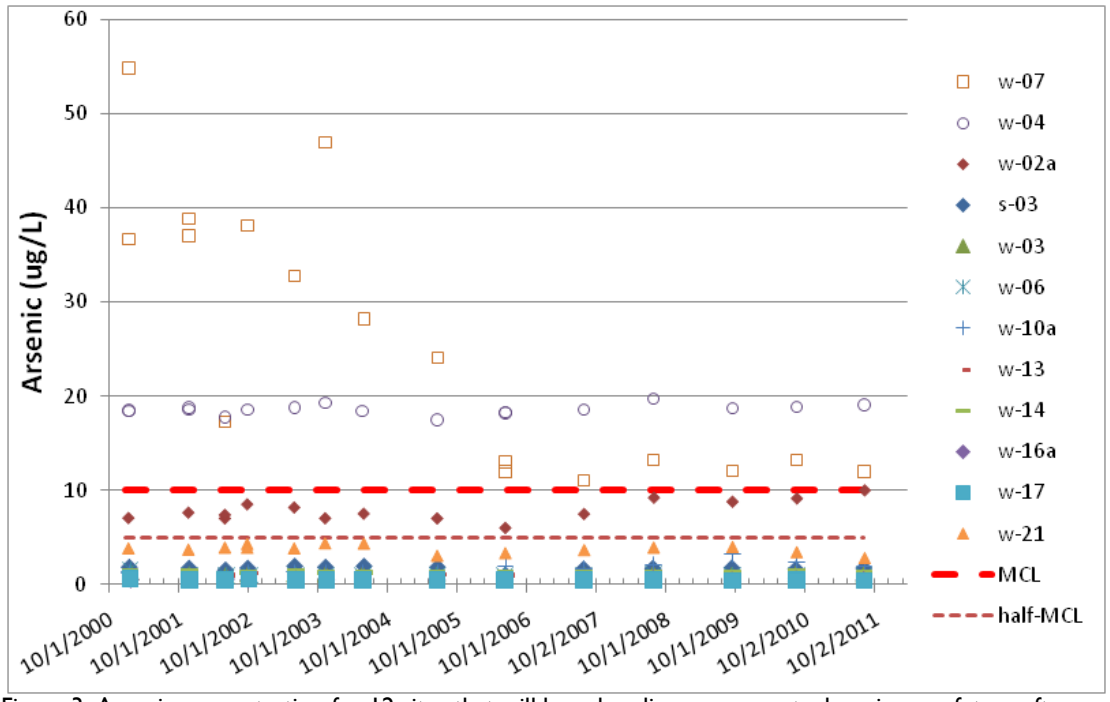


Figure 3. Arsenic concentration for 12 sites that will have baseline assessments done in near future after additional data is collected. The variability seen in site w-07 is likely a result of sampling techniques then environmental changes.

1C. Groundwater Quality — Chloride

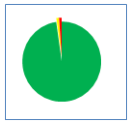
Target: Drinking Water below the Maximum Contaminant Level (MCL)

About this indicator: Chloride is one of three parameters selected as an indicator of groundwater quality because it can affect potability and may act as a conservative tracer of human activities. The secondary standard for chloride is over 250 mg/L (mg/L).

Influencing factors: Pumping wells in aquifers that are hydraulically connected to the Puget Sound can cause salt water intrusion into the aquifer. Chloride is also concentrated in animal urine and concentrations of animals (human or otherwise) have the potential to elevate the chloride levels in groundwater.

2010 Target: Groundwater quality meets drinking water quality standards (test results are below the MCL).

2010 Finding: 1 sites above MCL is no longer being used for drinking water



2010 Status: One of the 90 sites had results above the drinking water standard (MCL of 250 mg/L). One additional site has a result value between 100 to 250 mg/L or half of the MCL up to the MCL. The remaining 88 locations had results values below 100 mg/L. Chloride data from 90 locations (55 public water sources and 35 long-term monitoring sites) was accessed and the maximum result values from 1990 to 2010 are presented in Figure 1.

Other Drinking Water Standards: The United States Environmental Protection Agency sets drinking water standards and MCL's for over 95 parameters including microorganisms, disinfectants & their byproducts, inorganic chemicals, organic chemicals and radionuclide's.

Review of the public drinking water source data for Group A water systems available from the Washington Department of Health Drinking Water Program from 2008 to 2010 found no value above the MCL for the other 92 regulated parameters.

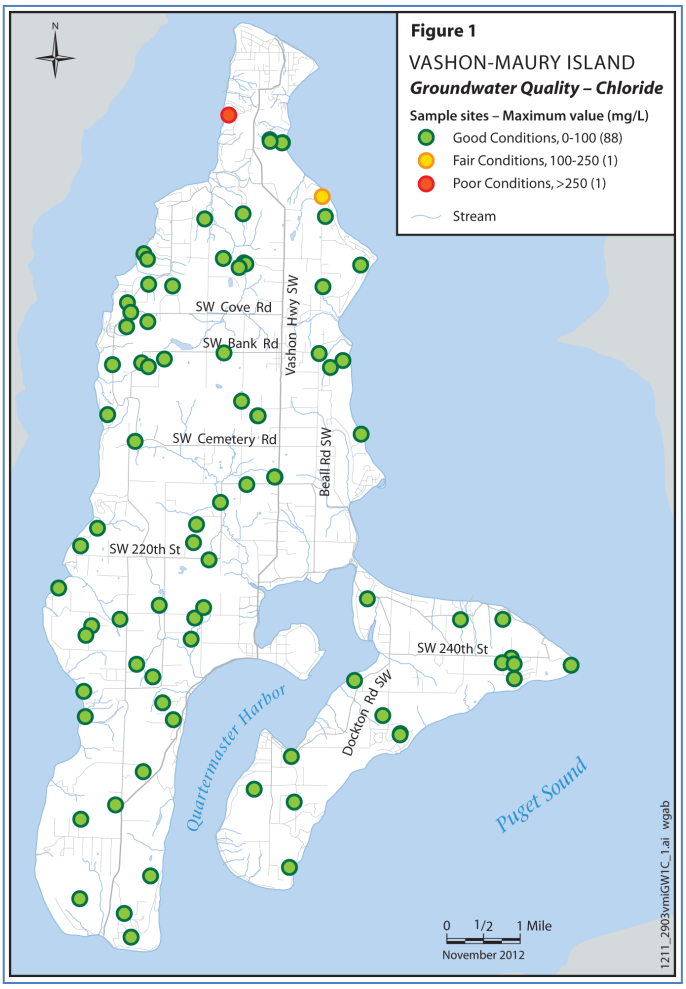


Figure 1. Maximum chloride results from 1990 to 2010 for 90 locations. One site had sample results are above the MCL of 250 mg/L. This location is no longer active. One additional result is between 100 – 250 mg/L while the remaining 88 sites have result values below 100 mg/L.

Trend Target: For locations with more than 10 years of water quality samples, new data will be compared to the baseline period to evaluate changes through time. Water quality changes that would trigger further evaluation were defined in the Vashon-Maury Island Ground Water Management Plan management strategies as:

- Any increase in the sampled contaminates level greater than 10% over the baseline for two or more years;
- Any trend that increases from zero to one quarter of the MCL or reaches one half the MCL limit.

Trend Finding:
Reported data has too short a period of record to complete an analysis.

Trend Status: Baseline assessment was not done due to insufficient data. No site has more than 10 years of chloride data. Fifteen sites have 10 years and two additional sites have eight years of data.

Recent Status: No apparent recent change in concentration in sites monitored on a regular basis, Figure 3.

Technical Notes: Chloride in Groundwater

Data source: The data for this indicator comes from multiple sources including VMI water purveyors, King County WLRD Groundwater Protection Program, Public Health - Seattle & King County Drinking Water Program, and Washington State Department of Health Office of Drinking Water.

Collection frequency: King County has been monitoring chloride concentrations annually on Vashon-Maury Island since 2001 and has monitoring data from 35 locations. Department of Health – local and state require chloride testing of public water system sources. Department of Health reported chloride data from 55 public water sources.

Methods for analysis: Each result is compared to the drinking water standard. Baseline assessment was not done due to insufficient data. No site has more than 10 years of chloride data. Fifteen sites have 10 years of data and Figure 3 shows the results for some of these sites.

Data Reliability and Quality: The data quality of this indicator is high based on SAP/SOP of sample collection. The reliability is fair to good. Data reliability from the sources can and does vary. King County has monitored 35 locations for chloride which is represents about 4% of the over 1000 wells on VMI. Department of Health reported chloride data from 55 public water sources which are 28% of the island's 200 public water sources.

Data Gaps: Collection of historic monitoring data directly from the public water purveyors might expand the data set sufficiently to permit extended trend analysis for many of the 71 public water sources.

Data Reference:

King County - Water Resources Evaluation Project – Data Report 2005-2009.
http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/vashon-island.aspx

Washington State Department of Health – Sentry - database of public water systems (1990-2010).
https://fortress.wa.gov/doh/eh/portal/odw/si/Intro.aspx

Washington Administrative Code (WAC) — 173-200 Water quality standards for groundwater

Nitrate (1A) and Arsenic (1B) were selected for the other groundwater quality indicator parameters.

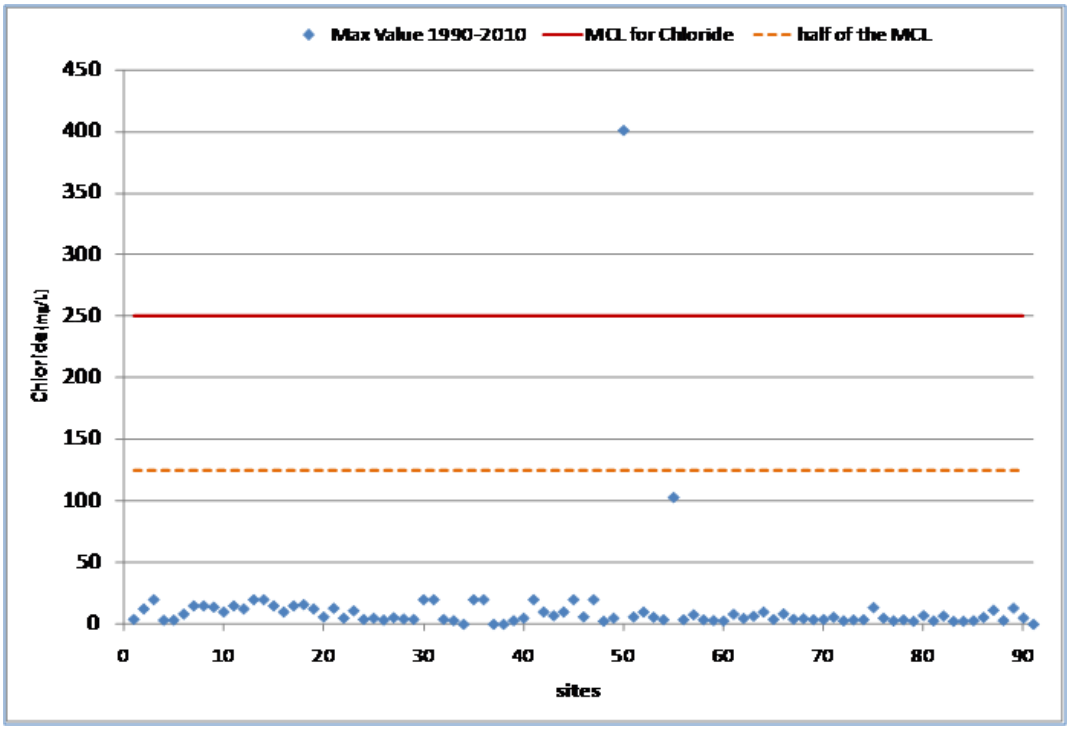


Figure 2. Maximum chloride concentration for each site from 1990 to 2010. The maximum contaminant level (MCL) for chloride is 250 mg/L. The one site with exceedance is a public water system source that is no longer being used for drinking water purposes.

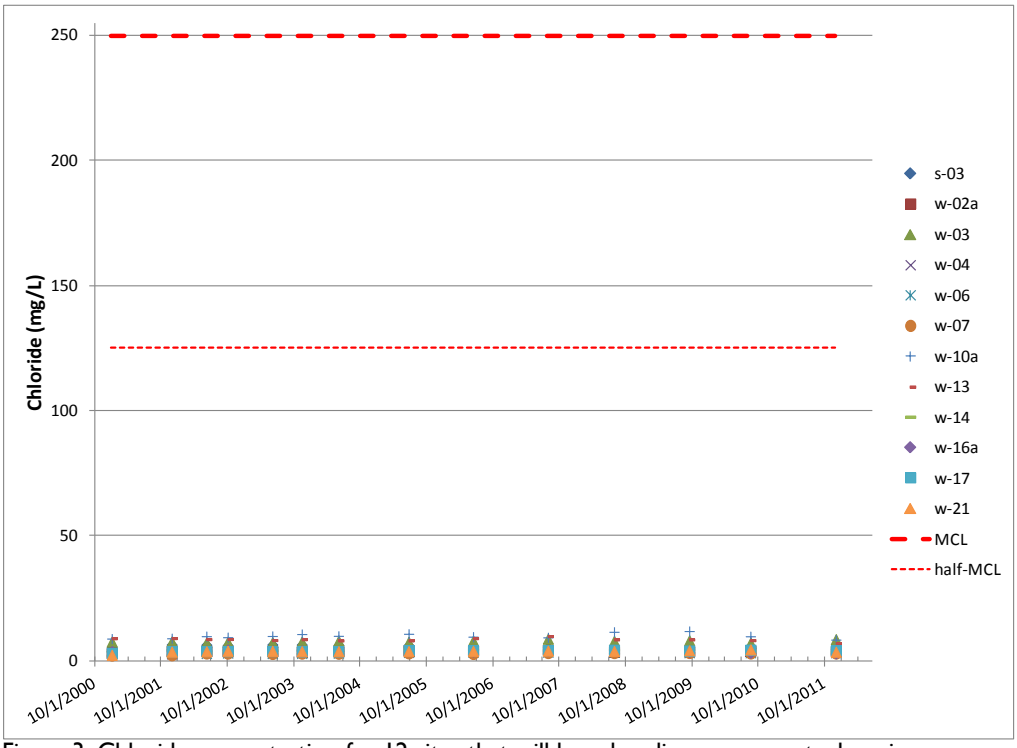


Figure 3. Chloride concentration for 12 sites that will have baseline assessments done in near future after additional data is collected.

2. Stream Water Quality Index

Target: Good Stream Water Quality

About this indicator: Water Quality Index (WQI) integrates key factors into a single number that can be compared over time and across locations. This index compares monthly data of temperature, pH, fecal coliform bacteria, dissolved oxygen, turbidity, total suspended solids, and nutrients (phosphorus and nitrogen) relative to state standards and guidelines.

Influencing factors: Overall stream water quality in King County is impacted by increased development in our region — primarily stormwater runoff. The reduced scores may have resulted from intense rainfall events.

2010 Target: Stream water quality index for the majority of the sites are "low concern" reflecting good water quality within those basins annually.

2010 Finding:
2 sites with Good water quality; 3 sites with Moderate water quality

2010 Status: The Water Year 2010[1] WQI scores indicated that 2 of the 5 sampling sites were of low concern (good water quality) while the remaining 3 sites had moderate concern (moderate water quality). No sites were rated of high concern with low water quality, Figure 1 and Table 1. Rating for scores are explained in the technical notes section.

Related indicator: Indicator #7 is another indication of stream health by assessing the Benthic Index of Biological Integrity (BIBI) of the islands creeks

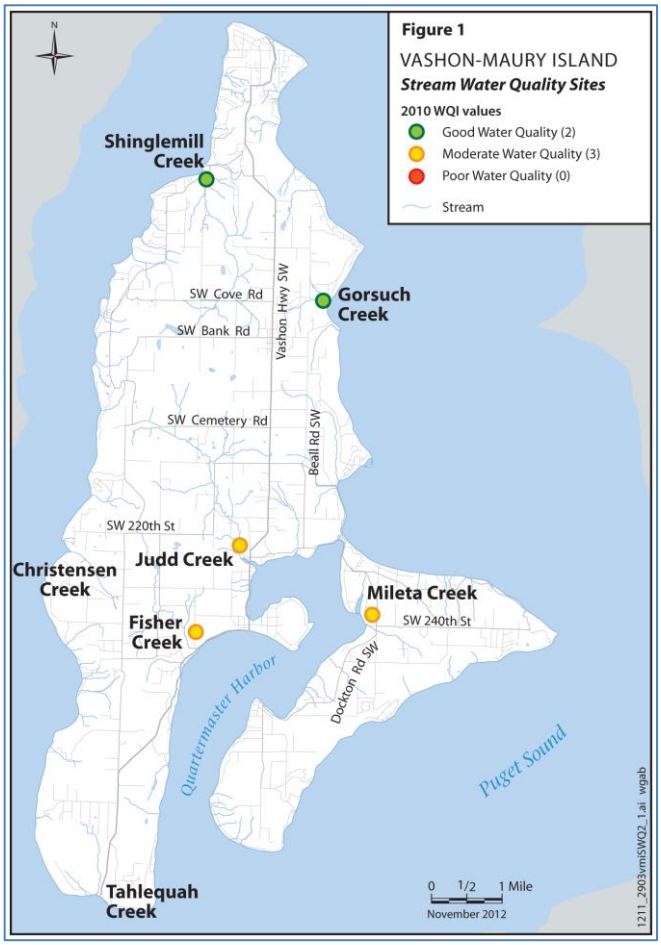


Figure 1. Stream water quality locations shown with WY 2010 WQI scores. Five sites were sampled. In 2010, two sites had scored "Good" water quality; three sites had scored "Moderate" water quality and zero sites had "Poor" water quality. Two inactive sites (Tahlequah and Christensen Creeks) are shown for reference.

2001-2010 Target: Maintaining or improved good water quality for stream sites through time.

[1] Water Year (WY) is a 12 month period starting October 1 and ending September 30 in the following year. Example given: WY2010 is from October 1, 2009 until September 30, 2010. Most hydrologic data are reported by the water year.

2001-2010 Assessment: 5 sites; All scores improved in 2010.

2001-2010 Status: Five of 5 sites had WQI scores in the good to moderate water quality range in 2010 which improved from the previous year, Figure 2 & Table 1. The data has been collected since November 2006. Gorsuch Creek only had 6 samples collected in water year 2010.

Figure 2. Water Quality Index (WQI) scores for Vashon-Maury Island creeks by water year (October to September). Scores 80 or higher are for sites of low concern – good water quality (green color); Scores 40 or less are for sites of high concern – poor water quality (red color) and scores between 40 and 80 are for sites with Moderate concern with a mix of good and poor water quality (yellow color). Christensen and Tahlequah creeks were only sampled in water year 2007. NOTE: colors above are for VMI indicators and are not 'typical' for reporting WQI scores

Technical Notes: Water Quality Index for Vashon-Maury Island Creeks

Data source: The data for this indicator comes from the King County DNRP/WLRD Science, Monitoring and Data Management Section.

Collection frequency: King County has been monitoring stream water quality monthly at five locations on Vashon-Maury Island since November 2006. Recent budget changes to the program required a removal of one site (Gorsuch Creek) from the monitoring program in April 2010.

Methods for analysis: This water quality index will generate a number ranging from 1 to 100. Higher numbers reflect better water quality. The index uses data for temperature, pH, fecal coliform bacteria, dissolved oxygen, turbidity, total suspended solids, and nutrients (phosphorus and nitrogen) relative to state standards required to maintain beneficial uses. The multiple water quality parameters are combined and results aggregated over the water year to produce a single score for each sample station. In general, stations scoring 80 and above meet expectations and are of "low

concern" with good water quality, scores 40 to 80 indicate "moderate concern and water quality", and stations with scores below 40 do not meet expectations and are of "high concern" with poor water quality. Analysis was done using Washington Department of Ecology - Water Quality Index for Washington State Streams (version 5).

Data Reliability and Quality: The data quality of this indicator is high based on the KC SAP/SOP of sampling collection. The reliability is good based on the consistent and regular collection of the data.

Data Reference: King County - Water Resources Evaluation Project – Data Report 2007-2010.

Washington Department of Ecology - Water Quality Index for Washington State Streams (version 5); http://www.ecy.wa.gov/programs/eap/fw_riv/docs/WQIOverview.html .

Table 1. Water Quality Index (WQI) for stream on Vashon-Maury Island. Data are presented as Water Year since data collected started in November 2006. WQI scores are explained in the Technical Notes section. Scores 80 or higher are for sites of low concern – good water quality; Scores 40 or less are for sites of high concern – poor water quality and scores between 40 and 80 are for sites with Moderate concern with a mix of good and poor water quality. NOTE: colors below are for VMI indicators and are not 'typical' for reporting WQI scores.

Creek Name	Locator	WY07	WY08	WY09	WY10
Shinglemill	VA12A	71	78	61	83
Fisher	VA41A	31	68	24	50
Judd	VA42A	58	67	26	61
Mileta	VA45A	72	61	47	68
Gorsuch	VA65A	74	75	44	83*
Christensen	VA23	71	—	—	—
Tahlequah	VA37A	55	—	—	—
Total Low Concern – Good WQ		0	0	0	1
Total Moderate Concern & WQ		6	5	3	3
Total High Concern – Poor WQ		1	0	2	0
Total Streams		7	5	5	4

"*" = Gorsuch Creek only has 6 samples (Oct-Mar) in WY10.
"— " = Not sampled during that water year.

3A. Marine Water Quality — Dissolved Oxygen — Quartermaster Harbor

Target: Marine water meets water quality criteria

About this indicator: Measures marine water quality at King County's monitoring locations within Quartermaster Harbor (Figure 1). Quartermaster Harbor has been designated by Washington State as an extraordinary water body

Influencing factors: Water carrying nutrients from septic systems, chemicals from motor vehicles and nitrogen from fertilizers degrade marine water quality and reduce oxygen levels for the animals that live and depend on Puget Sound habitats.

2010 Target: Quartermaster Harbor water quality meets or exceeds the extraordinary marine water quality criteria for dissolved oxygen with no more than 50% of the samples below the criteria within a given year.

2010 Finding:
2 sites. 1 site low DO
55% of samples below criteria
1 site moderate DO
45% of samples below criteria

2010 Status: Both stations (Inner and Outer) in Quartermaster Harbor are of high level of concern in 2010 for low dissolved oxygen levels, Figure 1. The inner harbor station had 55% of the 2010 samples below the extraordinary criteria of 7 mg/L while the outer harbor station had 45% of the 2010 samples below this threshold, Table 1.

2001-2010 Target: All marine monitoring sites have results at or above the state water quality standard (extraordinary criteria of 7 mg/L) on a regular basis.

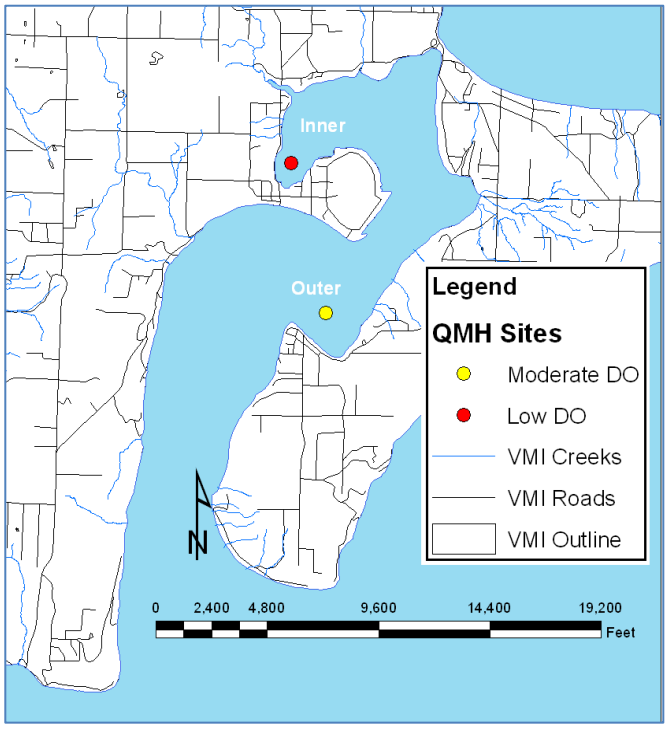


Figure 1. Two locations within Quartermaster Harbor are sampled for dissolved oxygen. The Inner Harbor station had 55% of the 2010 samples below the extraordinary criteria of 7 mg/L while the outer harbor station had 45% of the 2010 samples below this threshold.

2001-2010 Target: All marine monitoring sites have results at or above the state water quality standard (extraordinary criteria of 7 mg/L) on a regular basis.

2001-2010 Assessment:
2 sites; Water Quality in 2010 decreased compared to previous years.

2001-2010 Status: The percentage of samples in 2010 below the water quality criteria

increased compared to previous years, Table 1. For the inner harbor station, the 2010 data had more samples below the criteria than any other year. For the outer harbor station, the 2010 data had more samples below the criteria than 3 out of the 4 previous years. The data has been collected since 2006.

Table 1. Dissolved Oxygen data from the bottom values with percentages below the state water quality standard (extraordinary criteria of 7 mg/L) for each year sampled since 2006. Locations of each site are shown in Figure 1.

Station	Year	Total Number	Percentage of samples below criteria
Inner	2006	9	22%
	2007	12	25%
	2008	12	17%
	2009	12	25%
	2010	11	55%
Outer	2006	12	25%
	2007	12	50%
	2008	12	42%
	2009	12	17%
	2010	11	45%

Technical Notes: Marine Water Quality – Dissolved Oxygen – Quartermaster Harbor

Data source: The data for this indicator comes from King County DNRP/WLRD Marine Monitoring Group.

Collection frequency: The King County DNRP/WLRD Marine Monitoring Group conducts monthly sampling at the inner and outer harbor since 2006. The Burton Acres County Park station is not used in the assessment of dissolved oxygen.

Methods for analysis: The dissolved oxygen (bottom station) data is compared to the extraordinary quality criteria of 7 mg/L, Figure 2. The total number of annual samples and the number of monthly samples below the criteria are used to calculate the percentage of samples below the criteria

Data Reliability and Quality: The data quality of this indicator is high based on the KC SAP/SOP of sampling collection. The reliability is good based on the consistent and regular collection of the data.

Data Reference: King County, Water and Land Resources Division, Science, Monitoring and Data Management Section

Fecal Coliform (3B) is another marine water quality indicator for overall health of Quartermaster Harbor.

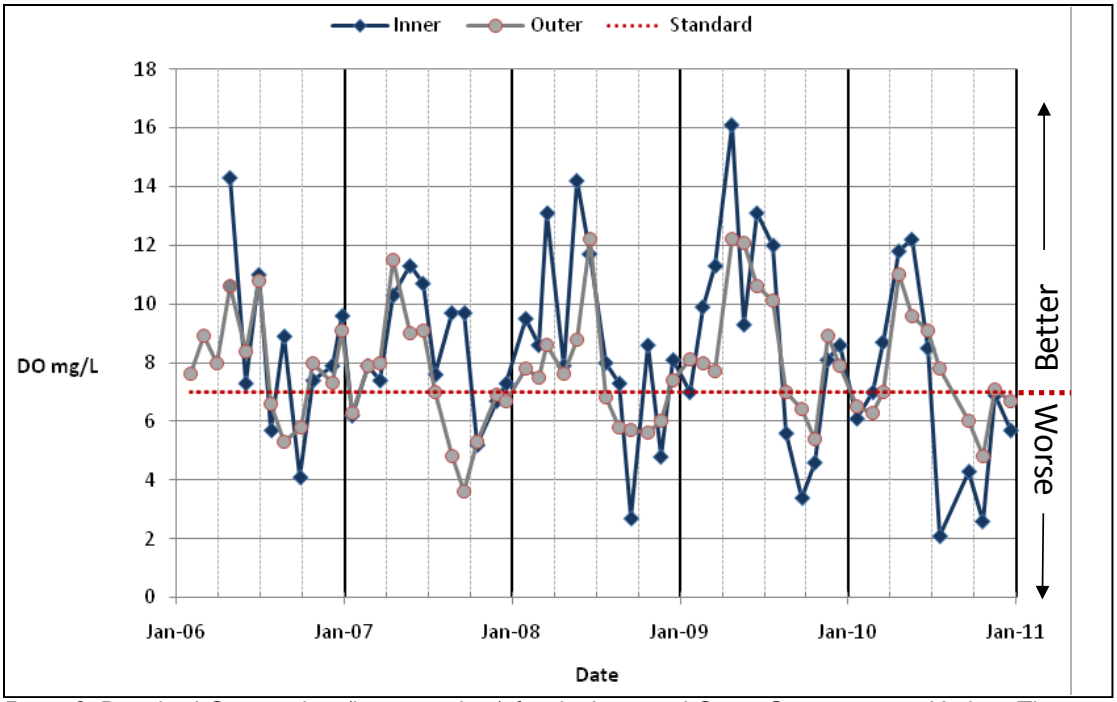


Figure 2. Dissolved Oxygen data (bottom values) for the Inner and Outer Quartermaster Harbor. The extraordinary quality criteria for DO in marine water is 7.0 mg/L - above the line is better

3B. Marine Water Quality — Fecal Coliform — Quartermaster Harbor

Target: Marine water meets water quality criteria

About this indicator: Measures marine water quality at King County's monitoring locations within Quartermaster Harbor (Figure 1). Quartermaster Harbor has been designated by Washington State as an extraordinary water body.

Influencing factors: Water carrying nutrients from septic systems, chemicals from motor vehicles and nitrogen from fertilizers degrade marine water quality and reduce oxygen levels for the animals that live and depend on Puget Sound habitats.

2010 Target: Quartermaster Harbor water quality meets marine water quality criteria for the bacteria relating to shellfish harvesting and primary contract recreation.

2010 Finding: All 3 sites meet state water quality criteria

2010 Status: All three Quartermaster Harbor stations met the state water quality criteria for fecal coliform bacteria (low bacteria counts), Figure 1 & 2.

2001-2010 Target: All marine monitoring sites meet the state water quality standard (low bacteria counts).

2001-2010 Assessment: 3 sites; 100% meeting Water Quality standards since 2006

2001-2010 Status: All three sites had annual data that meet state water quality criteria for fecal coliform bacteria, Figure 2. The data has been collected since 2006. The 2006-2010 average is 100% for sites meeting the state water quality criteria.

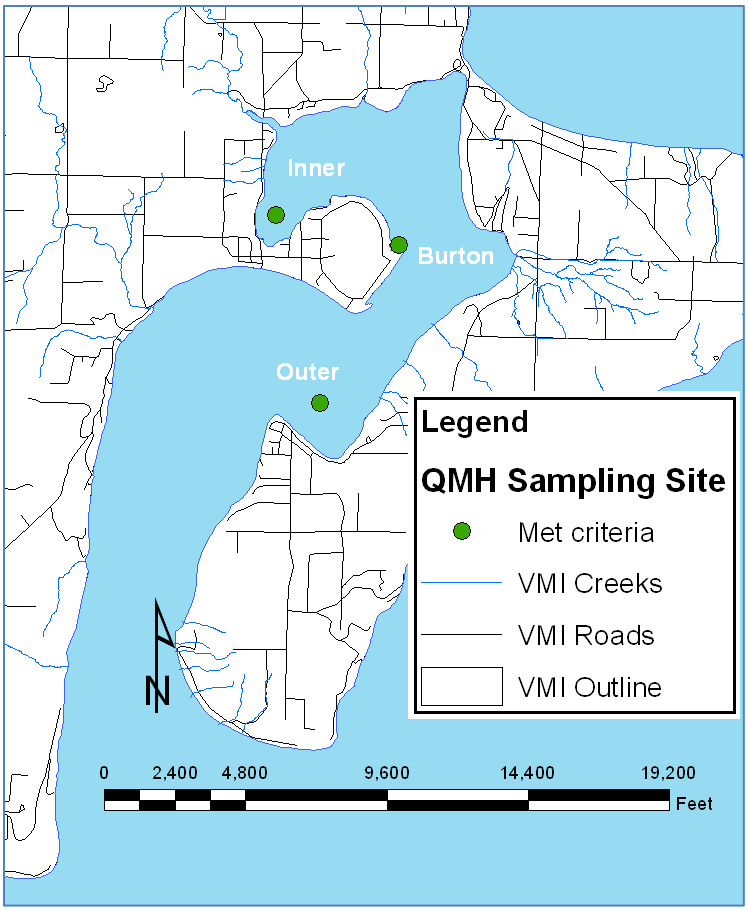


Figure 1. Sampling locations within Quartermaster Harbor for fecal coliform bacteria. All three stations (Inner Harbor, Burton, and Outer Harbor) met (below) the state water quality criteria for fecal coliform bacteria in 2010.

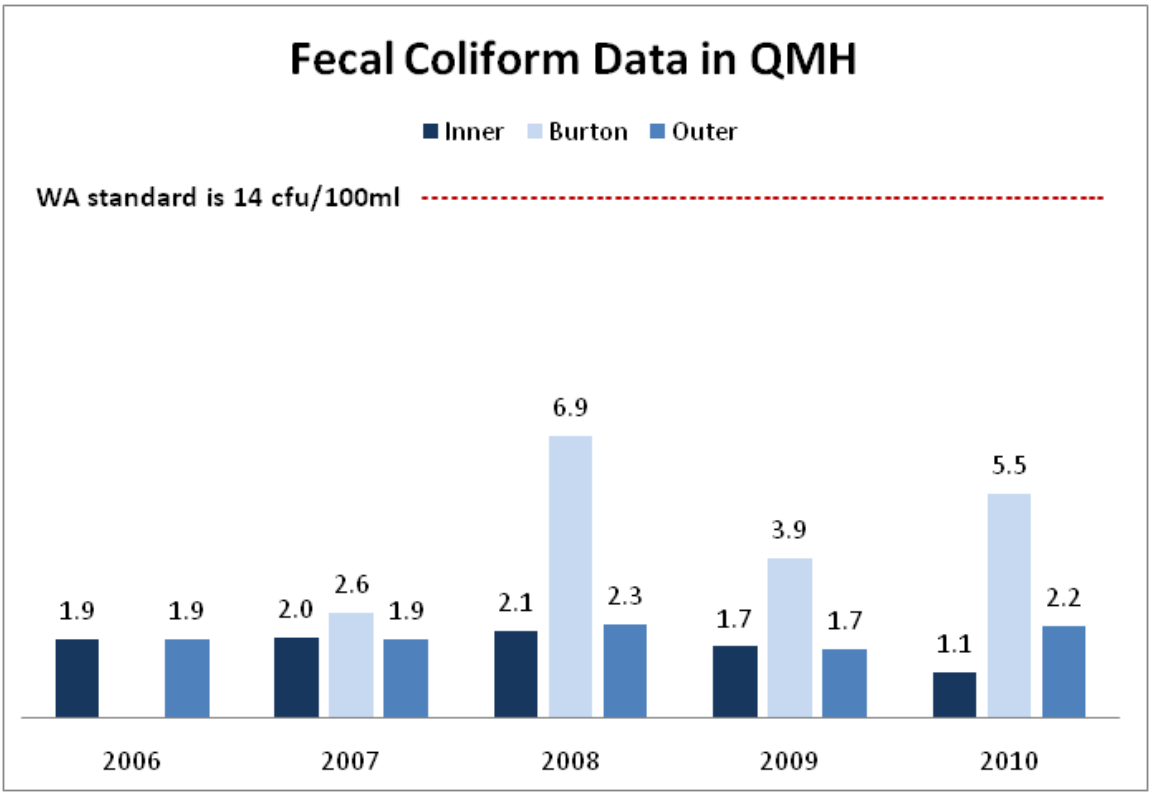


Figure 2. Fecal Coliform bacteria data shown as geometric mean (cfu/100ml) for each station within Quartermaster Harbor (QMH). Inner and outer harbor stations started in 2006 and the Burton station started in 2007. Washington State (WA) standard for fecal coliform bacteria in marine waters is shown at 14 cfu/100ml.

Technical Notes: Marine Water Quality – Fecal Coliform – Quartermaster Harbor

Data source: The data for this indicator comes from King County DNRP/WLRD Marine Monitoring Group.

Collection frequency: The King County DNRP/WLRD Marine Monitoring Group conducts monthly sampling at the inner and outer harbor since 2006. A third station in Quartermaster Harbor, Burton Acres County Park, started in 2007 and is used in the assessment of fecal coliform bacteria.

Methods for analysis: Fecal coliform results are compared to the current marine water fecal coliform criteria, a geometric mean of 14 colony forming units /100ml. Samples either meet or do not meet the marine water fecal coliform criteria. This fecal coliform criteria is calculated over a 12-month sampling period.

Data Reliability and Quality: The data quality of this indicator is high based on the KC SAP/SOP of sampling collection. The reliability is good based on the consistent and regular collection of the data.

Data Reference: King County, Water and Land Resources Division, Science, Monitoring and Data Management Section

Dissolved Oxygen (3A) is another marine water quality indicator for overall health of Quartermaster Harbor.

4. Groundwater Water Levels

Target: Water table levels are maintained or improved with time

About this indicator: Water levels are measured at numerous locations across the island within several different water bearing zones. The frequency of this dataset varies from monthly to annual to longer periods of time between measurements.

Influencing factors: Amount of precipitation for a given year. Changes to recharge areas from land use changes. Changes in water use patterns for a given year.

2010 Target: 2010 data within one standard deviation of baseline average.

2010 Finding: 13 sites; 3 sites higher, 6 sites lower, 4 no change

2010 Status: Sixty sites have water level data during 2001-2010. The majority of these sites are not being actively monitored or monitored on an infrequent (once a year) basis. Thirteen sites have 2010 water level data along with an averaged baseline (2001-2008), Figure 1 and Table 1. Three sites have higher water table elevations in 2010 compared to their baseline average value shown in Figure 1 with bold green color. Six sites have lower 2010 values compared to baseline: yellow for values between 1 & 2 standard deviations; red for values past 2 standard deviations, Table 1 and Figure1. The remaining four sites have 2010 values within their standard deviation also reported as green color in Table 1.

Vashon-Maury Island has multiple water bearing zones, aquifers that are being monitored with the help of volunteers and monitoring wells, Table 1 and Table 2. Consistent regular data allows for the assessment of conditions. Volunteer monitoring began in 2001 while monitoring wells were installed in 2005 and 2007.

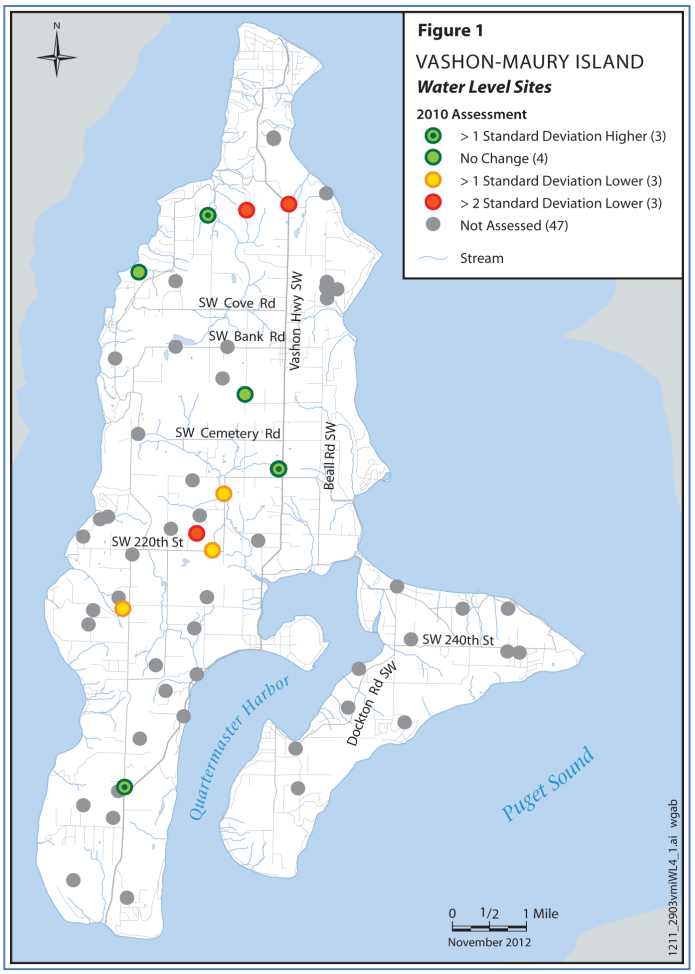


Figure 1. Water level locations used in this indicator. Data shown represent 2010 assessment compared to baseline average. Three sites have higher water table elevations in 2010 compared to their baseline average value: green w/ dot. Six sites have lower 2010 values compared to baseline: yellow for values between 1 & 2 standard deviations; red for values past 2 standard deviations. The remaining four sites have 2010 values within their standard deviation also reported as green color. The remaining 47 sites have too few data points to assess baseline.

Table 1. 2010 Water Table elevations for baseline sites and King County Monitoring wells. An average of the data collected in 2010 was compared to the baseline average (see Table 2) to assess any change. Colors represent change: green (with bold) for sites with higher 2010 values compared to baseline; Yellow for sites with lower (> 1 st dev) values; Red for sites with lower (>2 st dev) values; Green also represent sites with no change (data within the standard deviation)

Site Id		2010 Assessment				Aquifer
		Count	Avg-WT elev	difference	st-dev_ft	
vol_w-06		12	197.0	-0.6	0.2	Qva - Main
vol_w-13		12	158.7	-1.4	1.3	Qpfc - Deep
w-21		11	184.1	**0.4**	0.3	Qva - Main
vol_w-02		6	25.8	-0.5	2.0	Qpo - Deep
KC Wells	w-60	9	178.2	-1.7	0.5	Qva - Main
	w-61	12	240.6	**0.2**	0.1	Qva - Main
	w-63	9	180.1	-0.2	0.1	Qva/Qpfc
	w-64	3	199.7	**1.0**	0.2	Qva - Main
	w-65	12	240.4	0.1	0.1	Qva - Main
	w-70	12	178.3	0.0	0.2	Qpo- Deep
	w-71	10	282.8	0.3	0.3	Qva - Main
	w-72	12	260.6	-0.8	0.3	Qva - Main
	w-73	3	134.7	-1.0	0.8	Qvr - Shallow

Count = Number of data points – volunteers typically report monthly – continuous recorder data are also shown as monthly.
Avg-WT elev = Average water table elevation in feet above sea level.

2001-2010 Target: No long term declines in water table levels over baseline.

2001-2010 Assessment:
15 sites; 1 site - lower levels,
1 site - higher levels, 13 sites - no change 2001 to 2010

2001-2010 Status: One site has a decrease in the water table elevation greater than 1 standard deviation when comparing recent (2009-2010) averaged water table levels to an averaged baseline (2001-2008), Table 2. One site has a greater than 1 standard deviation increase in their recent averaged water table levels as compared to baseline. The remaining 13 sites in Table 2 have difference within 1 standard deviation of data. Another 45 sites have too few data points to assess change through time. King County has 10 monitoring wells which have a limited dataset of water levels data from 2006-2010.

Technical Notes Water Levels on Vashon-Maury Island

Data source: The data for this indicator comes from multiple sources including volunteers, VMI water purveyors and King County WLRD Groundwater Protection Program. Vashon-Maury Island has over 1000 wells including public water sources and individuals.

Collection frequency: A volunteering program was started in 2001 for well owner to self monitor their water levels. Four sites are currently active that started in 2001. Water purveyors monitor their sources on a regular basis and have report their data to King County upon request. The groundwater program collects water level data at 10 monitoring well locations which began in 2006. The KC wells typically have continuous data loggers recording daily water level information. Additional water level data is collected during annual water quality sampling if possible.

Methods for analysis: Total count of water level measurements per site done over 2001 to 2010. For those sites with more than 30 measurements, a baseline average was calculated. This baseline average was compared to a recent (2009-2010) average of water level measurements to assess any change greater than 1 standard deviation. One site has a decline more than 1 standard deviation when comparing recent averaged water level data to baseline. Another site shows an increase over the same time period yet has a limited dataset, Table 2. The remaining 13 sites have no change (within the standard deviation) when comparing baseline to recent data. All other sites (45) have too few data to assess changes through time. The KC well data is reported as monthly data for similar count periods as other datasets.

Data Reliability and Quality: The data quality of this indicator is high based on the KC SOP/training of data collection. The reliability is fair to good. Data reliability from the sources varies. A direct solicitation of data from the water purveyors began in 2011. Vashon-Maury Island has over 1000 wells including public water sources and individuals. King County monitors water levels in 10 monitoring wells.

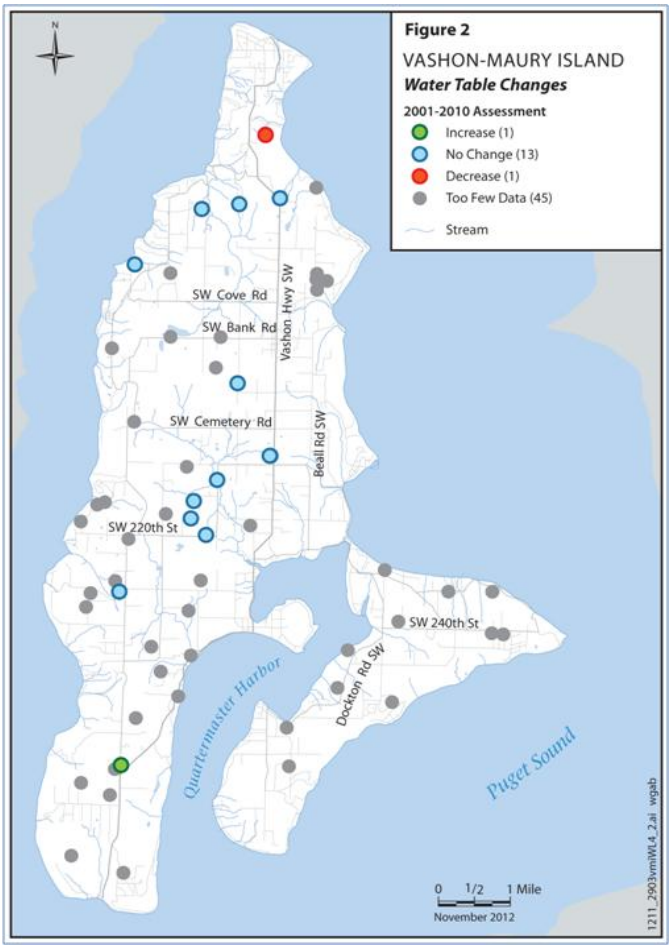


Figure 2. Water level locations used in this indicator. Data shown represent recent status conditions with 1 site having lower recent water table elevation data compared to their baseline while one site has an increase in their recent water table data, Table 2. Thirteen sites have no change in the water table levels when comparing baseline (2001-2008) data to recent (2009-2010) data based on their standard deviation. The remaining 45 sites have too few data points to assess baseline.

Data Reference: King County - Water Resources Evaluation Project – Data Report 2005-2009. http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/vashon-island.aspx

Table 2. Water Table elevations for baseline sites and King County Monitoring wells. For those sites with more than 30 measurements, a baseline average was calculated*. This baseline average was compared to a recent (2009-2010) average of water level measurements to assess any change greater than 1 stand deviation highlighted in color – red for sites with lower recent compared to baseline and green for sites with higher recent compared to baseline.

Site Id		Baseline (2001-08)		Recent (2009-10)		Assessment		Aquifer
		Count	Avg-WT elev	Count	Avg-WT elev	difference	st-dev_ft	
vol_w-06		91	197.5	24	197.1	-0.5	0.5	Qva - Main
vol_w-13		85	160.2	24	158.0	-2.2	2.2	Qpfc - Deep
w-21		77	183.7	23	184.1	0.3	0.9	Qva - Main
vol_w-09		77	159.7	11	160.8	1.1	3.9	Qpo - Deep
vol_w-02		52	26.3	12	24.4	-2.0	2.9	Qpo - Deep
w-02a		35	113.8	2	107.3	**-6.4**	1.5	Qva - Main
KC Wells	w-60	26	179.9	15	178.2	-1.7	2.1	Qva - Main
	w-61	33	240.4	24	240.5	0.1	0.4	Qva - Main
	w-63	31	180.2	15	180.1	-0.1	0.7	Qva/Qpfc
	w-64	8	198.8	4	200.3	**1.4**	0.9	Qva - Main
	w-65	33	240.3	24	240.1	-0.2	0.6	Qva - Main
	w-70	1	178.4	20	178.3	-0.1	0.3	Qpo- Deep
	w-71	1	282.5	18	282.4	-0.1	0.9	Qva - Main
	w-72	1	261.4	14	260.5	-0.9	1.0	Qva - Main
	w-73	1	135.7	5	134.6	-1.1	1.1	Qvr - Shallow

Sites w-60 thru w-73 are King County monitoring wells. Wells 60-65 were installed late 2005 and wells 70-73 were installed late 2007.

*All monitoring wells have continuous water level probes except w-73. This well data is reported as monthly data for similar count periods as other datasets. Sites w-60 and w-64 had multiple rounds of well development which affected the water level data and have lower count values as a result. Site w-62 is "dry" – no water in the screen zone. The continuous data supports the depth to water data noted above.

5. Surface water: Summer Low Flows

Target: Summer low flows are maintained or improve

About this indicator: Summer 7-day average low flow is the metric chosen to represent stream low flow conditions. Summer flows are a critical period for stream health.

Influencing factors: Amount of precipitation for a given year. Changes to the hydrologic pathways from development or modifications to the land cover. Changes to water demand.

2010 Target: Summer (July-October) low flows are maintained or improved.

2010 Finding: 4 sites – 2010 data for all sites are within historic mean flows

2010 Status: Four sites have flow monitored continuously on Vashon-Maury Island – Shinglemill, Tahlequah, Fisher and Judd Creeks, Figure 1. The summer low flow data for all sites are within one standard deviation of the historic mean. Sites are assessed green when within one stand deviation of the mean or above; yellow when below one standard deviation and red when below two standard deviations of the historic mean, Table 1. Figure 2 is an example of a control chart of 7-day average low flow for Judd Creek.

Under the Water Resources Act of 1971, Washington State Department of Ecology is authorized to "establish minimum water flows or levels for streams, lakes, or other public waters for the purposes of protecting fish, game, birds, or other wildlife resources, or recreational or aesthetical values of public waters. Judd, Shinglemill, Fisher and Christensen Creeks have been designated as closed basins by Ecology to preserve flows, Figure 1. Judd Creek was closed in 1951 on the basis that there were no waters available for further appropriation for consumptive use. Christensen, Fisher and Shinglemill Creeks were closed in 1981 on the basis of the need for high instream flow for anadromous fish.

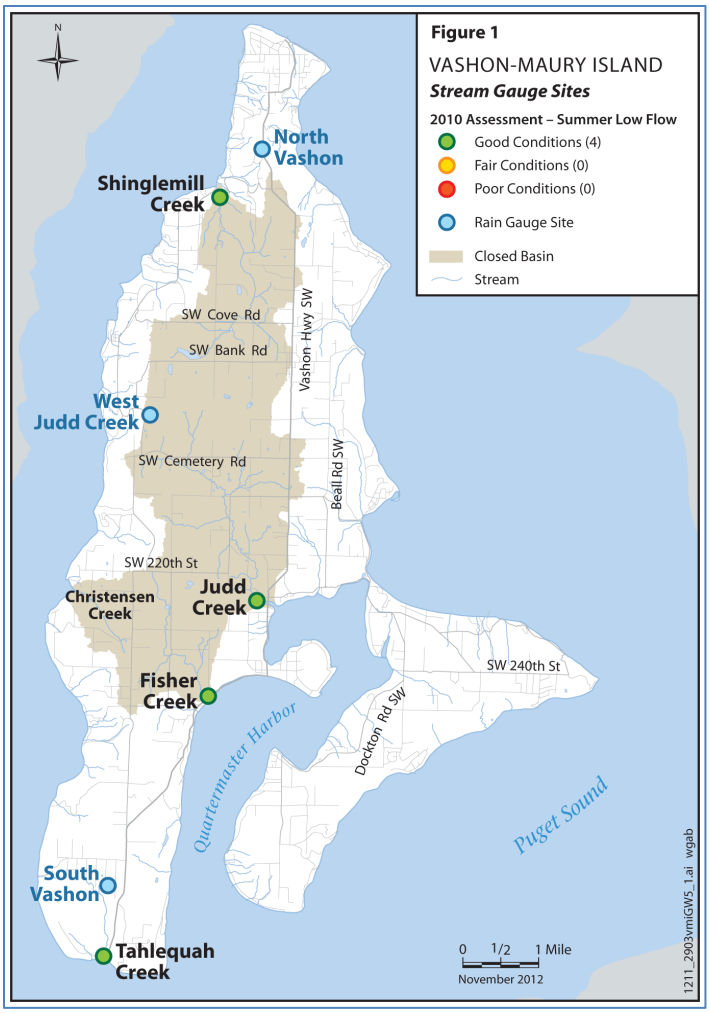


Figure 1. Stream gauge locations used in this indicator. Four sites have flow monitored continuously on Vashon-Maury Island – Shinglemill, Tahlequah, Fisher and Judd Creeks. Summer 7-day average low flow is the metric chosen to represent low stream flow conditions. All sites maintained or improved in 2010. Four basins (Shinglemill, Christensen, Fisher and Judd Creeks) have been designated by Ecology as closed to preserve flow.

2001-2010 Target: Summer low flows are maintained or improve

2001-2010 Assessment: All sites maintained or improved in 2010

2001-2010 Status: Three of the four sites (all but Tahlequah) show changes in summer low flows that reflect changes in total amount of precipitation when looking over the last ten years; 2001-2010, Figure 3. Tahlequah has maintained the same flows for the last five years and doesn't show the same pattern that reflects total rainfall as the other sites.

Table 1. Summer low flow data for 4 creeks on Vashon-Maury Island. Data are presented as 7-day low flow for July through October for each Water Year 2001-2010. Sites are assessed green when within one stand deviation of the mean or above; yellow when below one standard deviation and red when below two standard deviations of the historic mean. Locations of each site are shown in Figure 1. Units are cubic feet per second (cfs).

Creek\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Judd	1.4	1.5	1.3	1.2	1.2	1.2	1.5	1.3	1.1	1.4
Shinglemill	1.4	1.4	1.5	1.5	1.4	1.6	1.8	1.4	1.4	1.4
Fisher	—	—	—	—	0.4	0.4	0.6	0.3	0.4	0.4
Tahlequah	—	—	—	—	0.1	0.2	0.2	0.2	0.2	0.2

Monitoring began on Fisher and Tahlequah Creek in 2005; Judd Creek in 2000 and Shinglemill Creek in 1999.

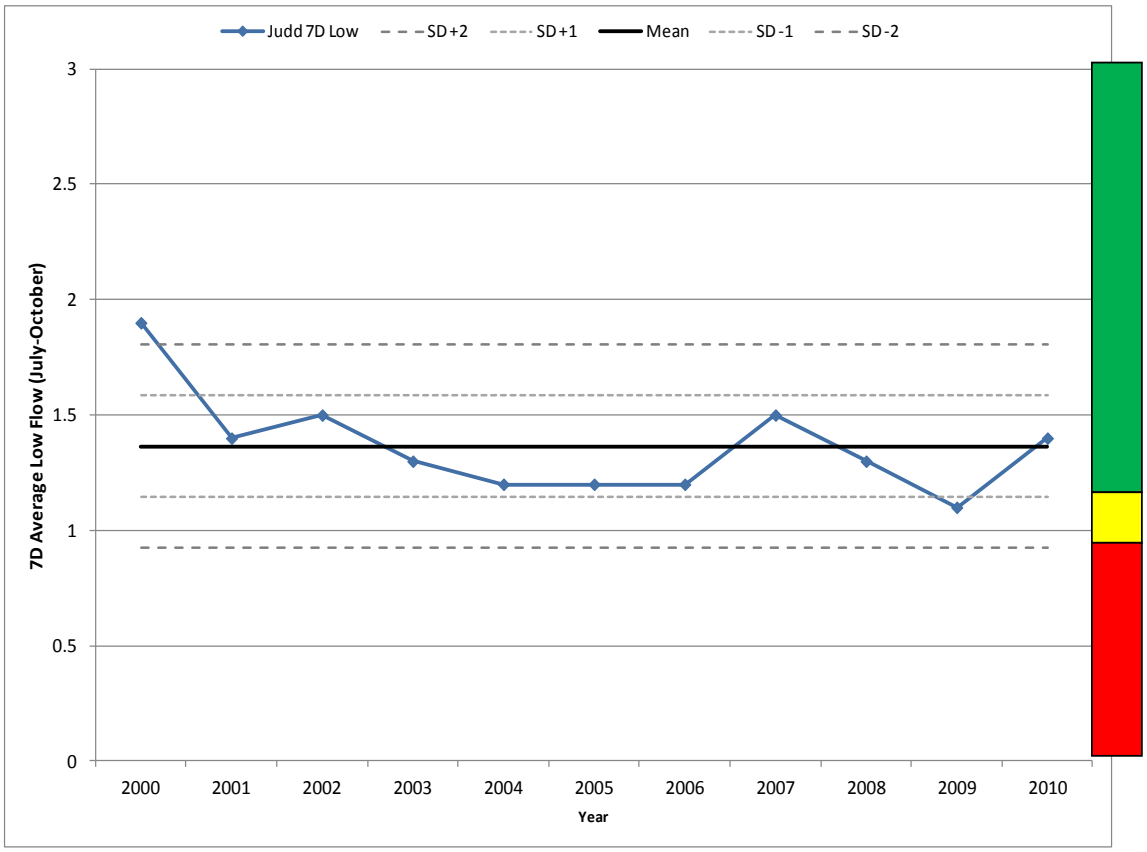


Figure 2. Control chart for Judd Creek. Data presented as 7-day low flow for July through October for each Water Year since data collection started. Solid line is the mean of all historic data. Dashed lines are standard deviations (SD) from the mean. Increasing values represent more flow. Assessment colors are shown for reference and are explained in greater detail within technical notes section. Units are cubic feet per second.

Technical Notes Surface Water: Summer Instream Flows

Data source: The data for this indicator comes from King County Water and Land Resources Division.

Collection frequency: King County has been monitoring stream flow continuously at four sites since 2005 – Shinglemill, Judd, Fisher, and Tahlequah Creeks. Shinglemill and Judd Creeks have been monitored since 1999 and 2000, respectively.

Methods for analysis: A 7-day low flow for a stream is the average flow measured during the 7 consecutive days of lowest flow during any given year. The summer period is assessed as July through October. The minimum flow for the summer period is recorded and tracked year to year, Figure 3. Sites are assessed 'green' when within one stand deviation of the mean or above; 'yellow' when below one standard deviation and 'red' when below two standard deviations of the historic mean, Table 1.

Data Reliability and Quality: The data quality of this indicator is high based on the KC SAP/SOP of the data collection. The reliability is good based on the consistent and regular collection of the data. Vashon-Maury Island has over 70 stream basins. Judd, Shinglemill, Fisher, and Tahlequah Creeks are the four largest basins representing 32% of the total area of the island.

Data Reference: King County Water Resources Evaluation Project – Data Reports 2005-2010.

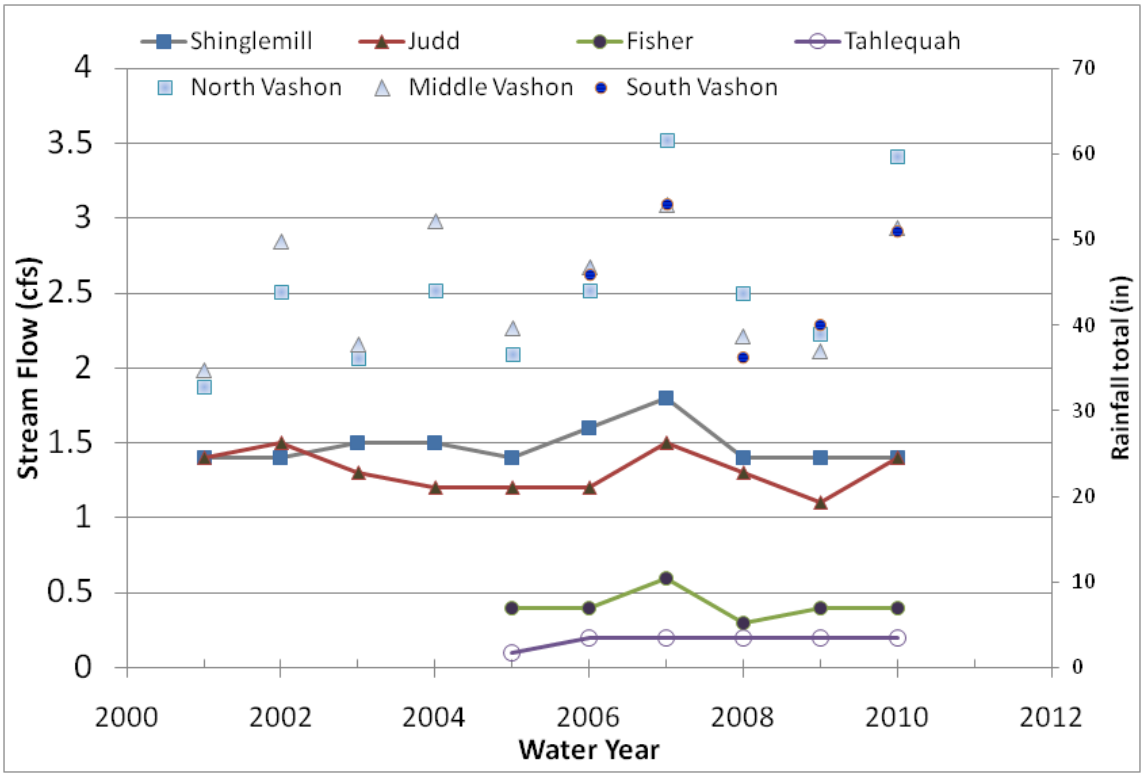


Figure 3. Summer low flow data for 4 creeks on Vashon-Maury Island. Data are presented as 7-day low flow for July through October for each Water Year 2001-2010. Increasing values represent more flow. All sites improved or maintained in the last two years (2009-2010). Rainfall totals (inches per water year) are shown on the second axis for three (North, Middle and South) precipitation sites on Vashon Island.

6. Surface water: Stream Flashiness

Target: Flashiness Indicator is maintained or improved

About this indicator: A metric to indicate how a stream responds to increased flow associated with routine storm events. The R-B Index has lower inter-annual variability than many other flow regime indicators, making it well suited for detecting gradual changes in flow regimes associated with changes in land use and in land management practices.

Influencing factors: Changes to the hydrologic pathways from development or modifications to the land cover. Amount of precipitation for a given year. The index values increase as the frequency and magnitude of storm events increase and decrease accordingly.

2010 Target: The flashiness indicator is maintained or improved.

2010 Finding: 4 sites – 2010 data for all sites are within historic mean values

2010 Status: Four sites have flow monitored continuously on Vashon-Maury Island – Shinglemill, Tahlequah, Fisher and Judd Creeks, Figure 1. All sites have maintained their R-B index values since measurements began however more time is necessary before a trend can be determined. For Shinglemill and Judd Creeks that began in 1999 while Fisher and Tahlequah creeks have been monitored since 2005. The R-B index values are shown in Table 1 and Figure 2 for the last ten years; 2001-2010.

2001-2010 Target: Flashiness Indicator is maintained or improved

2001-2010 Assessment: All sites maintained in 2009 and 2010.

2001-2010 Status: When assessing the ten year period of 2001-2010, all four sites respond to changes to the environment such as lower R-B index values for years with lower precipitation totals and higher values when the opposite occurs, Figure 2. Judd and Shinglemill Creek have 10 years of flow data and appear to be maintaining R-B index values however additional data (5+ years or more) is required to determine if any changes are more than variations in total amount of precipitation.

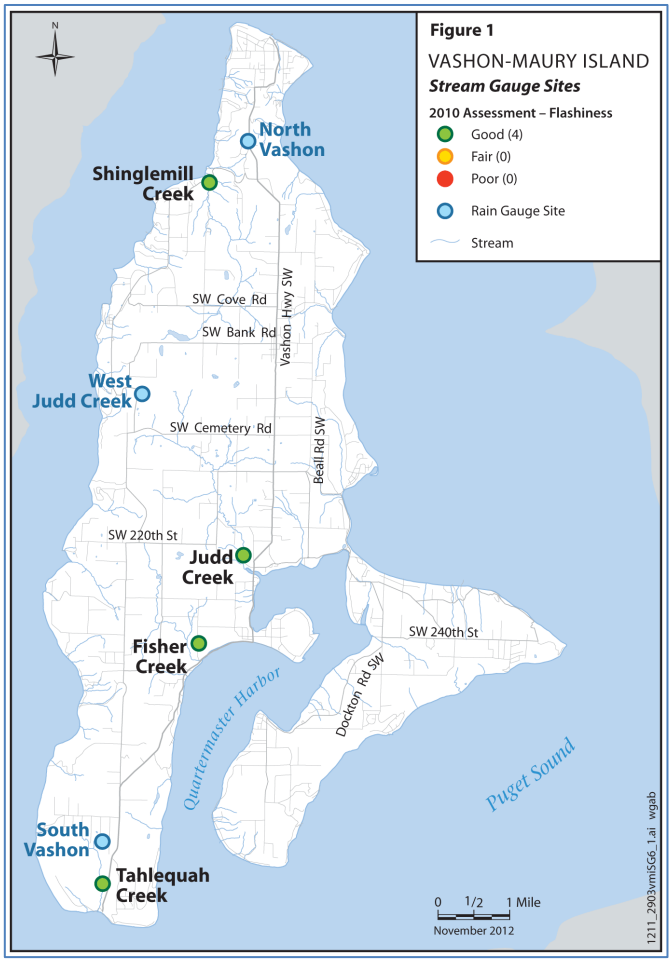


Figure 1. Stream gauge locations used in this indicator. Four sites have flow monitored continuously on Vashon-Maury Island – Shinglemill, Tahlequah, Fisher and Judd Creeks. All sites maintained or improved in 2009 and 2010.

Table 1. R-B Index data for 4 creeks on Vashon-Maury Island for each Water Year 2001-2010. The R-B Index has annual variability and the overall trend (over many years) can indicate gradual changes in flow regimes associated with changes in land use and in land management practices. Locations of each site are shown in Figure 1. A range of R-B index values is shown in Figure 3. Units are cubic feet per second.

Creek\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Judd	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3
Shinglemill	0.2	0.4	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.3
Fisher	—	—	—	—	0.2	0.2	0.3	0.2	0.2	0.2
Tahlequah	—	—	—	—	0.2	0.3	0.3	0.3	0.3	0.3

Technical Notes **Surface Water: Stream Flashiness**

Data source: The data for this indicator comes from monitoring done by King County Water and Land Resources Division.

Collection frequency: King County has been monitoring stream flow continuously at four sites since 2005 – Shinglemill, Judd, Fisher, and Tahlequah Creeks. Shinglemill and Judd Creeks have been monitored since 1999 and 2000, respectively.

Methods for analysis: Each site has flow measured continuously. The R-B index is calculated for each site for a given water year. The flashiness indicator is the sum of the absolute values of the day-to-day changes in mean daily flow divided by mean daily flow for the year. The resulting index is unit-less. The data are presented for the last 10 water years 2001 - 2010, Figure 2. Lower values represent a more stable hydrologic system than higher values, Figure 3.

Data Reliability and Quality: The data quality of this indicator is high based on the KC SAP/SOP of the data collection. The reliability is good based on the consistent and regular collection of the data. The R-B index is an indicator that shows trends with longer (~20 years or more) data sets. As notes above, additional data will need to be collected before a full assessment can be done. Vashon-Maury Island has over 70 stream basins. Judd, Shinglemill, Fisher, and Tahlequah Creeks are the four largest basins representing 32% of the total area of the island.

Data Reference:

King County - Water Resources Evaluation Project – Data Report 2005-2009.
http://www.kingcounty.gov/environment/waterandland/groundwater/management-areas/vashon-maury-island-gwma/vashon-island.aspx

Baker et al., 2004, A new flashiness index: Characteristics and applications to Midwestern rivers and streams, Journal of the American Water Resources Association (JAWRA) 40(2):503-522.

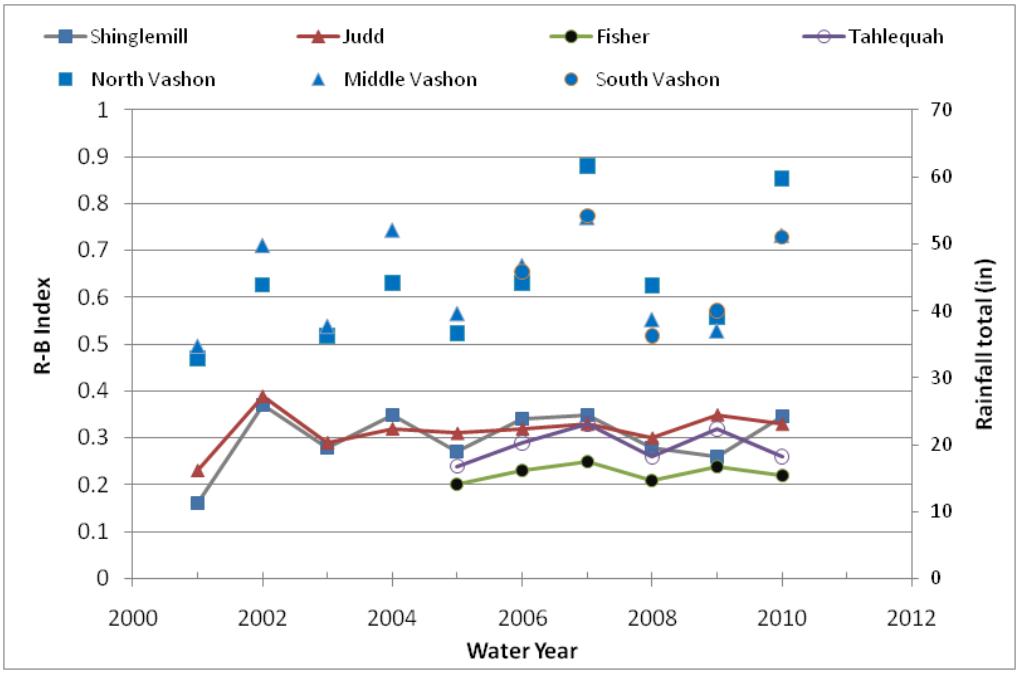


Figure 2. Flashiness indicator shown as R-B index for 4 creeks on Vashon-Maury Island. Data are shown by Water Year 2001-2010. The R-B Index has annual variability and the overall trend (over many years) can indicate gradual changes in flow regimes associated with changes in land use and in land management practices. Rainfall totals (inches per water year) are shown on the second axis for three (North, Middle and South) precipitation sites on Vashon Island.

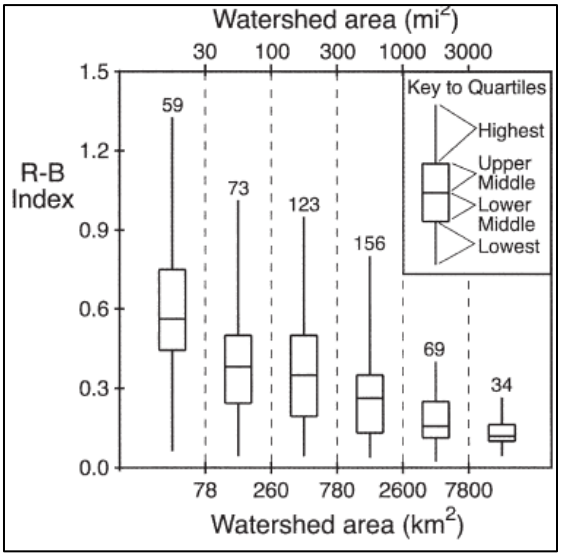


Figure 3. Distribution of R-B Index Values for stream in 6 size classes of watersheds. Quartiles of index values along a continuum of Stable (lower values) to Flashy (higher values) streams. Vashon streams would be within the first size class and have the lowest quartile values, Table 1. [Adapted from Baker et al., 2004 – Figure 4.]

7. Stream Benthic Macroinvertebrate Monitoring

Target: BIBI scores are ranked 'Good' to 'Excellent' each year

About this indicator: Benthic macroinvertebrates are monitored because they are good indicators of the biological health of stream systems and play a crucial role in the stream ecosystem.

Influencing factors: Stream flows, increased sedimentation in stream flows – increased sediment typically infers low benthic community diversity; and excessive nutrients/contaminants in stream can have a negative effect on benthic communities.

2010 Target: The Benthic Index of Biologic Integrity (BIBI) scores are ranked Good to Excellent indicating diverse biological conditions in local creeks.

2010 Finding:
14 sites have data in 2010:
4 sites – Fair;
10 sites – Poor & Very Poor

2010 Status: Fourteen sites in eight different stream basins were monitored in 2010. All sites ranked Fair to Very Poor in 2010, Figure 1. Four sites ranked as 'Fair' while 2 other sites ranked as 'Very Poor'. The remaining 8 sites were ranked 'Poor'. See Table 1 for comparisons to previous data. Data collection started in 2005 at three sites.

2001-2010 Target: BIBI scores are maintained or improved with time.

2001-2010 Assessment:
Overall Island BIBI scores decreased from 2005 to 2010.

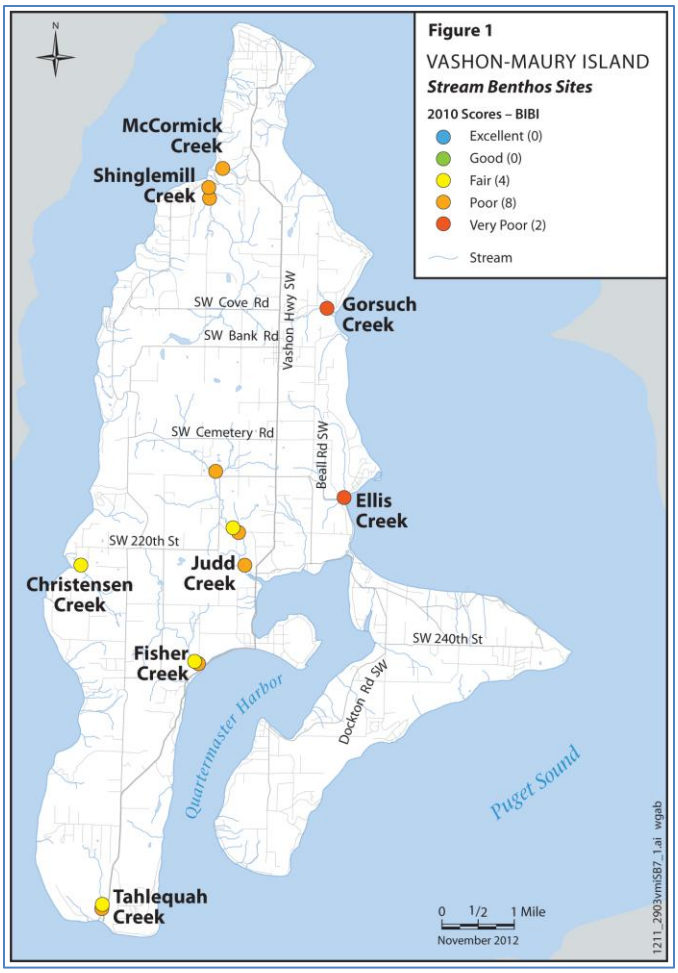


Figure 1. Stream Benthos locations used in this indicator – color shown are for 2010 scores. Fourteen sites in 8 stream basins were monitored in 2010. All sites ranked in the Fair/Poor/Very Poor categories. Fisher and Tahlequah creeks have 2 sites each that are close in proximity. These sites are graphically shown apart to display their rankings.

2001-2010 Status: Annual BIBI scores for each stream are shown in Figure 2 and Table 1 for years 2005-2010. The sites appear to have slight annual variability with a few sites improving from 2009 to 2010. Overall, the island wide average has decreased since 2005 to 2010 from a score of 28.0 to 24.5.

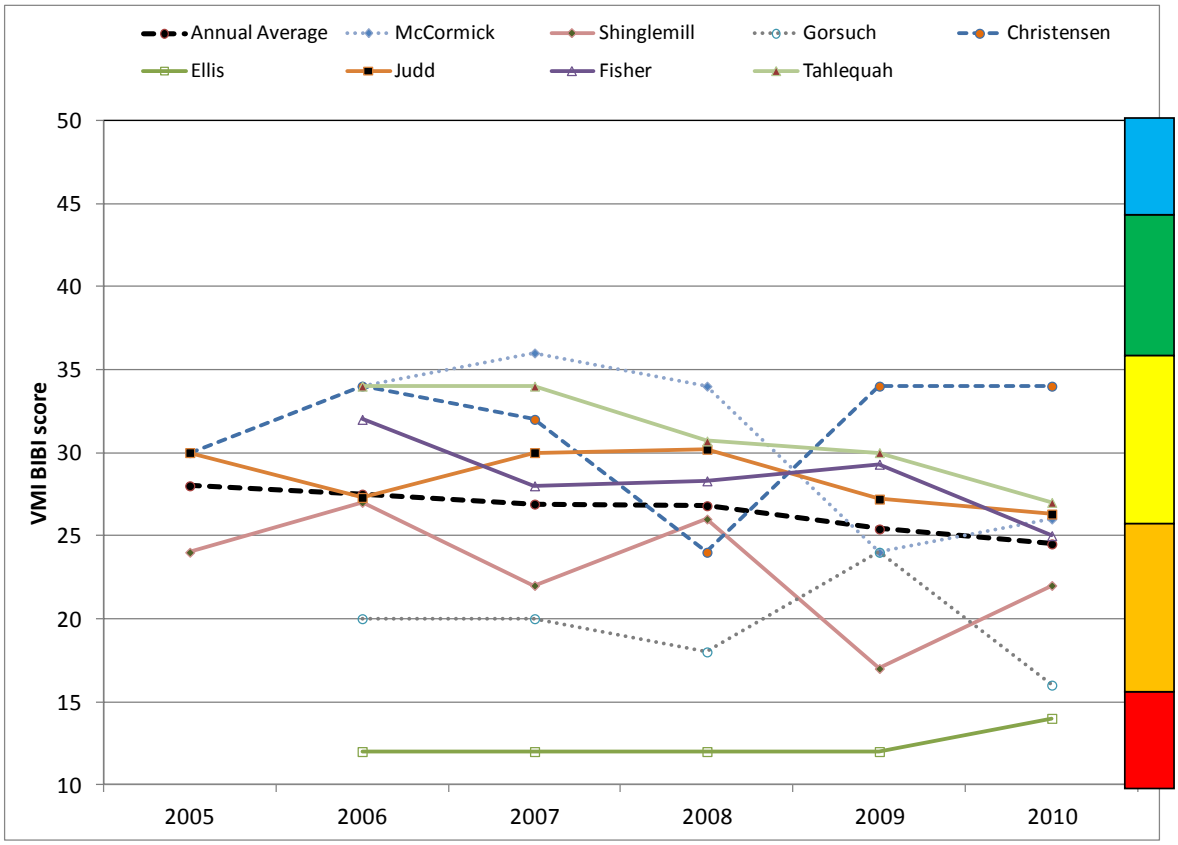


Figure 2. BIBI score for all Vashon Island sites from 2005 to 2010. All sites rank Fair to Very Poor based on the BIBI categories, see Table 1. An averaged Island-wide score was calculated and shows a decline from 2005 to 2010. This decline starts in Year 2005 ranked as Fair while the remaining years are ranked as Poor. Rankings are as follows: Very Poor 10-17 + red color; P = Poor 18-27 + orange color; F = Fair 28-37 + yellow color; G = Good 38-45 + green color; E = Excellent 46-50 + blue color

Technical Notes Stream Benthic Macroinvertebrate Monitoring

Data source: The data for this indicator comes from sampling efforts done by two King County departments: Transportation - Roads and Natural Resources and Parks.

Collection frequency: Initial annual stream benthos sampling started in 2005 at three locations. The number of sites has increased since then to 14 locations monitored in 2010. A total of eight different stream basins are being monitored annually – McCormick; Shinglemill, Christenson, Tahlequah, Fisher, Judd, Ellis, and Gorsuch.

Methods for analysis: The BIBI scoring system is a quantitative method for determining and comparing the biological condition of streams. The Puget Sound Lowlands BIBI is calculated three different ways based on the taxonomic resolution of macro-invertebrate data: Species-Family, Species-Genus, and Family. Each of the BIBI scoring methods is composed of these metrics which are then added together for the single, integrated overall BIBI score. The overall BIBI score is associated with one of the following biological condition categories. The categories are Excellent, Good, Fair, Poor and Very Poor. The BIBI scores can range from 10 (Very Poor) to 50 (Excellent). An example of category totals for Species-Family is: Very Poor [10-16]; Poor [18, 26]; Fair [28, 36]; Good [38, 44]; Excellent [46, 50].

Data Reliability and Quality: The data quality of this indicator is high based on the KC SAP/SOP of sampling collection. The reliability is good based on the consistent and regular collection of the data. Vashon-Maury Island has 75 mapped streams discharging into Puget Sound.

Data Reference: Puget Sound Stream Benthos http://pugetsoundstreambenthos.org/default.aspx

Table 1 Benthic Index of Biologic Integrity (BIBI) scores for all Vashon Island creeks from 2005 to 2010. For creeks with more than one site, the score represents an average. All sites rank between Fair to Very Poor based on the BIBI categories. An Island-wide score was calculated by averaging all the data into a single score and shows a decline from 2005 to 2010.

Creeks\Year	2005	2006	2007	2008	2009	2010
Christensen	30	34	32	24	34	34
Ellis	—	12	12	12	12	14
Fisher	—	32	28	28.3	29.3	25
Gorsuch	—	20	20	18	24	16
Judd	30	27.3	30	30.2	27.2	26.3
McCormick	—	34	36	34	24	26
Shinglemill	24	27	22	26	17	22
Tahlequah	—	34	34	30.7	30	27
Annual Average	28.0	27.5	26.9	26.8	25.4	24.5

Ranks: Very Poor =10-17 + red color
Poor = 18-27 + orange color
Fair = 28-37 + yellow color
Good = 38-45 + green color
Excellent = 46-50 + blue color

8. Salmon Population

Target: Number of Salmon returning is maintained or increased

About this indicator: The number of returning salmon are recorded and tracked year to year. This is an indicator of the biological health of stream systems and can play a crucial role in the stream ecosystem.

Influencing factors: Numerous items influence the number of salmon returning year to year. Data on Vashon is not assessed due to lack of data collection in 2010.

2010 Target: The number of returning salmon are recorded and tracked year to year

2010 Finding: No data reported in 2010

2010 Status: No data were reported to Salmon Watchers in 2010. Overall participation in Salmon Watchers data collection has been decreasing since 2002. Data shown in Figure 1 is from 2002 as an example of the potential data collection.

2001-2010 Target: The number of returning salmon are maintained or increase over time.

2001-2010 Assessment: Overall Salmon Watchers data collection effort has been decreasing from 2002 to 2010.

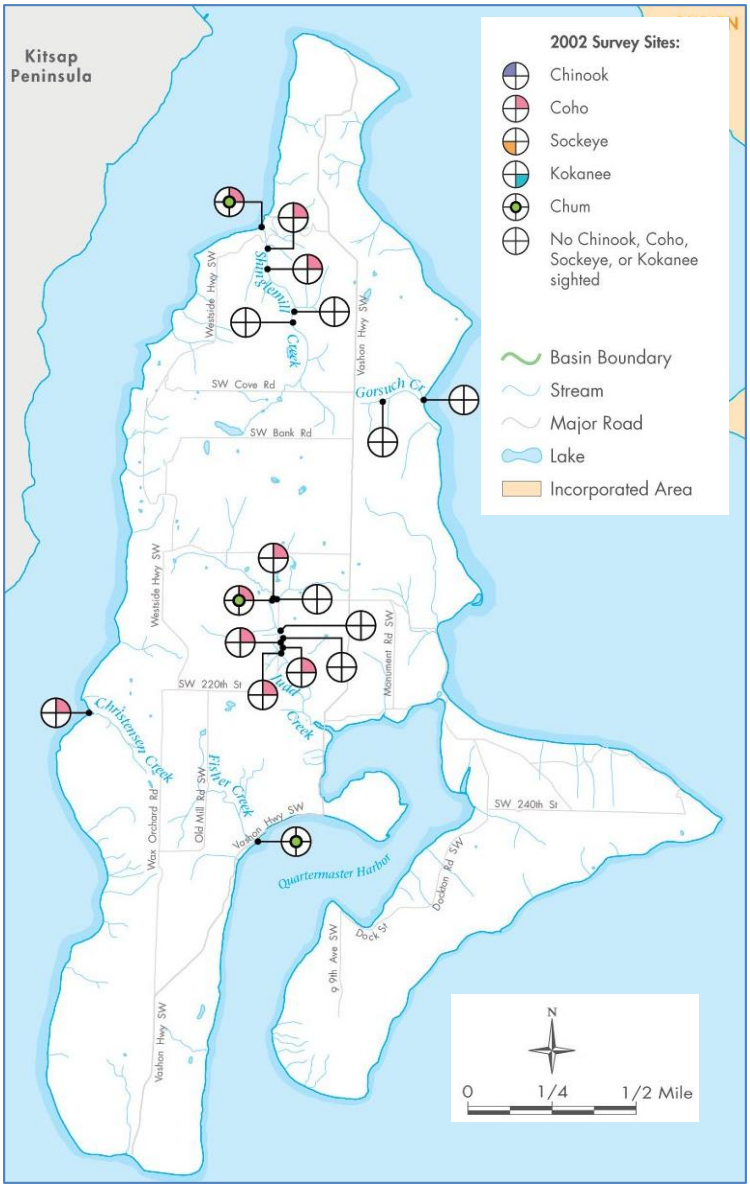


Figure 1. Salmonids Observed on Vashon-Maury Island in 2002. No data was reported in 2010. This Figure is an example plot of data if community involvement in Salmon Watchers increases again to previous levels. Most recent data in 2009 had no salmonids observed at two locations on Shinglemill Creek.

2001-2010 Status: No data were reported to Salmon Watchers program in 2010. Overall participation in Salmon Watchers data collection has been decreasing since 2002. The number of salmon reported per survey year has decreased since 2001 for several creeks, Table 1. However, the number of volunteers reporting the data and the number of sites surveyed has also decreased over the same period. At this point, there is insufficient data to conclude whether salmon populations are maintaining.

Table 1. Overall Salmon Watchers data collection effort on Vashon Maury Island in the last 10 years. The table shows an "**S**" for surveyed creek or "N" for no data collected for a given creek by year from 2001 until 2010. The number shown in parenthesis (1) refers to the number of live fish reported during that surveyed year. Each creek may have numerous reaches surveyed – as example in 2002: 5 reaches in Shinglemill Creek were surveyed, 2 reaches in Gorsuch Creek and 8 reaches in Judd Creek. No data were reported in 2010. In 2009, only 2 reaches of Shinglemill Creek were surveyed.

Creek\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Shinglemill Creek	**S (33)**	**S (11)**	**S (2)**	**S (0)**	**S (1)**	**S (0)**	**S (1)**	**S (0)**	**S (0)**	N
Christensen Creek	**S (0)**	**S (1)**	**S (1)**	N	**S (0)**	**S (0)**	N	N	N	N
Fisher Creek	**S (30)**	**S (6)**	**S (1)**	N	**S (2)**	N	**S (2)**	**S (1)**	N	N
Judd Creek	**S (136)**	**S (163)**	**S (321)**	**S (146)**	**S (31)**	**S (27)**	**S (1)**	**S (4)**	N	N
Gorsuch Creek	N	**S (0)**	N	N	N	N	N	N	N	N
Number of reported surveyed periods per year - all creeks	195	302	285	79	113	67	58	70	16	0

Technical Notes Salmon Population

Data source: The data for this indicator comes from King County's Salmon Watchers Program. This program involves volunteers watching streams for spawning salmon in King and Snohomish Counties.

Collection frequency: Volunteers watch for fish on their assigned creeks two times a week from September through December. Volunteers report their data to King County when completed. No data were reported in 2010. As many as five creeks have been monitored in the past – Shinglemill, Christenson, Fisher, Judd, and Gorsuch Creek, Table 1.

Methods for analysis: Volunteers are trained to identify fish in creeks and report their data to King County when their surveying period is completed. King County compiles the data by stream, reach, Juveniles, Redds, Citizens, SpeciesCode, LiveCount, DeadCount, FinsClipped, and Tagged. King County writes a report summarizing the data collected annually, (see link below).

Data Reliability and Quality: The data quality of this indicator can be good to high based on the training of observers. The reliability is poor based on the recent participation. Vashon-Maury Island has 75 mapped streams. Sixteen of these creeks are reported as fish bearing in the VMI Reconnaissance Report (2004).

Data Reference: Salmon Watcher Program, Volunteer Monitoring Program
http://www.kingcounty.gov/environment/animalsandplants/salmon-and-trout/salmon-watchers.aspx

Vashon-Maury Island Reconnaissance Report (2004) King County
http://www.kingcounty.gov/environment/watersheds/central-puget-sound/vashon-maury-island/recon-report.aspx

9. Total Annual Island-wide Water Use

Target: Total water consumption is reliability tracked year to year

About this indicator: The total island-wide water consumption is calculated from four water users – Group A public water systems (PWS), Group B PWS, individuals and agricultural water users.

Influencing factors: Not all of the water users report their usage. Weather influences overall usage with drier years typically having higher annual totals

2010 Target: Total island-wide water consumption is calculated per year

2010 Finding: 2010 total water usage estimated to be 489 Million gallons per year (MGY)

2010 Status: Water use is estimated to be 489 Million gallons per year (MGY) Island-wide for 2010. The water usage is estimated from the following water users: 21 Group A PWS; 143 Group B PWS; over 1000 individual wells and almost 200 agricultural water users, Figure 1.

Public water systems serve approximately 90% of the island population with Group A PWS (~80%) and Group B PWS (~10%). The remaining (~10%) population get their water from individual wells.

Several studies have assessed the amount of recharge that potentially occurs annually on VMI and provides a range of recharge from 3200 to over 10,900 Million gallons per year. Not all of the recharge water is available for usage due to aquifer retention and recovery factors. The 2010 water use estimate of 489 MGY is 4 to 15% of the recharge range, Table 1.

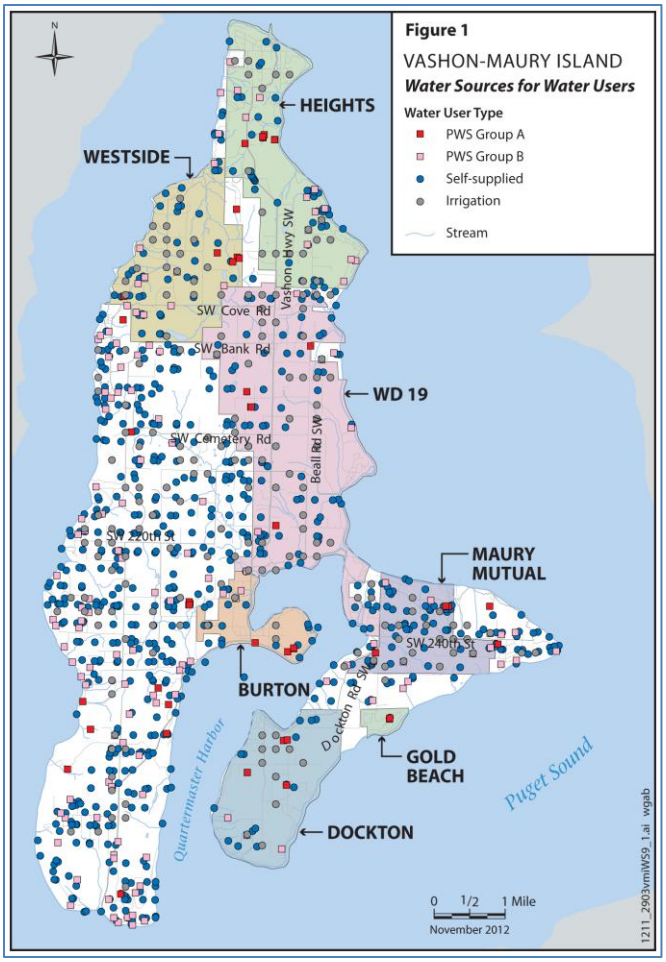


Figure 1. Location of water sources for four water users – Group A public water systems (PWS), Group B PWS, individuals and irrigators. The water service areas for seven Group A PWS are shown. These seven water service areas are the largest on the island serving an associated population of 7,500. In total, there are 21 Group A PWS; 143 Group B PWS; over 1000 individual wells and almost 200 agricultural water users.

2001-2010 Target: Total island-wide water consumption is tracked year to year

2001-2010 Assessment: Average annual consumption – 515 MPY from 2001-2010

2001-2010 Status: The 10 year (2001-2010) average of total Island-wide water consumption is 515 MGY. The annual total consumption ranged from 496 to 535 MGY during this period. Typically, consumption increased during periods with lower rainfall totals and decreased during periods with higher rainfall totals. Water use is estimated from four types of water users as noted in the Technical Notes section.

Technical Notes Annual Total Island-wide Water Consumption

Data source: The data for this indicator comes from Group A and Group B public water systems (PWS), individuals and agricultural water users. Group B PWS are not required to report their usage and individual wells do not typically have meters to assess their usage. Both of these user groups have a small subset that do report their usage. However, this subset of users and their usage data are not totally representative of the entire user group. The irrigation data was estimated based on agricultural categories [horticulture; livestock; mixed and unknown], input from King County agricultural program & King Conservation District. Irrigation rates are derived from NRCS – Natural Resources Conversation Service and refined based on irrigation practices on island.

Collection frequency: Group A PWS are required to keep track of their water usage. Recent changes require more Group A PWS to report their usage annually. Thirteen of the 21 Group A PWS have reported their usage for 2010 via the new state reporting requirement. The other water users are not required to report their usage. King County has volunteers who reported their usage. Two group B PWS report their usage along with eight individual well owners. Data from each of these user groups represent about 1% of their respective users. Water use data has been requested from a variety of users.

Methods for analysis: Annual data that is reported is compiled into island-wide totals. For systems without data, averages of reported data are applied to the remaining PWS. Recent modeling work on VMI required a gathering of water use information. Much of this data is based on that initial gathering and supplemented with a small subset of users who report their water usage.

Data Reliability and Quality: The data quality of this indicator can be good when data is reported from users. Estimates are based on a small subset of data users and compared to other published data – see collection frequency for number of reported users for each type. The reliability is fair based on the recent participation and should improve due to changes in reporting requirements for most Group A PWS. In total, there are 21 Group A PWS; 143 Group B PWS; over 1000 individual wells and almost 200 agricultural water users.

Data Reference: Water Purveyors; various King County programs including Groundwater, Agricultural, UTRC; and VMI Volunteer Monitoring Program who self report usage.

Carr / Assocs. 1983. Vashon / Maury Island Water Resources Study. Submitted to the King County Dept of Planning and Community Development. December 1983.

U.S. Geological Survey, 2004b, Estimated domestic, irrigation, and industrial water use in Washington, 2000: U.S. Geological Survey Scientific Investigations Report 2004-5015,16p.

Vashon-Maury Island Groundwater Advisory Committee (VMI GWAC). 1998. Vashon-Maury Island Ground Water Management Plan. Prepared by King County DNR and Seattle-King County Dept of Public Health. Final, submitted December 1998

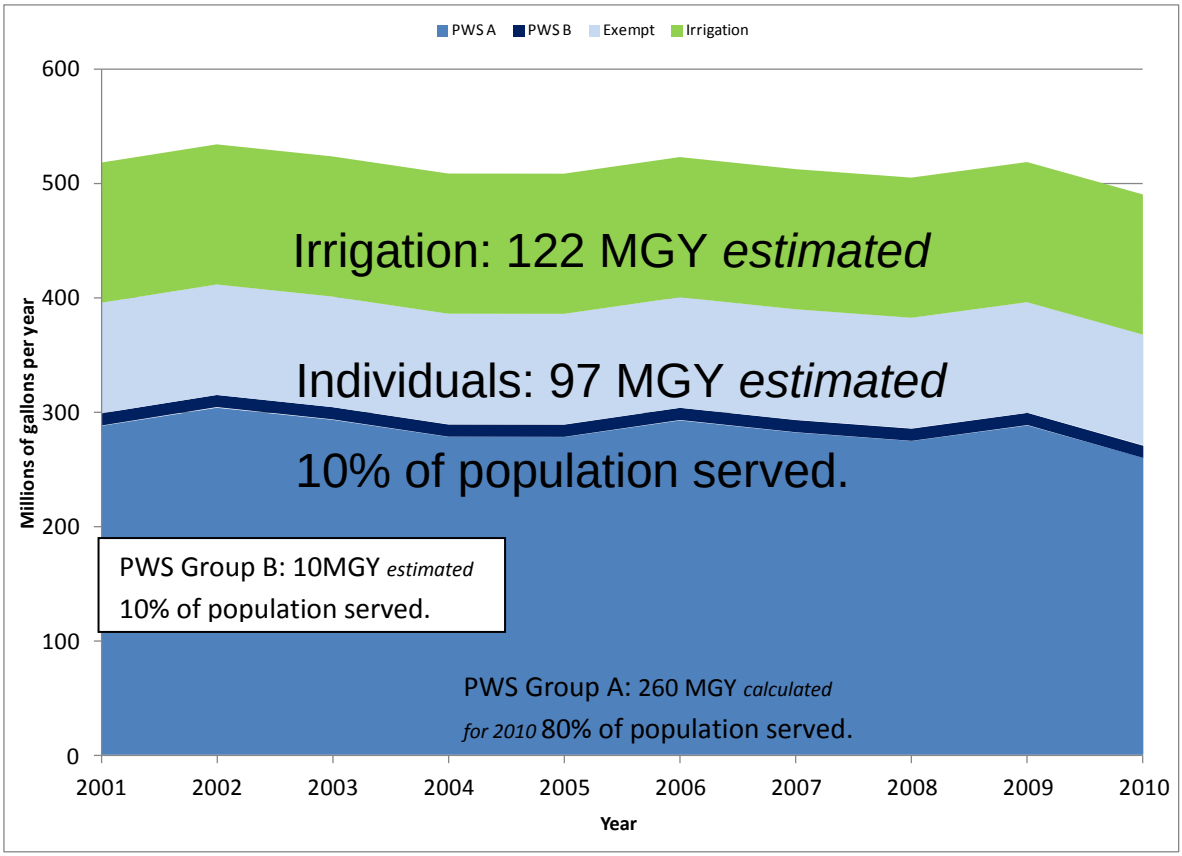


Figure 2. The total island-wide water consumption is calculated from four water users – Group A public water systems (PWS), Group B PWS, individuals and irrigators. The data are presented as millions of gallons per year (MGY). Only the Group A PWS report their water usage data on a regular basis. The other water users are shown with constant usage based on their estimations: PWS B = 10MGY; Exempt/Individuals = 97 MGY and Irrigators = 122 MGY. See technical notes section for more details about usage estimates.

Table 1. Amount of recharge that potentially occurs annually on Vashon-Maury Island. Several studies have provided a range of recharge from 3200 to over 10,900 Million gallons per year (MGY). Not all of the recharge water is available for usage due to aquifer retention and recovery factors. The 2010 Total Island-wide water use estimate of 489 MGY is 4 to 15% of the recharge range. Water balance data adapted from Carr, 1983 and VMI GWAC, 1998.

Water Budget	GWMP	Carr
	Units: MGY	
Recharge	10973	3212
2010 usage	% of total recharge	
489	4%	15%

10. Per Capita Water Consumption

Target: Per Capita water usage is tracked year to year

About this indicator: Per capita water consumption is calculated from the total island wide water consumption divided by population. This indicator reports data from three types of water users Group A public water system (PWS) users, Group B PWS users and individuals.

Influencing factors: Weather conditions - amount of precipitation and average daily temperature for a given year. Limited water usage data available because not all water users report their usage.

2010 Target: Per capita water usage is calculated per year

2010 Finding: 2010 per capita water usage ~ 80 gallons per day

2010 Status: 2010 Per capita water use of 80 gallons per day is based on an average of the two largest group A PWS per capita data (70 and 90), Table 1.

Table 1. 2010 Per Capita Data shown as gallons per day based on the two largest Group A public water systems on Vashon-Maury Island. NOTE*: both systems have non-residential connections and residential equivalence units are shown – average population per connection is 2.3. GPD: gallons per day.

	2010 Data	
User	Group A PWS - H	Group A PWS - 19
Total - Gallons	46,578,890	107,138,197
Population served	1,830	2,641
Residential usage per connection - GPD	160	208
Per Capita - GPD*	70	90
Averaged Per Capita - gallons per day (GPD)	80	

2001-2010 Target: No long term (10 or more years) increase in per capita water consumption.

2001-2010 Assessment: Per capita usage – 83 GPD from 2001-2010

2001-2010 Status: Per capita water consumption is estimated to be 83 gallons per person per day from 2001 to 2010. The per capita data is estimated from the total usage divided by the population served to provide a per person usage value. Selected per capita usage data are shown in Figure 1.

Technical Notes **Per Capita Water Consumption**

Data source: The data for this indicator comes from Group A public water systems (PWS), Group B PWS, and individual water users. Group B PWS are not required to report their usage and individual wells do not typically have meters to assess their usage. Both of these user groups have a small subset that do report their usage. However, this subset of users and their usage data are not totally representative of the entire user group.

Collection frequency: Group A PWS are required to keep track of their water usage. Recent changes require more Group A PWS to report their usage annually. The other water users are not required to report their usage. Water use data has been requested from a variety of users.

Methods for analysis: Total Annual water consumption is divided into a daily measure. This daily usage is divided by the number of people per household (2.3 – 2010 US Census data). For PWS with data, the total water use is divided by the number of connections. This usage per connection is divided by the population per connection value. This population per connection is a calculation of reported population served divided by the number of connections. The range of per capita usage for Group A PWS is 45 to 140 gallons per person per day with the average being 83 gallons per person per day. Eight individual well owners have installed a meter and reported usage data. This subset of users has a range of per capita from 40 to 150 gallons per person per day from annual usage totals with the average being 100 gallons per person per day.

Data Reliability and Quality: The data quality of this indicator can be good when reported from purveyors. Estimates are based on a small subset of data users and compared to other published data. The reliability is fair based in the recent participation and should improve due to changes in reporting requirements for most Group A PWS.

Data Reference: VMI Water Purveyors; US Census Data – 2010; various King County program including Groundwater, UTRC; and VMI Volunteer Monitoring Program who self report usage.

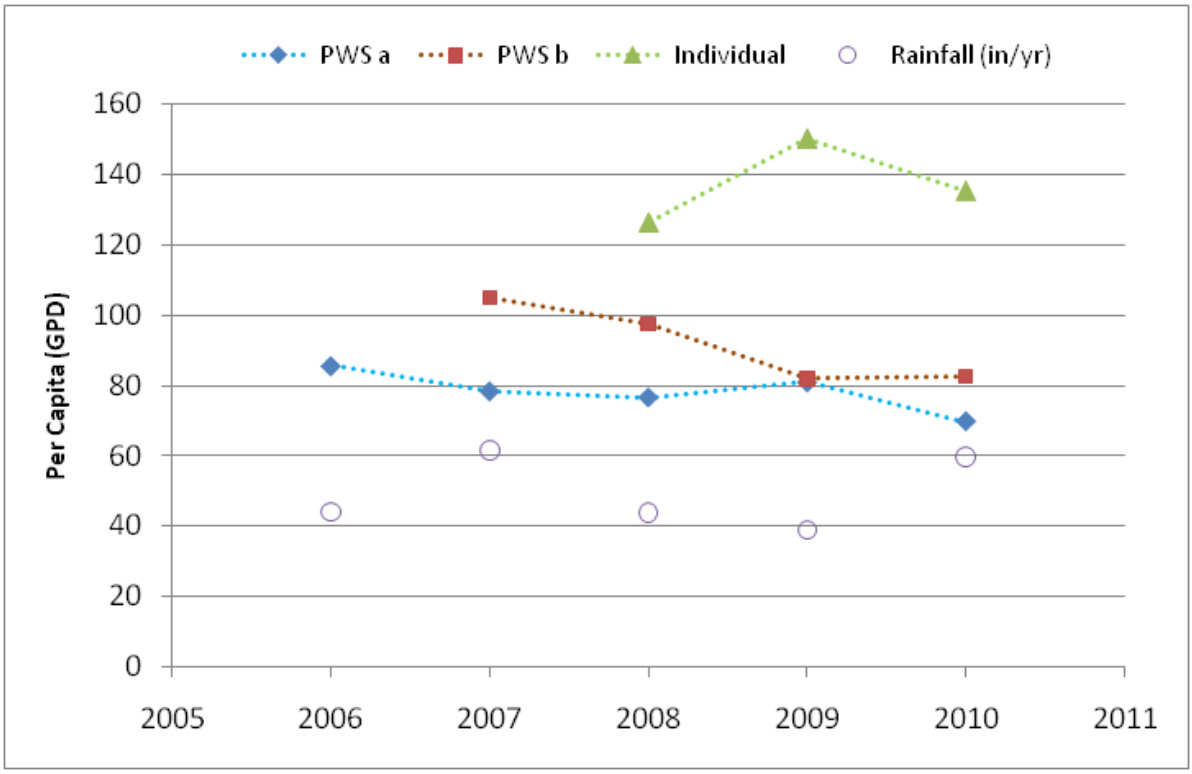


Figure 1. Example of per capita water usage by user type – Group A Public Water System (PWS); Group B PWS and individuals. One example of each type is shown to highlight annular variation. This data was calculated based on annual total usage divided by the number of people per household and reported as a daily usage – gallons per person per day (GPD). Rainfall for the North Vashon gauge also shown as inches/year. Data collection of usage for selected Group B PWS and individual well users began in 2007 and 2008, respectively.

11. Summer Water Use Peaking Factor

Target: Peaking factor is tracked year to year

About this indicator: Summer water use peaking factor is calculated from the maximum consumption divided by average usage. This indicator reports data from three types of water users Group A public water system (PWS) users, Group B PWS users and individuals.

Influencing factors: Weather conditions during the summer time - amount of precipitation for a given year and/or the average daily temperature. Limited water usage data available.

2010 Target: Summer water use peaking factor is tracked year to year.

2010 Finding: Water use peaks in the summer by a factor 1.8 based on an island-wide average.

2010 Status: Summer water use peaking factors range from 1.2 to 2.4 based on data from selected Group A public water systems. The average of the 2010 data is 1.8. No assessment is done annually.

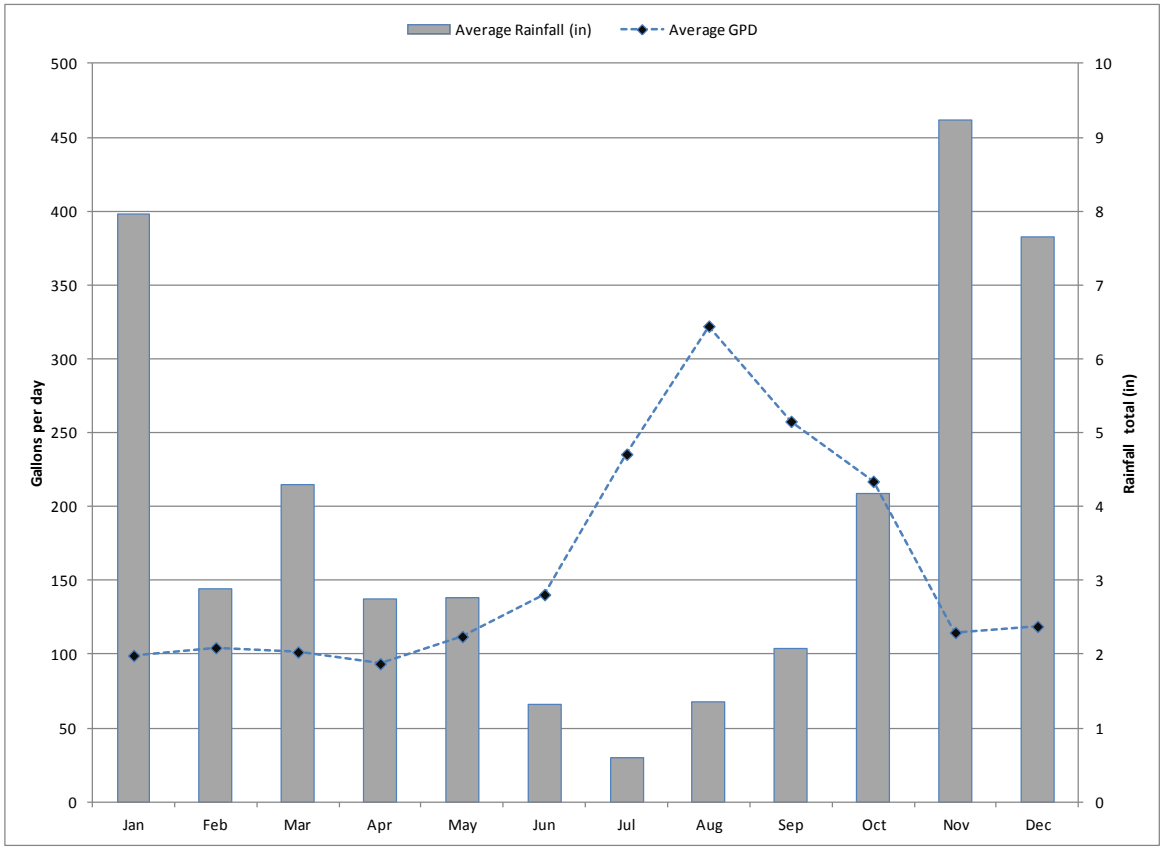


Figure 1. Average water use of individuals with monthly rainfall totals for the North Vashon rain gauge (43U). Rainfall data are average monthly totals from water years 2004-2010. Water usage is averaged gallons per day (GPD) by month from individuals who participate in self monitoring/metering volunteer program. This usage data is from 2007 to 2010. Maximum usage typically occurs in August with a peaking factor of 3.2 for all users. On average, two-thirds of the total annual usage is consumed during May thru October period while July thru September can be over 40% of the total annual usage.

2001-2010 Target: No long term (10 or more years) increase in summer water use peaking factor.

2001-2010 Assessment: Summer water use peaking factors range from 1.2 to 4.4 based on 2001 – 2010 data from selected Group A public water systems.

2001-2010 Status: Summer water use peaking factors range from 1.2 to 4.4 based on data from selected Group A public water systems, Table 1. A Group B PWS and individuals who report their usage have similar peaking factor. High peaking factor of ~8 can occur as noted by one individual user, Table 1. A range of calculated peaking factor from different users are presented in Figure 2.

Table 1. Peaking Factors (2001 to 2010) from selected water users. Peaking factor is calculated annually from the maximum monthly usage divided by an average monthly usage.

Water User\Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Grp A PWS - H	1.4	1.9	2.2	2.1	1.9	1.9	1.9	1.8	2.3	1.6
Grp A PWS -19	1.6	1.9	1.7	2.3	2.0	2.2	1.9	2.0	2.4	2.0
Grp A PWS -D	*	*	*	*	*	*	*	*	*	1.8
Grp A PWS -NC	*	*	3.7	2.8	2.8	4.4	2.8	2.6	3.3	2.4
Grp A PWS -BP	*	*	*	*	*	*	1.9	2.0	1.6	1.2
Grp B PWS - BC	*	*	*	*	*	*	2.3	1.6	1.7	1.6
Individual A	—						1.3	1.7	2.3	1.3
Individual B	—						8.8	8.6	7.4	ND

"*" = Data not reported
ND = No data collected for this year.
"—" = Data collect did not start until 2007.

Technical Notes Summer Water Use Peaking Factor

Data source: The data for this indicator comes from Group A public water systems (PWS), Group B PWS, and individual water users. Group B PWS are not required to report their usage and individual wells do not typically have meters to assess their usage. Both of these user groups have a small subset that do report their usage. However, this subset of users and their usage data are not totally representative of the entire user group.

Collection frequency: Group A PWS are required to keep track of their water usage. Recent changes require more Group A PWS to report their usage annually. The other water users are not required to report their usage. Water use data has been requested from a variety of users.

Methods for analysis: For Group A systems with a published water system plan, the peaking factor is for that system is reported. For users with monthly usage data, a peaking factor is calculated annually from the maximum monthly usage divided by an average usage month. When multi-years of data are assessed, the annual peaking factor is averaged. The range of peaking factors for Group A PWS is 1.2 to 4.4 based on data from 7 systems. Eight individual well owners have installed a meter and reported usage data. One Group B PWS reports their usage on a regular basis.

Data Reliability and Quality: The data quality of this indicator can be good when data is provided by the island purveyors. Estimates are based on a small subset of data users and compared to other published data. The reliability is fair based in the recent participation and should improve due to changes in reporting requirements for most Group A PWS.

Data Reference: VMI Water Purveyors; various King County programs including Groundwater, UTRC; and VMI Volunteer Monitoring Program who self report usage.

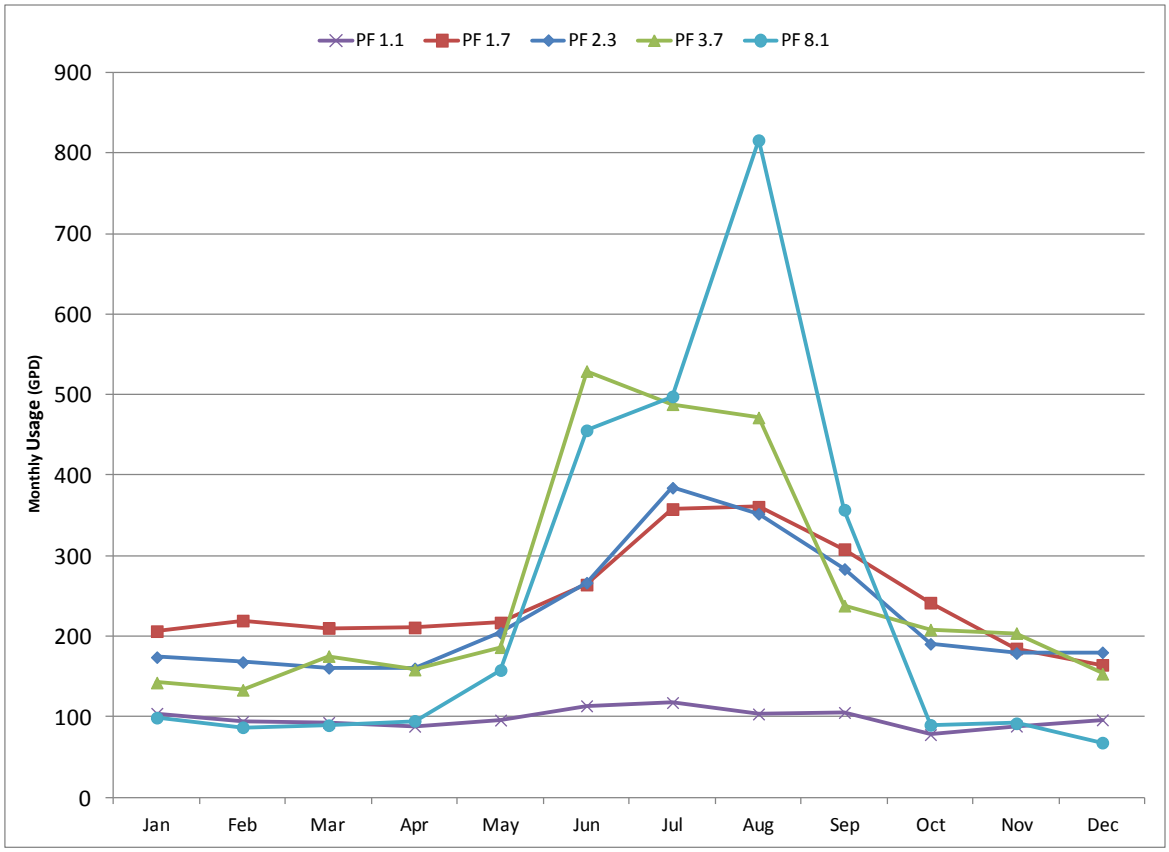
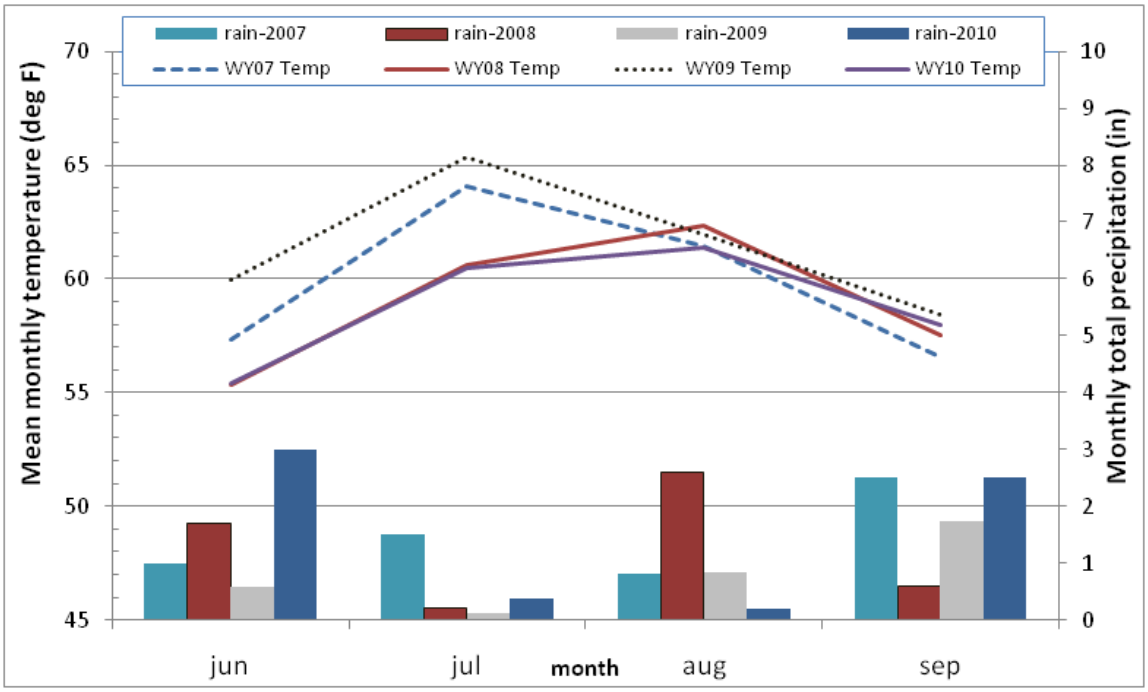


Figure 2. Example of peaking factors by user type – Group A Public Water System (PWS); Group B PWS and individuals. The peaking factor calculation is the maximum monthly usage divided by the average monthly usage. Example data are from 2 Group A PWS (pf 1.7; pf 3.7), 1 Group B PWS (pf 2.3) and 2 individual well owners (pf 1.1; pf 8.1). The user with a PF 1.7 (not pf 8.1) uses the most water annually based on the cumulative total of the daily usage.

a.



b.

Figure 3 (a + b). Data from West Judd Creek – gauge site 28Y and one Group A public water system from 2007 to 2010. Figure 3a - Monthly maximum temperatures are shown for the summer period of June through September along with total usage from a public water system shown on the second axis. Figure 3b - Monthly median temperatures along with monthly total precipitation (second axis). Peaking occurs typically during July or August during periods of higher temperatures and lower precipitation. Units are degrees Fahrenheit (deg F); inches (in); millions of gallons (Mgal).