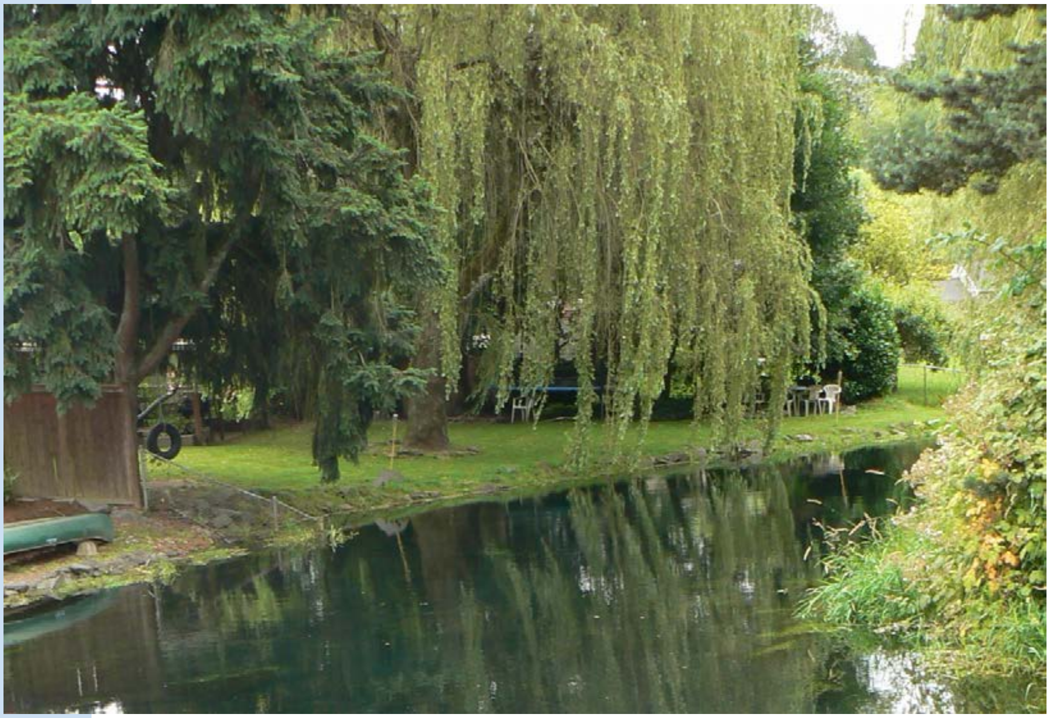

Clarks Creek Dissolved Oxygen and Sediment Total Maximum Daily Load

Water Quality Improvement Report
and
Implementation Plan

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Cover photo: Clarks Creek near West Pioneer Avenue, Puyallup, WA, July 12, 2010. Courtesy of USEPA summer interns Dominique Porcincula and Ann Christianson.

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Clarks Creek
Dissolved Oxygen and Sediment
Total Maximum Daily Load

Water Quality Improvement Report
and
Implementation Plan

by

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Abstract

Clarks Creek and its tributaries do not meet state water quality standards for dissolved oxygen and sediment, which harms fish and other species that depend on a healthy aquatic habitat. This report, the Clarks Creek Watershed Total Maximum Daily Load (TMDL) Water Quality Improvement Report (WQIR) and Implementation Plan, documents this problem and describes solutions to improve water quality in Clarks Creek. Clarks Creek has three Category 5 (303(d)) listings for dissolved oxygen (DO) in the Washington State Water Quality Assessment and 20 additional impaired areas.

The Washington Department of Ecology (Ecology), Puyallup Tribe of Indians (PTI), and the U.S. Environmental Protection Agency (EPA) Region 10 initially worked with a team of stakeholders to review existing data. Ecology, Washington State University (WSU) Puyallup, PTI, and Pierce County then conducted fieldwork to collect additional data on dissolved oxygen, stormwater, elodea and shade, sediment erosion, and macroinvertebrates in Clarks Creek and its tributaries. The combined data showed that dissolved oxygen levels and macroinvertebrate health were low, and the amount of sediment in streams was high compared to state standards.

EPA's contractor, Tetratech, expanded a landscape model, HSPF, used by Pierce County, and used the stream water quality model, QUAL2Kw (Pelletier and Chapra, 2008) to investigate how stormwater runoff, elodea, temperature, and sediment affect dissolved oxygen in the impaired reaches. The model predicted that less elodea and polluted stormwater runoff would improve dissolved oxygen in Clarks Creek.

Ecology also evaluated reference streams in the Puget Sound lowlands to compare the existing sediment loading in Clarks Creek to natural sediment loading in streams that support a healthy fish habitat. This comparison showed sediment loadings were sixteen times greater than reference streams, and reduced sediment loads are needed to improve aquatic health.

HSPF and QUAL2Kw models were used to look at processes that affect both sediment and DO in the watershed. This analysis was then used by Ecology to develop load and wasteload allocations for DO and sediment to address the impairments and to return Clarks Creek back to meeting state water quality standards. The analysis determined the amount of pollutants that can be loaded to Clarks Creek before the water quality standards are violated.

This WQIR presents wasteload and load allocations for municipal stormwater permittees, the state hatchery, the Clarks Creek Tribal hatchery, the Diru Creek Tribal Hatchery, and other sources of stormwater. To improve DO and reduce sediment, the TMDL allocations are:

- Reduce sediment loading
- Reduce dissolved oxygen deficit
- Control the density of elodea
- Increase riparian shade

The implementation target for DO is:

- Reduce 50% of stormflow volume or treat 50% of untreated stormwater

The implementation plan lays out a framework for how the stakeholders will track, monitor, and implement the water cleanup plan. It outlines what must be done, establishes a schedule, and guides corrective actions with adaptive management practices. When completed the TMDL reductions should be achieved by 2034.

Executive Summary

In 2009 the Washington Department of Ecology (Ecology) determined that Clarks Creek has dissolved oxygen and sediment levels greater than Washington State allows in its fresh waters. A total maximum daily load (TMDL) study was done on this water body. This water quality improvement report contains the study, recommendations for cleaning up the water body, and an implementation plan that lays out roles and responsibilities for the cleanup process.

Introduction

Clarks Creek, a four-mile spring-fed tributary to the Puyallup River, is a "jewel in the crown" for the Puyallup Tribe because it has five salmonid species that spawn, rear, and migrate there. Clarks Creek is on the 303(d) impaired water bodies list due to low dissolved oxygen, and will be listed for sediment during the next assessment. Low dissolved oxygen (DO) levels, excess fine sediment and sand, and the overgrowth of elodea (*Elodea nuttalii*) create conditions in Clarks Creek that harm fish and their supporting habitat.

Why did we develop a total maximum daily load (TMDL)

The federal Clean Water Act (CWA) requires that a TMDL be developed for each of the water bodies on the 303(d) list. The 303(d) list is a list of water bodies, which the CWA requires states to prepare, that do not meet state water quality standards. The TMDL study identifies pollution problems in the watershed, and then specifies how much pollution needs to be reduced or eliminated to achieve clean water. Then Ecology, with the assistance of local governments, agencies, and the community develops a plan that describes actions to control the pollution and a monitoring plan to assess the effectiveness of the water quality improvement activities. The water quality improvement report (WQIR) consists of the TMDL study findings, recommendations for cleaning up the water body, and implementation plan.

Watershed description

The study area for this WQIR is Clarks Creek, which is located in the lower Puyallup River watershed within the South Puget Sound Lowlands. The Puyallup River is the largest river in South Puget Sound, with a total watershed area of 970 square miles and an average flow of 3,300 cubic feet per second (cfs). Clarks Creek has a watershed area of about 13 square miles and an average flow of roughly 60 cfs. Tributaries to Clarks Creek include Rody, Diru, Woodland, and Meeker Creeks. Clarks Creek flows year-round, with summer baseflows of 30-40 cfs out of Maplewood Springs. Tributaries to Clarks Creek flow primarily in the wet season in response to rain. This study area is in Water Resource Inventory Area (WRIA) 10.

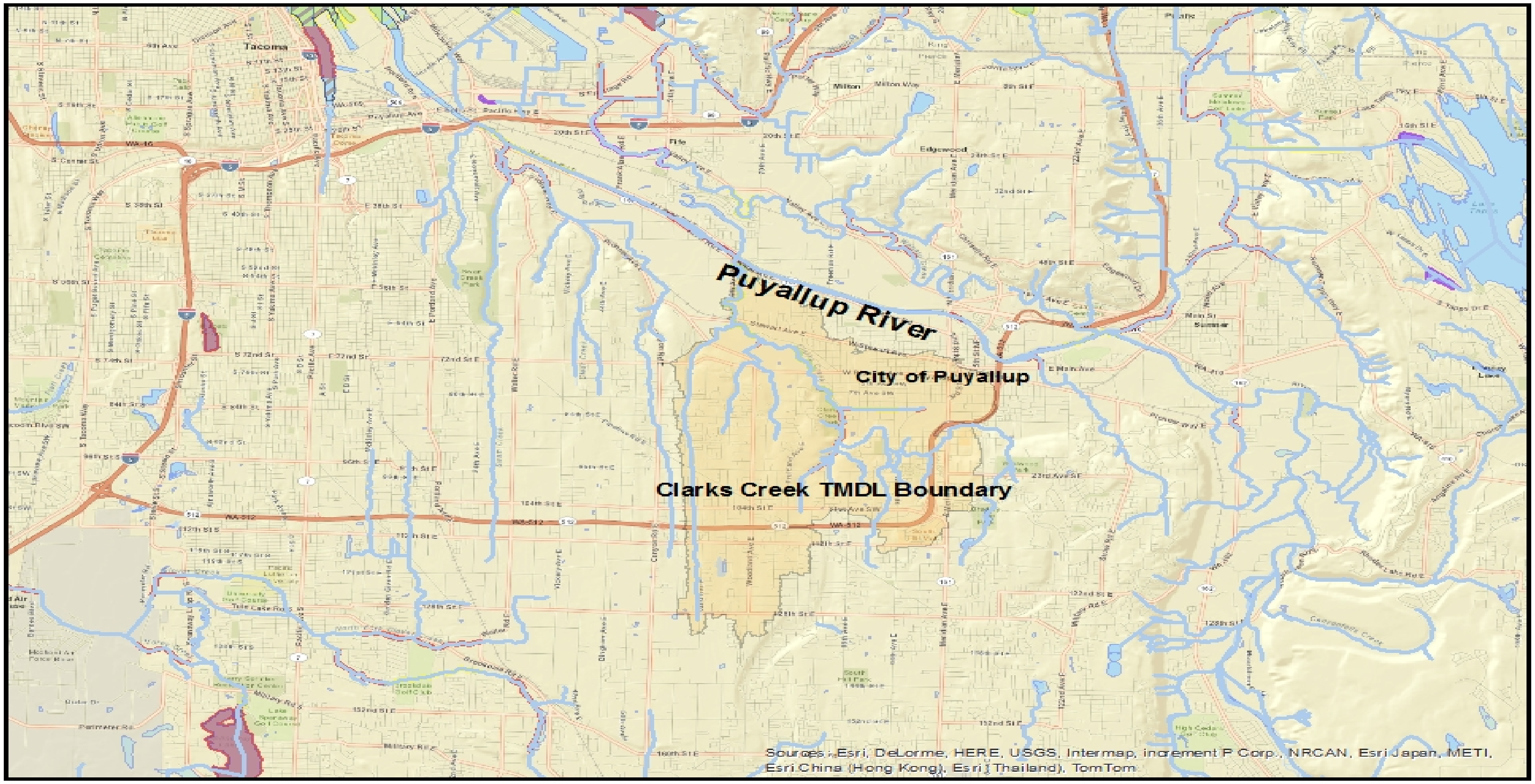

Figure ES 1. Clarks Creek Watershed and TMDL Boundary Map

Goals and objectives

The goal of this Clarks Creek Dissolved Oxygen and Sediment Total Maximum Daily Load (TMDL) Water Quality Improvement Report is to describe the problems and actions needed to meet water quality standards and improve the ecosystem, increase DO concentrations, and reduce sediment loads in the creek.

What needs to be done in this watershed?

Ecology, EPA, and the Puyallup Tribe are working together on this TMDL project under a memorandum of understanding. A stakeholder group (Pierce County, city of Puyallup, WSU Puyallup, local citizens, Washington State Department of Transportation (WSDOT), Puyallup Tribe, EPA, and Ecology) has met since May 2009. Ecology, Washington State University (WSU) Puyallup, the Puyallup Tribe, and Pierce County conducted fieldwork to collect additional data on dissolved oxygen, stormwater, elodea and shade, sediment erosion and macroinvertebrates in Clarks Creek and its tributaries. Computer models were used to look at processes that affect both sediment and DO in the watershed. The analysis determined the amount of pollutants that can be loaded to Clarks Creek before the water quality standards are violated.

Table ES 1. Dissolved Oxygen Allocations Expressed as DOD (kg/day)

	DOD (kg/day)
TMDL (kg/d) = WLA + LA + MOS	**719**
Total WLA (kg/d)[+]	**625**
*WLA: State hatchery**	24
WLA: City of Puyallup MS4	318
WLA: Pierce County MS4	263
WLA: WSDOT	21
Total LA (kg/d)	**94**
LA: Properties adjacent to creek	90
LA: Diru Creek Tribal Hatchery	2.4**
LA: Clarks Creek Tribal hatchery	1.6***
MOS (kg/d)	*implicit*

[+]Due to rounding, the WLAs add up to 626 kg/day.
*This translates to a CBOD-5 of 47.7 kg/day.
**This translates to a CBOD-5 of 4.56 kg/day.
***This translates to a CBOD-5 of 3.04 kg/day.

Table ES 2. Sediment Allocations

	Annual Load (tons/year)
TMDL (tons/year) = WLA + LA + MOS	**209**
Total WLA (tons/year)	**173**
WLA: City of Puyallup MS4	85
WLA: Pierce County MS4	70
WLA: WDFW Puyallup Hatchery	10
WLA: WSDOT	6
WLA: Construction Permittees	2
Total LA (tons/year)	**26**
LA: Properties adjacent to creek	26
Reserve Capacity (tons/year)	10
MOS (tons/year)	*Implicit*

The Clarks Creek TMDL assigns specific loading capacity, load allocations, and wasteload allocations to carbonaceous biochemical oxygen demand (CBOD), dissolved oxygen deficit, sediment, elodea density, and riparian shade. Numeric wasteload allocations are assigned to the following permittees: Pierce County municipal separate storm sewer systems (MS4), city of Puyallup MS4, Puyallup Hatchery permit, WSDOT, and Construction Stormwater General Permit. Numeric load allocations are assigned to tribal hatcheries and properties adjacent to the creek. Load allocations for elodea density and riparian shade, implemented through non-point source compliance programs by state and local governments, are required to achieve water quality standards in Clarks Creek.

To guide implementation the TMDL sets implementation targets for stormwater flow. Flow is important because high flows can erode stream banks. The eroded sediment affects salmon spawning beds and fuels the growth of elodea. The implementation targets are estimates (based on water quality models) of what is needed to achieve goals for sediment and dissolved oxygen in Clarks Creek. We need to reduce sediment and increase dissolved oxygen concentrations, and we will ultimately measure our success by meeting sediment and dissolved oxygen requirements. Controlling flow is important to controlling these impacts. The implementation target for DO is to reduce 50% of stormflow volume or treat 50% of untreated stormwater. The Sediment TMDL wasteload allocation prescribes a 64% sediment reduction. Pierce County and the city of Puyallup are required to develop a plan with best management practices (BMPs) to meet these targets. When the TMDL is released they will have 18 months to develop this plan.

The implementation plan describes the work needed to improve water quality. It explains the roles of the cleanup partners/stakeholders and guides the implementation of BMPs needed to reduce pollution. When completed, the TMDL reductions should be achieved by 2034.

Why this matters

Improving water quality and the supporting ecosystem is necessary to attain applicable water quality standards, including the designated uses. Attaining water quality standards will enable the recovery and protection of threatened cold water fish and species of concern that spawn and rear there and will ensure the local community can continue enjoying the creek in the near future. These fish species are highly valued by the many state residents, including tribal members who depend on them for cultural, recreational, or economic reasons.

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What is a Total Maximum Daily Load (TMDL)

A TMDL is a numerical value representing the highest pollutant load a surface water body can receive and still meet water quality standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

Federal Clean Water Act requirements

The Clean Water Act (CWA) established a process to identify and clean up polluted waters. The CWA requires each state to have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of (1) designated uses for protection, such as cold water biota and drinking water supply, and (2) criteria, usually numeric criteria, to achieve those uses.

The Water Quality Assessment and the 303(d) List

Every two years, states are required to prepare a list of water bodies that do not meet water quality standards. This list is called the CWA 303(d) list. In Washington State, this list is part of the Water Quality Assessment (WQA) process.

To develop the WQA, the Washington State Department of Ecology (Ecology) compiles its own water quality data along with data from local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data in this WQA are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the assessment. The WQA divides water bodies into five categories. Those not meeting standards are given a Category 5 designation, which collectively becomes the 303(d) list].

Category 1 – Meets standards for parameter(s) for which it has been tested.

Category 2 – Waters of concern.

Category 3 – Waters with no data or insufficient data available.

Category 4 – Polluted waters that do not require a TMDL because they:

- 4a. – Have an approved TMDL project being implemented.
- 4b. – Have a pollution control program in place that should solve the problem.
- 4c. – Are impaired by a non-pollutant such as low water flow, dams, or culverts.

Category 5 – Polluted waters that require a TMDL – the 303(d) list.

Further information is available at Ecology's Water Quality Assessment website (www.ecy.wa.gov/programs/wq/303d/).

The CWA requires that a TMDL be developed for each of the water bodies on the 303(d) list.

TMDL process overview

Ecology uses the 303(d) list to prioritize and initiate TMDL studies across the state. The TMDL study identifies pollution problems in the watershed and specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology, with the assistance of local governments, tribes, agencies, and the community, develops a plan to control and reduce pollution sources as well as a monitoring plan to assess effectiveness of the water quality improvement activities. This comprises the *water quality improvement report* (WQIR) *and implementation plan* (IP). The IP section identifies specific tasks, responsible parties, and timelines for reducing or eliminating pollution sources and achieving clean water.

After the public comment period Ecology addresses the comments as appropriate. Then, Ecology submits the WQIR/IP to the U.S. Environmental Protection Agency (EPA) for approval.

Who should participate in this TMDL process

Nonpoint source pollutant load targets have been set in this TMDL and described in Table 13 and 18. Because nonpoint pollution comes from diffuse sources, all upstream watershed areas have potential to affect downstream water quality. Therefore, all potential nonpoint sources in the watershed must use the appropriate best management practices to reduce impacts to water quality. The area subject to the TMDL is shown in Figure 1. Similarly, all point source dischargers in the watershed, discussed in the Potential Pollutant Sources section, must also comply with the TMDL.

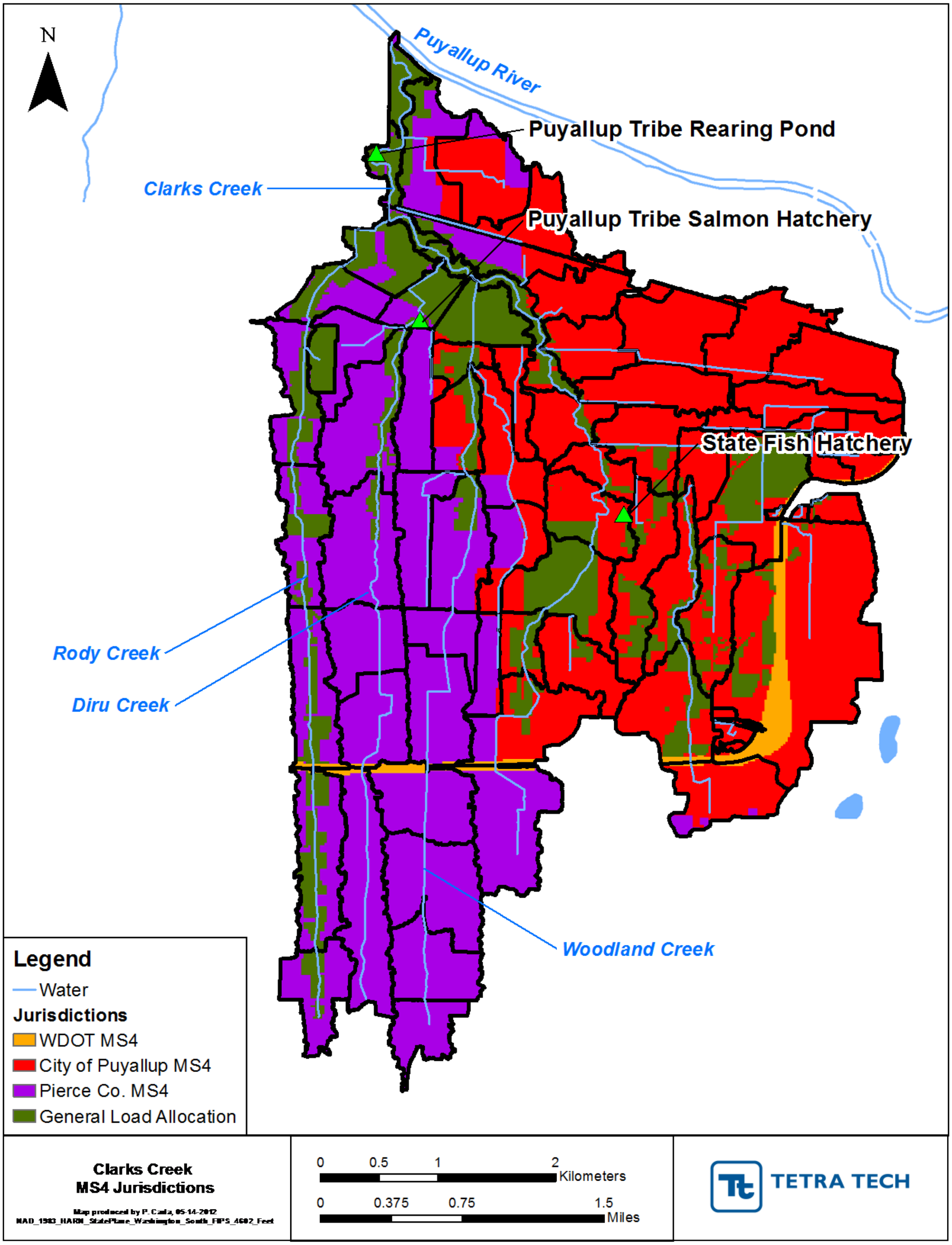

Figure 1. Clarks Creek Allocations by Jurisdiction

Elements the Clean Water Act requires in a TMDL

Loading capacity, allocations, seasonal variation, margin of safety, and reserve capacity

A water body's *loading capacity* is the amount of a given pollutant that a water body can receive and still meet water quality standards. The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a water body into compliance with the standards.

The portion of the receiving water's loading capacity assigned to a particular source is a *wasteload* or *load* allocation. If the pollutant comes from a discrete (point) source subject to a National Pollutant Discharge Elimination System (NPDES) permit, such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation*. If the pollutant comes from diffuse (nonpoint) sources not subject to an NPDES permit, such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation*.

The TMDL must also consider *seasonal variations* and include a *margin of safety* that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A *reserve capacity* for future pollutant sources is sometimes included as well.

Therefore, a TMDL is the sum of the wasteload and load allocations, any margin of safety, and any reserve capacity. The TMDL must be equal to or less than the loading capacity.

Identification of the pollutant's loading capacity for a water body is an important step in developing a TMDL. EPA defines the loading capacity as "the greatest amount of loading that a water body can receive without violating water quality standards" (EPA, 2001). The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring a water body into compliance with standards. The portion of the receiving water's loading capacity assigned to a particular source is a load or wasteload allocation.

A TMDL targets a level of pollutant loading by adding the pollutant sources, both point and nonpoint, and a margin of safety. A TMDL is typically expressed as:

TMDL = WLA + LA + Reserve + MOS

Where:

WLA = Wasteload Allocation – the portion of the loading to the water body assigned to each existing and future point source of the pollutant

LA = Load Allocation – the portion of the pollutant loading assigned to existing and future nonpoint sources of the pollutant and natural background

Reserve = an allocation reserved for loading from future development

MOS = Margin of Safety – an accounting of the uncertainty in the estimate of the loading capacity of the water body

Why Ecology Conducted a TMDL Study in this Watershed

Background

Clarks Creek, a spring-fed tributary of the Puyallup River in Pierce County, Washington State, is an important spawning and rearing area for salmonids. Clarks Creek flows through the city of Puyallup and is subject to strong development pressure. The entire length of Clarks Creek is designated for Core Summer Salmonid Habitat, Primary Contact, and Water Supply Uses. Recent monitoring in Clarks Creek indicated that the stream is impaired for dissolved oxygen (DO) and sediment, harming its designated uses. Sediment oxygen demand (SOD), stormwater, macrophytes (elodea, also known as American waterweed or *Elodea nuttalii*), and lack of riparian shade play a role in this impairment. Secondary factors, such as removal of riparian canopy and increased temperatures, also contribute to impairments.

In May 2008, Ecology conducted a fecal coliform bacteria TMDL analysis on Clarks and Meeker Creeks. At that time those waters were listed as Category 2 (waters of concern) for DO and pH, and scientists thought the low DO and high pH was likely caused by the natural conditions in the groundwater that feeds Clarks Creek. Therefore, Ecology did not pursue TMDL development for DO or pH in the basin at that time.

Since 2008, the Puyallup Tribe of Indians (PTI) has conducted studies to confirm DO impairment. In November 2009, Brown and Caldwell performed an investigation that also showed there was DO impairment in Clarks Creek. The studies indicated anthropogenic causes and elodea overgrowth were contributing to the DO excursions. The DO in the lower reaches of Clarks Creek appeared to be influenced by biochemical oxygen demand (BOD) and SOD. At the time of the studies, Ecology was completing the TMDL for fecal coliform and, to continue the momentum, decided that the DO impairment needed to be addressed even though it was not officially on the 303(d) list at the beginning of this study. As a result of the new data, the creek was placed on the 2012 303(d) list with an impairment for DO.

While total suspended solids (TSS) and turbidity have been measured historically in the watershed, much of the work studying sediment in Clarks Creek occurred in recent years and was initiated for the purposes of understanding the sediment impairment, sedimentation and its role in DO impairment. The interaction between sediment and dissolved oxygen led to the assessment that sediment itself is also impairing designated uses as well as contributing to the DO impairment. Ample evidence of the sediment impairment has been collected through studies on fine sediment and fine sediment levels compared to reference stream conditions, sediment loading evaluations and biotic integrity. (Brown and Caldwell, 2012 and Hayslip, 2013)

Tribal jurisdiction and Clarks Creek's significance for PTI

PTI's federally-approved water quality standards apply to surface waters on trust and restricted lands within the 1873 Survey Area of the Puyallup Reservation as described in the Land Claims Settlement Agreement of August 27, 1988, ratified by Congress in the Puyallup Land Claims

Settlement Act, 25 U.S.C. Section 1773 (b). This jurisdiction applies to lands recognized as having on-reservation status pursuant to the Puyallup Land Claims Settlement Act. Surface waters within PTI's water quality jurisdiction include, but are not limited to, the lower seven miles of the Puyallup River within the exterior boundary of the 1873 survey area.

According to the Land Claims Settlement Agreement federal, state, and local governments have exclusive jurisdiction to administer and implement federal, state, and local laws on non-trust lands within the 1873 Survey Area, which includes lands underlying Clarks Creek. Accordingly, Ecology regulates water quality in Clarks Creek, and the state water quality standards apply. In 2009, PTI requested contractor funds from EPA to initiate a TMDL for DO on Clarks Creek. The basis of this request was predicated on the following: 1) Clarks Creek is a significant spawning stream within the 1873 Survey Area of the Puyallup Reservation, and due to its consistent supply of cold spring water, has significant restoration potential; 2) DO concentrations in the creek are below water quality standards and dip to near lethal limits at the time of the adult return of fall Chinook to PTI's Clarks Creek Tribal hatchery; and 3) methods long employed to control flooding and manage water levels in the creek compromised tribal hatchery operations. To control flooding in the creek, the nuisance weed elodea was mechanically harvested. Weed fragments and re-suspended fine sediment from the channel bed clogged Clarks Creek Tribal hatchery pond intakes, causing a decline in pond oxygenation and premature release of juvenile salmon when oxygenation was also low in the creek. Harvesting the elodea in this fashion served to accelerate the growth of the elodea as the plant efficiently propagates and re-establishes rooting systems via fragments. PTI wanted more effective, long-term source control and treatment that would improve water quality, enhance and restore the fishery, and protect tribal hatchery operations.

Clarks Creek is a very productive salmon spawning stream within the 1873 Survey Area of the Puyallup reservation. Clarks Creek supports the most significant number and variety of spawning salmon within Puyallup city limits found anywhere in the Puyallup River watershed. Over the past 9 years, Clarks Creek has averaged 390 returning Chinook and 1,650 chum salmon. In addition, the creek hosts coho, steelhead, pink, and cutthroat. Historically, bull trout have also been found foraging in the creek in the fall. Chinook salmon, bull trout, and steelhead trout using Clarks Creek are part of the threatened Puget Sound population designated by the National Marine Fisheries Service (NMFS) under the Endangered Species Act (ESA). Clarks Creek, from its mouth to Maplewood Springs, is part of the species' critical habitat. Also, the Puget Sound/Georgia Basin coho salmon population is listed as a "species of concern" under the ESA.

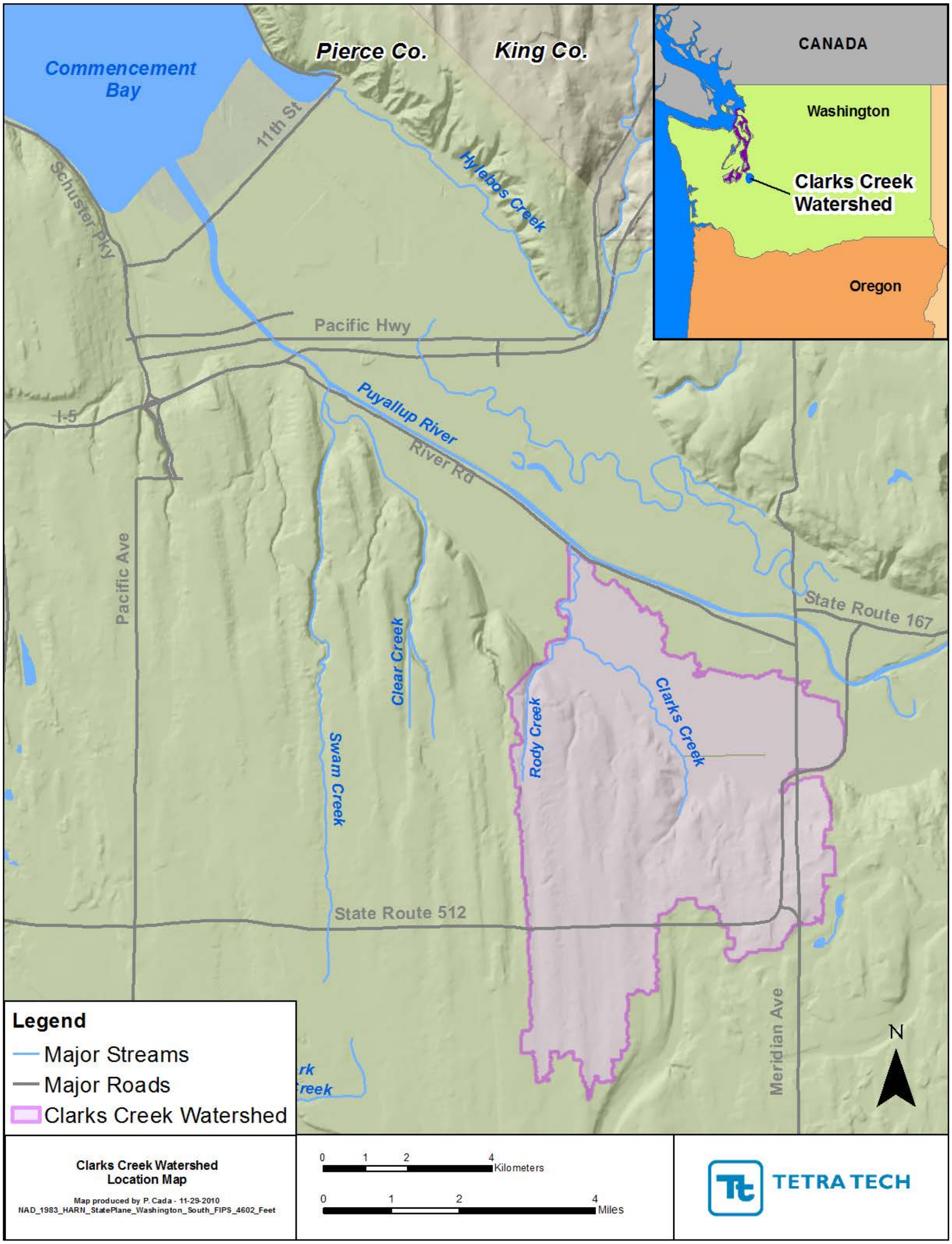

Figure 2. Clarks Creek Watershed Location map

Impairments addressed by this TMDL

The main uses to be protected by this TMDL are Core Summer Salmonid Habitat, Primary Contact Recreation, Water Supply Uses and Miscellaneous Uses. These uses are explained in more detail in the Water Quality Standards and Numeric Targets Section.

Dissolved oxygen

Meeker Creek and mainstem Clarks Creek have been monitored and assessed for impairments due to low DO since the 1990s. The upper portion of Meeker Creek was listed on the 1998 303(d) list (Category 5) as impaired for DO based on data collected in 1996 by the Pierce County Conservation District at three stations. The listing was changed to Category 2 in 2004 due to lack of data on excursions for more than one year. However, the 2008 303(d) list changed the segment back to a Category 5 based on monitoring completed in 2002 and 2003 by Ecology. Lower Meeker Creek was on the 2008 303(d) list due to 2002 and 2003 monitoring data collected by Ecology.

Figure 3. Sediment Retention to Address Bank Erosion, Rody Creek

The entire reach of Clarks Creek (mouth to headwaters) was included as a Category 2 water (a "water of concern") for DO impairment on the 2004 and 2008 Integrated Reports. The middle portion of Meeker Creek was also listed as Category 2 in the 2008 listing cycle. Excursions were measured in these reaches during this time period, but not a sufficient number to warrant listing in Category 5. PTI provided data to show that these waters were impaired for DO (Brown and Caldwell, 2009). These impaired waters would have been included on the Category 5 list had Ecology been aware of the impairment at the time the list was completed. In January 2013, these water bodies impaired for DO were added to Category 5 of the 303(d) List. As explained in the "What is a TMDL" section, the Clean Water Act requires that a TMDL be developed for all water bodies assessed as Category 5. This WQIR addresses the 2013 303(d) listings outlined in Tables 1, 2 and 3.

Sediment

During the development of the DO TMDL it became apparent that sediment loading, both suspended and bedded, was not only a factor in the DO impairment but was itself impacting the quality of the creek and its ability to support designated uses. While numeric water quality standards are not available for sediment field investigations, the Study Results and Discussion section, provided detailed evidence that sediment loading has impaired the designated uses in Clarks Creek and its tributaries.

From 2010-2012, PTI conducted a sediment reduction project that showed sediment loading in the watershed was sixteen times what would occur naturally (Brown and Caldwell, 2013). In addition to observations by PTI (Marks, 2008), a survey of the streambed composition in Clarks Creek showed that the percentage of fine sediment and sand within the main stem exceeds that of reference systems and impairs invertebrate and fish assemblages in the creek. Additionally, the impairment to the invertebrate community has been confirmed through macroinvertebrate sampling by Pierce County, PTI, and others. Clarks Creek benthic index of biologic integrity (B-IBI) scores rate as "poor" and therefore indicate impairments to aquatic life use.

Several salmonid species are known to use Clarks Creek for spawning, rearing and foraging. These include ESA-threatened Chinook, steelhead, and bull trout, as well as Coho which are designated a species of concern." The non-listed species that use Clarks Creek include pink, chum and cutthroat trout. Fish and habitat limiting factors involving sediment have been observed in Clarks Creek and include flooding, channel erosion, and deposition of fine sediment. While the portion of Clarks Creek immediately below the sediment pond near the Washington Department of Fish and Wildlife (WDFW) hatchery (state hatchery) provides suitable habitat for spawning for all species (a total of approximately a quarter of a mile), the remaining stream channel below this portion contains little gravel, and the substrate consists of fine sand and mud. The WDFW sediment pond hinders the fluvial movement of gravel further downstream to the remaining stream channel, while the transport of finer sediment past the pond fills in existing gravel with fine sand and silt. Subsequently, little or no spawning has been observed below this point. In addition, this small segment exceeds its carrying capacity for spawning. When the carrying capacity is exceeded, the spawning nests, called redds, are disturbed by subsequent females, which can cause embryo mortality in the eggs that were already deposited. This event, referred to as superimposition of redds, has been observed from multiple species of salmon in this segment (Marks, 2008).

As a result, sediment impairments found during the development of the TMDL are addressed in this TMDL and will be added to future 303(d) listings (Table 3).

Table 1. Study-area water bodies on the 2012 303(d) list for DO

Water Body	Listing ID	Listing Category	NHD ID Number	Township	Range	Section
Clarks Creek	35407	5	17110014016524	20N	04E	19
Meeker Creek Upper end	7510	5	17110014015740	20N	04E	33
Meeker Creek Lower End	47578	5	17110014015740	20N	04E	32

Table 2. Study-area waters of concern for DO on the 2012 Water Quality Assessment

These water bodies are covered by this TMDL.

Water Body	Listing ID	Listing Category	NHD ID Number	Township	Range	Section
Clarks Creek	47590	2	17110014000641	20N	04E	38
Clarks Creek	47591	2	17110014000641	20N	04E	37
Clarks Creek	47592	2	17110014000641	20N	04E	32
Meeker Creek (Middle)	47579	2	17110014015740	20N	04E	33
Rody Creek	47593	2	17110014016631	20N	04E	19

Table 3. Unlisted but impaired for sediment on the 2012 Water Quality Assessment

These water bodies for sediment are covered by this TMDL.

Water Body	Listing ID	Category	NHD ID Number	Township	Range	Section
Clarks Creek	None	Proposed 5	17110014016641	20N	04E	32
Clarks Creek	None	Proposed 5	17110014015982	20N	04E	32
Clarks Creek	None	Proposed 5	17110014000641	20N	04E	32
Clarks Creek	None	Proposed 5	17110014000641	20N	04E	32
Clarks Creek	None	Proposed 5	17110014000641	20N	04E	37
Clarks Creek	None	Proposed 5	17110014000641	20N	04E	29
Clarks Creek	None	Proposed 5	17110014000641	20N	04E	29
Clarks Creek	None	Proposed 5	17110014000635	20N	04E	19
Clarks Creek	None	Proposed 5	17110014000635	20N	04E	19
Rody Creek	None	Proposed 5	17110014016631	20N	04E	31
Rody Creek	None	Proposed 5	17110014016631	20N	04E	31
Silver Creek	None	Proposed 5	17110014016631	20N	04E	33
Silver Creek (West Fork Tributary	None	Proposed 5	17110014016989	20N	04E	33
Silver Creek (East Fork Tributary)	None	Proposed 5	17110014001357	20N	04E	33

There are other 303(d) listed segments in the watershed, but this report does not address them:

- pH: The upper end of Meeker Creek and Clarks Creek upstream of Meeker Creek were listed as Category 5 impaired waters in the 2003 303(d) listing. In the 2008 Clarks Creek Fecal Coliform TMDL it was determined not to be needed due to the natural low pH of the ground water feeding these streams.
- Fecal Coliform: To address the 2004 Category 5 listing of Clarks Creek, a TMDL was developed and approved by EPA in 2008.
- Temperature: The upper end of Meeker Creek was listed as a Category 5 impaired water in the 2003 303(d) listing. A TMDL has not been completed for temperature; a separate analysis would be required.

Water Quality Standards and Numeric Targets

Aquatic organisms are very sensitive to reductions in the level of DO and high sediment concentrations in the water. The health of fish and other aquatic species depends upon maintaining an adequate supply of oxygen dissolved in the water. Dissolved oxygen affects growth rates, swimming ability, susceptibility to disease, and response to other environmental stressors. The state's criteria are designed to maintain conditions that support healthy populations of fish and other aquatic life.

Oxygen levels can fluctuate over the day and night in response to changes in climatic conditions, as well as the respiratory demands of aquatic plants and algae. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criteria are expressed as the lowest one-day minimum oxygen concentration that occurs in a water body. In the state water quality standards, fresh water aquatic life use categories are described using key species (salmonid species or warm water species) and life-stage conditions (spawning or rearing). Minimum concentrations of DO are used as criteria to protect different categories of aquatic communities [WAC 173-201A-200; 2011 edition].

Table 602 of WAC 173-201A-600 and 602 lists the designated uses for waters in the state (https://fortress.wa.gov/ecy/publications/SummaryPages/0610091.html). The entire lengths of Clarks Creek and its tributaries have the following aquatic life use designation and description:

- Core Summer Salmonid Habitat – The key identifying characteristics of this use are summer (June 15 – September 15) salmonid spawning or emergence, or adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and sub-adult native char. Other common characteristic aquatic life uses for waters in this category include spawning outside of the summer season, rearing, and migration by salmonids. [1]

The entire length of Clarks Creek has the following additional use designations:

- Primary Contact – This use protects for recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, canoeing and fishing.
- Water Supply Uses – Clarks Creek is designated for all water supply uses: domestic, industrial, agricultural, and stock water.
- Miscellaneous Uses – Clarks Creek is designated for all miscellaneous uses including wildlife habitat, harvesting, commerce/navigation, boating, and aesthetics.

The state of Washington designates numeric and narrative criteria to protect the designated uses of fresh and marine waters in the state, including all of Clarks Creek. The following sections summarize the fresh water criteria relevant to the designated uses of Clarks Creek and the low

[1] In past versions of the water quality standards, it was unclear how much of Clarks Creek was designated as core summer salmon habitat with a DO water quality standard of 9.5 mg/L. This was corrected in 2011. The entire length of Clarks Creek is now clearly designated as core summer salmonid habitat.

DO/organic enrichment impairment. While each of these criteria are related to DO impairment, this WQIR is specifically covering impairment in Clarks Creek and its tributaries due to exceedance of the DO criteria. Following are descriptions of the parameters.

Parameters

Temperature

Temperature affects the physiology and behavior of fish and other aquatic life. Temperature may be the most influential factor limiting the distribution and health of aquatic life and can be greatly influenced by human activities.

Temperature levels fluctuate over the day and night in response to changes in climatic conditions and river flows. Since the health of aquatic species is tied predominantly to the pattern of maximum temperatures, the criteria are expressed as the highest 7-day average of the daily maximum temperatures (7-DADMax) occurring in a water body.

In the state water quality standards, aquatic life use categories are described using key species (salmon versus warm-water species) and life-stage conditions (spawning versus rearing) [WAC 173-201A-200; 2003 edition].

(1) To protect the designated aquatic life uses of "Core Summer Salmonid Habitat," the highest 7-DADMax temperature must not exceed 16°C (60.8°F) more than once every ten years on average.

Washington State uses the criteria, previously described, to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying below the fully protective temperature criteria. When a water body is naturally warmer than the previously-described criteria, the state provides a small allowance for additional warming due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.3°C (0.54°F) increase above the naturally higher (inferior) temperature condition. Whether or not the water-body's temperature is naturally high is determined using a model. The model roughly approximates natural conditions, and is appropriate for determining the implementation of the temperature criteria. This model results in what is called the "system thermal potential" or "system potential" of the water body.

Special consideration is also required to protect spawning and incubation of salmonid species. Where it has been determined that the temperature criteria established for a water body would likely not result in protective spawning and incubation temperatures, the following criteria apply: A) Maximum 7-DADMax temperatures of 9°C (48.2°F) at the initiation of spawning and at fry emergence for char; and B) Maximum 7-DADMax temperatures of 13°C (55.4°F) at the initiation of spawning for salmon and at fry emergence for salmon and trout.

While the criteria generally applies throughout a water body, it is not intended to apply to discretely anomalous areas such as in shallow stagnant eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason the standards direct that measurements be taken from well-mixed portions of rivers and streams. For similar reasons, samples should not be taken from anomalously cold areas such as discrete points where cold groundwater flow into the water body.

According to the temperature criteria for Core Summer Salmonid Habitat, the 7-day average of daily maximum water temperatures must not exceed 16 ºC. A supplemental spawning / incubation criterion of 13 ºC (as a 7-day average of daily maximum temperatures) from September 15 to July 1 is required for much of Clarks Creek as part of a recent rulemaking, revised in January 2011. The subject reach is shown on an online map (https://fortress.wa.gov/ecy/publications/SummaryPages/0610038.html). The segment of Clarks Creek affected by this change extends from the middle of Clarks Creek Park (near 15th Avenue) downstream to 66th Avenue near the 5900 block. Temperatures should not exceed these criteria at a probability frequency of more than once every 10 years.

Dissolved oxygen

Aquatic organisms are very sensitive to reductions in the level of dissolved oxygen in the water. The health of fish and other aquatic species depends on maintaining an adequate supply of oxygen dissolved in the water. Oxygen levels affect growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants. While direct mortality due to inadequate oxygen can occur, the state designed the criteria to maintain conditions that support healthy populations of fish and other aquatic life.

Oxygen levels can fluctuate over the day and night in response to changes in climatic conditions as well as the respiratory requirements of aquatic plants and algae. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criteria are the lowest 1-day minimum oxygen concentrations that occur in a water body.

The DO criteria are also based on the aquatic life designated use. For Core Summer Salmonid Habitat, the minimum allowable DO concentration is 9.5 mg/L. DO concentrations should not drop below these criteria at a probability frequency of more than once every ten years on average. If DO concentrations are naturally below or within 0.2 mg/L of these criteria, then human influences should not cause an additional decrease of more than 0.2 mg/L.

Turbidity

Turbidity is a measure of light refraction in the water and one uses it to control the amount of sediment and suspended solids. Suspended solids in the water column and sediment that has settled out on the bottom of the water body affect fish and other aquatic life. Effects are similar for both fresh and marine waters.

The state established turbidity criteria in the state water quality standards primarily to protect aquatic life. Two different turbidity criteria are established to protect six different categories of aquatic communities [WAC 173-201A-200; 2003 edition].

(1) To protect the designated aquatic life uses of “Char Spawning/Rearing,” “Core Summer Salmonid Habitat,” “Salmonid Rearing and Migration” and “Non-anadromous Interior Redband Trout,” turbidity must not exceed: (A) 5 NTU over background when the

background is 50 NTU or less; or (B) a 10% increase in turbidity when the background turbidity is more than 50 NTU.

(2) To protect the designated aquatic life uses of “Salmonid Rearing and Migration Only” and “Indigenous Warm Water Species” turbidity must not exceed: (A) 10 NTU over background when the background is 50 NTU or less; or (B) a 20% increase in turbidity when the background turbidity is more than 50 NTU.

The effects of suspended solids on fish and other aquatic life can be divided into four categories:

(1) Acting directly on the fish swimming in the water and either killing them or reducing their growth rate, resistance to disease, or other normal functions.

(2) Preventing the successful development of fish eggs and larvae.

(3) Modifying natural movements and migrations.

(4) Reducing available food.

Suspended solids may also serve to transmit attached chemical and biological contaminants to waterbodies where they can be taken up in the tissue of fish. This can affect the health of humans or wildlife that eat the fish.

Turbid waters also interfere with the treatment and use of water as potable water supplies, and can interfere with the recreational use and aesthetic enjoyment of the water.

Turbidity is used by Ecology as a proxy for the amount of sediment and suspended solids. This is measured as nephelometric turbidity units (NTU), a measure of light scattering. Turbidity criteria are based on background conditions for the Core Summer Salmonid Habitat aquatic life use. If background turbidity is less than or equal to 50 NTU, turbidity should not exceed 5 NTU over background level. If background turbidity is greater than 50 NTU, turbidity should not increase by more than 10% over the background level.

Total dissolved gases

The state intends criteria for total dissolved gas (TDG) to protect aquatic species from the effects of super saturation of nitrogen. Fish that swim in water that contains excessive dissolved gases experience the simmular effect of what humans experience when scuba diving in deep water. When dissolved gases in fish circulatory systems come out of solution to form bubbles, the flow of blood through capillary vessels is blocked. External bubbles also appear on the fins, the skin, and in other body tissues.

TDG is the amount of air held in saturation in the water. The state describes criteria in the standards in terms of percent of saturation pressure relative to ambient barometric pressure. One can also express TDG in units of pressure. TDG has been a major water quality issue for many dams.

Several phenomena can increase TDG levels. Water plunging into a deep pool, such as below a dam spillway or natural waterfall, causes air bubbles to be forced into solution and TDG levels to

increase. Bubbles may also be introduced into solution in the high-pressure zones around hydropower turbines.
A single water quality criterion has been established for total dissolved gas in fresh waters (e.g., lakes, rivers, streams) at 110 percent of saturation at any point of sample collection [WAC 173-201A-200; 2003 edition]. The TDG criterion applies at all times except when the stream flow exceeds the seven-day, ten-year frequency flood. This is a statistically determined high flow period that can be described as the highest average one-week flow that is likely to reoccur once every ten years on average.

For the aquatic life uses assigned to Clarks Creek, total dissolved gases should not exceed 110% of saturation at any point of sample collection.

Suspended sediment, bedded sediment, and biocriteria

Ecology has established a numeric standard for turbidity. Other common methods for quantifying sediment impairment include analysis of the total suspended solids (TSS) in the water column and the percentage of fines and/or sands as part of the streambed composition. Ecology has not established numeric criteria for TSS or percent fines/sand. However, sediment impairments and targets can be established under the narrative water quality standards in WAC 173-201A-260(2).

Toxics and aesthetics criteria

The state applies toxics criteria (e.g., arsenic, mercury, chromium, lead, ammonia, etc.) to waters of the state to protect aquatic life and human health. In some cases, the state designs criteria to protect wildlife that are drinking water and eating fish contaminated with the toxins.

The following narrative criteria apply to all existing and designated uses for fresh and marine water:

> (a) Toxic, radioactive, or deleterious material concentrations must be below those which have the potential, either singularly or cumulatively, to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health (see WAC 173-201A-240, toxic substances, and 173-201A-250, radioactive substances).
>
> (b) Aesthetic values must not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste (see WAC 173-201A-230 for guidance on establishing lake nutrient standards to protect aesthetics).

Additionally, the 2012 Water Quality Policy Document 1-11, *Assessment of Water Quality for the Clean Water Act Section 303(d) and 305(b) Integrated Report*, specifically incorporates the use of bioassessment data in the determination of water-body impairments based on the previously cited narrative standard (WA ECY, 2012c). Ecology uses the River Invertebrate Prediction and Classification System (RIVPACS) multivariate model and multi-metric Benthic Index of Biologic Integrity (B-IBI) to help identify impairments of the biologic community. A Category 5 determination, indicating a water-body segment is biologically impaired, occurs when:

- *The RIVPACS score calculated from the two most recent years of available macroinvertebrate assemblage data results in a score less than 0.73, or*
- *A B-IBI score indicates a level of degradation such that the uses in the water body are impaired.*

Current Washington Water Quality Policy 1-11 guidelines allow the use of both RIVPACS and multi-metric index models like (B-IBI) for assessment of biological condition in streams and rivers. The policy has clear guidelines for the use of the RIVPACS model, but not for B-IBI scores. The scientific community defines biotic integrity in the following way: "capable of 'supporting and maintaining a balanced, integrated, adaptive community of organisms having a composition and diversity comparable to that of the natural habitats of the region' (Frey 1977)." Since then the term biotic integrity has been refined to mean: "a balanced, integrated, adaptive system having a full range of ecosystem elements (genes, species, assemblages) and processes (mutation, demographics, biotic interactions, nutrient and energy dynamics, metapopulation dynamics) expected in areas with no or minimal human influence (Karr 2000)."

This definition has been supported by the US EPA (Davies and Jackson, 2006) and is a key concept in their Biological Condition Gradient.

The Puget Sound Stream Benthos (PSSB) project uses the (B-IBI) to rate stream health from excellent to very poor based on a series of metrics. The definition of "poor" water is "Overall taxa diversity depressed; proportion of predators greatly reduced as is long-lived taxa richness; few stoneflies or intolerant taxa present; dominance by three most abundant taxa often very high." The B-IBI score for a "poor" water is less than or equal to 27.

TMDL allocation targets

The TMDL targets for dissolved oxygen are based on the water quality standards. The DO TMDL target is based on the state water quality criterion of 9.5 mg/L DO, and the total dissolved gases criterion of 110% of saturation. These targets represent the most protective criteria and are protective of all designated uses. The DO criterion addresses the basis for the 303(d) listing. In this TMDL the DO target is expressed in pollutant terms of dissolved oxygen deficit (DOD), the amount of oxygen depleted by sources in the Clarks Creek watershed.

Because sediment transport occurs in the water column and at the stream bed, the sediment TMDL loading capacity is defined in terms of the total sediment load in the stream. This includes both suspended solids (TSS) and bedload transport to account for processes that erode channel banks in one reach and cause excess sediment deposition in downstream reaches. The required sediment load reduction is based on the difference between the percentage of sand and fines in Clarks Creek and the 90th percentile percentage of sand and fines in Puget Sound lowland reference systems. These reference systems represent a variety of Puget Sound lowland reference streams that support a healthy fish community and have high biological integrity (Hayslip, 2013). A 64% reduction allocation is required to meet the reference conditions in Clarks Creek at 66th Avenue.
Fish and other aquatic life are affected by turbidity in the water column and sediment that has settled out on the bottom of a stream or river bed. The effects of turbidity, sediment, and solids

on fish and other aquatic life include the prevention of successful development of fish eggs and larvae (Tappel and Bjornn, 1983), modifying behavior (Center for Streamside Studies 2001), natural movements and avoidance and displacement (Birtwell 1999), and a reduction in the abundance of available food. The erosion and transport of sediment can also serve to transmit attached chemical and biological contaminants.

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Watershed Description

Geographic setting

The Clarks Creek watershed is located in the lower Puyallup River Basin, not far from Commencement Bay (southern end of Puget Sound) and the northwest corner of Pierce County, Washington. Figure 4 provides locations of local government entities relative to the Clarks Creek watershed. The city of Puyallup is the largest municipality in the watershed, comprising approximately 54% of the Clarks Creek watershed area. The northern portion of the watershed is within the PTI Reservation, as indicated on Figure 4 by the 1873 Tribal Survey Area.

Clarks Creek has a surface water drainage area of about 13 square miles. The watershed consists of glacial deposits, foothill ridges, and flat valley land along the Puyallup River. The headwaters of the Clarks Creek surface water drainage network start approximately one-third of a mile south of Maplewood Springs and flow 3.6 miles north through Pierce County, the city of Puyallup, and Puyallup Tribal lands before discharging into the Puyallup River.

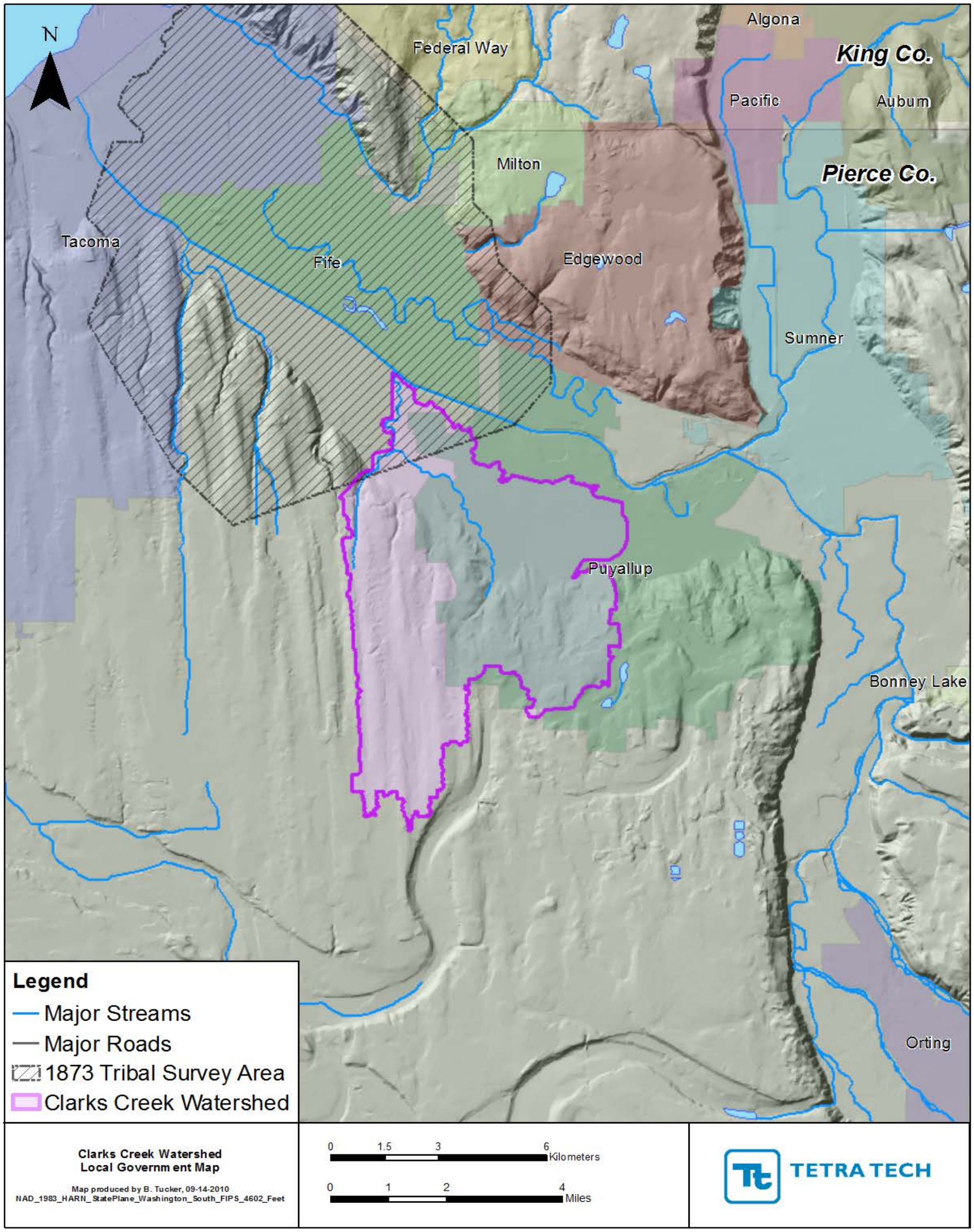

Figure 4 Clarks Creek watershed and local government boundaries.

Geology and topography

Located in the Puget Sound uplands, the Clarks Creek watershed is part of an extensive plateau of glacial deposits that border the Sound. Clarks Creek and adjacent tributaries are fed by swale and wetland-dominated stream channels, as well as by ravines between the rolling terrain of northern-aligned ridges that descend from the southern part of the watershed.

Elevations in the watershed range from sea level at the mouth in Puget Sound to 120 meters on adjacent bluffs and 210 to 245 meters in the upper foothills. The surficial geology of the Clarks Creek area is a product of glaciations and subsequent alluvial processes (Jones et al., 1999; Crandell et al., 1958). The difference in elevation from the headwaters of Clarks, Rody, Diru, Woodland and Silver creek watersheds to the Puyallup River valley bottom is approximately 140 meters. The downstream, northern portion of the watershed is located in the flat Puyallup River Valley, which includes most of Clarks Creek. The headwaters of the Clarks Creek drainage are primarily in the Vashon recessional outwash, a highly permeable shallow aquifer. From there, the creek descends for a few miles through the upper aquifer unit before transitioning to a semi-confining unit in the Puyallup River valley.

The upper parts of the Clarks Creek mainstem and tributaries of Clarks Creek have steep slopes with varying levels of vegetative cover. The upland areas that drain into these creeks are relatively flat before running down the steep glacial terrace, which is made up of sands and gravels, glacial till, and recessional outwash sand and gravels. These materials erode easily and provide substantial amounts of sediment to the tributaries and Clarks Creek. The lower mainstem of Clarks Creek and tributaries become flatter and broader.

Soils

Most of the soils in the watershed were formed in consolidated glacial till (hardpan) and typically yield low infiltration rates, although they may include an overlay of well-drained outwash sands and gravel. The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while well-drained sandy soils have the greatest infiltration rates. The distribution of NRCS Hydrologic Soil Group (HSG) in the watershed is 50% C (slow infiltration rates), 22% B (moderate infiltration rates), 21% D (very slow infiltration rates), and 7% A (high infiltration rates). Various wetlands exist in the southern headwaters of the watershed due to perched water tables and poor soil infiltration rates common in that area.

Climate

Based on 1980-2009 monitoring at McMillan Reservoir in Puyallup, the annual average precipitation is 39.1 inches. The highest annual precipitation was recorded in 1996 at 61.1 inches; the minimum was recorded in 1985 when the annual precipitation was 24.5 inches. Most rain falls between October and April. Average daily minimum and maximum air temperatures are 41 and 59 degrees Fahrenheit, respectively, and record low and high temperatures are -1 and 102 degrees Fahrenheit, respectively.

Groundwater

The highly permeable surface aquifers of upper Clarks Creek result in substantial exchanges between the surface and groundwater systems (Savoca et al., 2010). Groundwater movement in the surface aquifer (Vashon recessional till or A1 aquifer) generally follows the land surface gradient, with seeps and springs where this layer thins out, such as at Maplewood Springs. While the exact extent is uncertain, it appears clear that the contributing area for Maplewood Springs is somewhat greater than shown on surface topography, and may include some flow coming from the adjacent Potholes area (Tetra Tech, 2010). The USGS is in the process of creating a regional groundwater model, and the initial framework report (Savoca et al., 2010) suggests that water in the A1 aquifer may flow to Maplewood Springs from a distance of up to five miles or so from the south, and perhaps from the Pothole area to the east as well.

The headwaters of Clarks Creek are supplied by perennial springs, with Maplewood Springs being the largest. Several entities withdraw water from Maplewood Springs, including the city of Puyallup, the state hatchery, Fruitland Water District, as well as several private landowners (City of Puyallup, 2006).

Land use

The Clarks Creek watershed is highly developed in most areas, with an effective impervious area of approximately 25%. Existing land use is shown in Figure 5. Land uses in the watershed vary from urban in the city of Puyallup to rural residential in the county. County planners estimate that the population in the Clear and Clarks Creek basins will increase by 15% (from 61,700 to 71,000), and at build-out effective impervious area could rise from 25% to 35% by 2020, an increase of 40%. Land uses consist mostly of single family residential (47% of the watershed) scattered with vacant forest land, pastures, lawns, and hobby farms. The land use becomes more urbanized closer to the city of Puyallup, Tacoma, and South Hill Mall. Commercial development is mostly concentrated along the major transportation corridors of Meridian Avenue and SR-12 interchange.

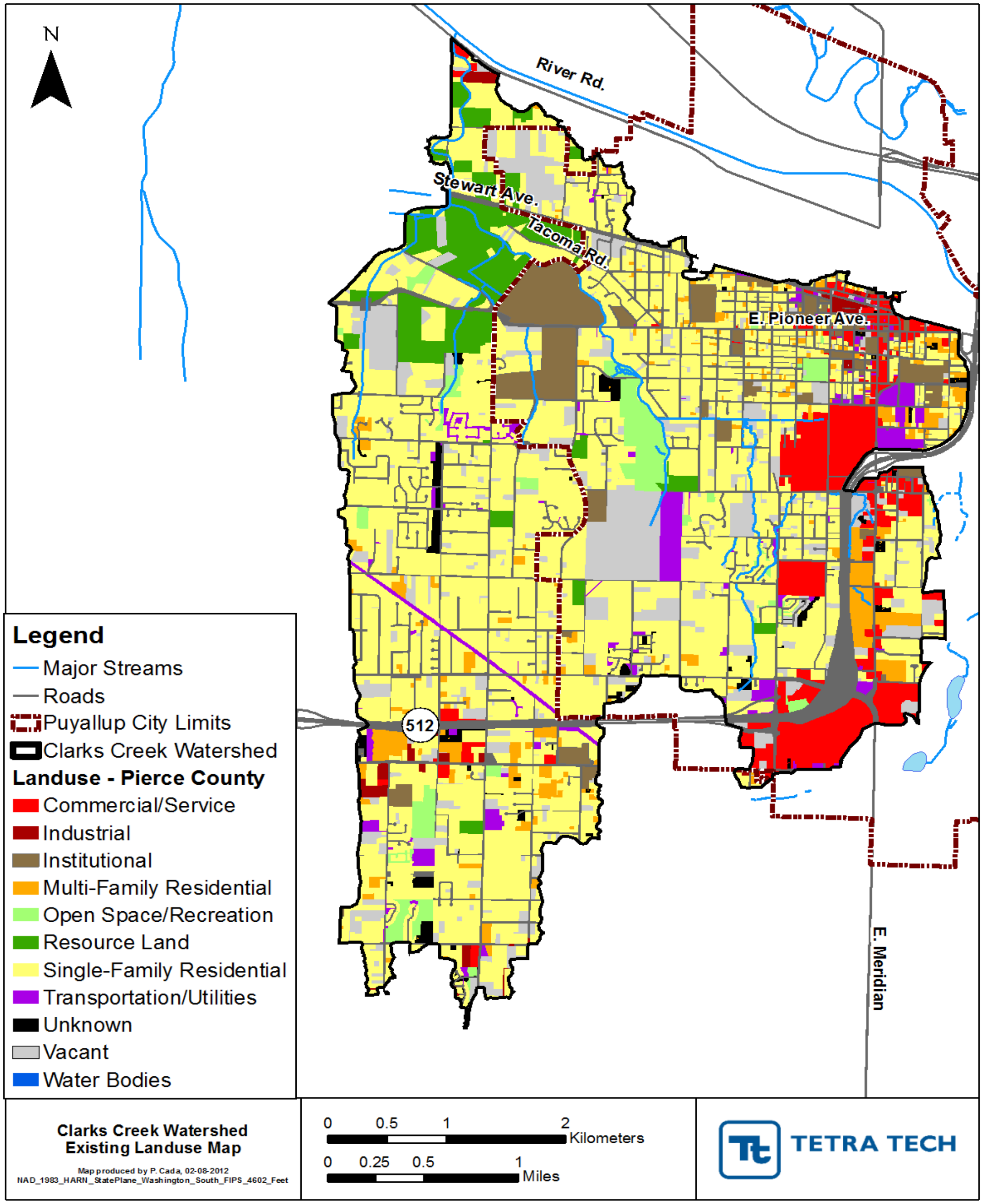

Figure 5 Existing land use for Pierce County and the city of Puyallup.

Potential pollutant sources

Dissolved oxygen can be depressed in surface water as the result of both point and nonpoint sources of sediment and nutrients, as well as the direct contribution of water with low DO concentrations. Sources of sediment loading include suspended sediment in stormwater runoff and stream bank and channel erosion. In Clarks Creek and its tributaries, excessive sediment accumulates in streams and promotes the growth of aquatic vegetation. Increased organic matter from decaying vegetation, in addition to other nutrient and sediment loading, leads to increased biological activity and depletion of DO. Landscape changes also contribute indirectly to low DO. For example, loss of riparian vegetation decreases shading, increases aquatic vegetation, increases stream temperatures, and results in lower DO concentrations. Natural conditions can also cause low DO, turbidity, and fluctuations in sediment loading. The following sections describe the point, nonpoint, and natural background sources of low DO and sediment in Clarks Creek.

Wastewater point sources

Point source discharges of wastewater to Clarks Creek include two fish hatcheries and a fish rearing pond (Figure 6). The Washington State Department of Fisheries operates a hatchery (State Hatchery) at Maplewood Springs (NPDES permit number WA0039748). PTI also operates hatcheries (one on Diru Creek and one on Clarks Creek) that do not have NPDES permits because their production levels are lower than federally defined thresholds.

The primary water pollution control issue at the hatchery facilities is organic fish waste, including uneaten food. The state hatchery uses a waste pond to treat organic solids. The combined discharges from the juvenile rearing raceways and waste pond result in a relatively small pollutant discharge to Clarks Creek below Maplewood Springs (WA ECY, 2008). According to Ecology 2005 – 2010 monitoring, TSS concentrations are generally less than 2 mg/L and average ammonia concentrations are 0.14 mg/L taken by monthly composite. As explained later in this document, excessive TSS can increase BOD and lead to low DO; sediment loading can also promote excessive aquatic vegetation, which also has been linked to low DO in the watershed. BOD5 measurements are mostly at non-detectible levels. The monitoring data suggest that the average discharge rate is about 6.3 million gallons per day (MGD) (9.7 cfs).

The tribal hatcheries are smaller than the state facility, and the EPA (the permitting authority for tribal activities) has not required PTI to obtain federal discharge permits. The Diru Creek Tribal hatchery discharges to Diru Creek near Pioneer Way and the confluence with Clarks Creek. The Clarks Creek Tribal hatchery discharges to Clarks Creek near 66th Avenue East (WA ECY, 2008). PTI's monitoring data from 2007 and 2008 showed only low levels of TSS and ammonia. Detailed monitoring of pollutant loading from the hatcheries has not been conducted at this time. Using the available TSS and ammonia data as indicators, the hatcheries contribute relatively small amounts of sediment and oxygen-demanding substances to Clarks Creek. PTI will collect monitoring data to better characterize the pollutants and loadings to Clarks Creek.

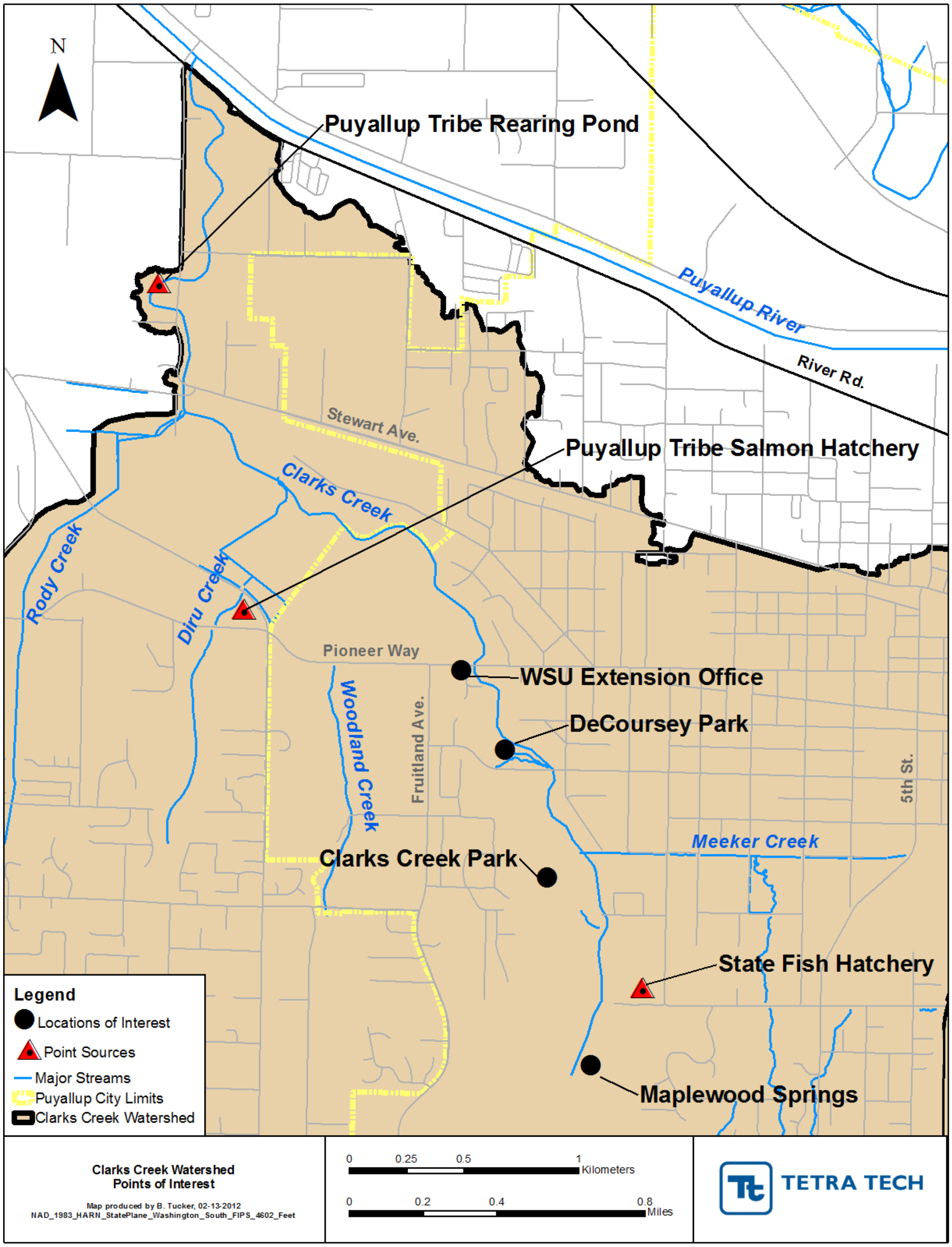

Figure 6 Locations of interest in Clarks Creek watershed.

Stormwater point sources

Municipal stormwater covered by NPDES permits

Urban stormwater discharged to Clarks Creek through municipal separate storm sewer systems (MS4s) is regulated under the federal NPDES permit program through permits issued by Ecology. Pierce County is a Phase I MS4 operator under the federal MS4 program requirements. Discharges from the Pierce County MS4 are subject to NPDES Permit No. WAR04-4002. WSDOT discharges from the MS4 are subject to NPDES Permit No. WAR04-3000A, which covers WSDOT facilities within Phase I and Phase II jurisdictions. The city of Puyallup is a Phase II MS4 operator and discharges from the Puyallup MS4 are subject to NPDES Permit No. WAR04-5017. The impacts from municipal stormwater conveyances are described in the Study Results and Discussion section.

Construction stormwater discharges covered by NPDES permits

Stormwater discharges from clearing, grading and excavation associated with construction activity disturbing one or more acres are regulated under the federal NPDES permit program. Such regulated construction activity is subject to Ecology's *Construction Stormwater General Permit* (most recently issued on December 1, 2010). According to Ecology's Permitting and Reporting Information System (PARIS) database reviewed in June 2012, five active construction sites are permitted by Ecology within the Clarks Creek watershed. However, only one of the five active permitted sites - The Lakes Development Phase I NPDES Permit No. WAR006193 - discharges directly into Clarks Creek.

Land disturbance occurring as part of construction activity can contribute substantial sediment loading to streams and can provide fine sediment for elodea growth. Detailed evaluation of available monitoring from the currently permitted construction sites has not been conducted at this time, and because these sites are regulated it is assumed to contribute relatively small amounts of nutrients and oxygen demanding wastes to Clarks Creek. By complying with Ecology's *Construction Stormwater General Permit,* the Lakes Development permit can reduce the likelihood that construction activity would contribute sediment loading (including fine sediment) to the streams and impair core summer salmonid habitat, primary contact recreation and other beneficial uses.

Industrial stormwater discharges covered by NPDES permits

Stormwater discharges from certain industrial activities, determined by Standard Industrial Classification (SIC) codes, are regulated under the federal NPDES permit program. Such discharges are subject to Ecology's *Industrial Stormwater General Permit* (as modified, effective July 1, 2012), or to Ecology's *Sand and Gravel General Permit* (effective October 2011). Depending on the type of industrial activity, stormwater discharges have the potential to contain nutrients or other constituents which can contribute to low oxygen levels in receiving waters. According to Ecology's PARIS database reviewed in June 2012, three industrial permitted facilities and two sand and gravel permitted facilities are located in the Clarks Creek watershed. None of these facilities directly discharge to Clarks Creek, and therefore do not contribute to the impairment in Clarks Creek.

Nonpoint sources

Direct surface runoff to Clarks Creek is considered a nonpoint source. Oxygen-demanding substances can be delivered through stormwater runoff from various land uses and land covers. As noted previously, land uses in the Clarks Creek watershed consists mostly of single-family residences (47% of the watershed) scattered with vacant forest land, pastures, lawns, and hobby farms. The land use becomes more urban closer to the city of Puyallup, Tacoma, and South Hill Mall. Some commercial development exists in the watershed, mostly concentrated along the major transportation corridors such as the Meridian Avenue and SR-512 interchange.

Nutrient and sediment loading from surface runoff is generated by a variety of sources. Pet waste can be a source of nutrient loading from urban and suburban areas. The application of fertilizer on residential lawns and recreational land (golf courses, soccer fields, etc.) can be a major source of nutrient loading to surface and ground water.

High stream flows caused by runoff from highly impervious drainage areas can lead to sediment loading via bank and channel erosion. This is further exacerbated by lack of riparian cover along stream channels due to the absence of root structures to hold the soil in place. Land disturbance, such as construction sites, can contribute substantial sediment loading to streams, providing fine sediment for elodea growth.

Nutrient loading from nonpoint sources also occurs during baseflow. In particular, onsite wastewater systems can contribute nutrients to streams during both baseflow and stormflow conditions. A large portion of the residential area is not sewered and relies on onsite wastewater treatment and disposal.

Not only do nonpoint sources lead to direct pollutant loading, but disturbance of vegetation near streams can alter ecological mechanisms and contribute to low DO. First, organic material in urban runoff contributes to sediment oxygen demand (SOD), which provides a substrate that enhances elodea growth. Second, poor riparian cover contributes to increased elodea growth and elevated instream temperatures. Many portions of Clarks Creek downstream of DeCoursey Park have poor riparian cover, especially where managed lawns associated with single-family residences extend up to the edge of the creek.

Natural background

Natural background sources of low DO and sediment include surface runoff from undisturbed areas, natural rates of stream bank erosion, and groundwater with low DO concentrations. While DO in groundwater has not been directly measured, DO concentrations could be either low or high depending on the source of groundwater. The definition of groundwater and what is strictly natural is ambiguous in the Clarks Creek watershed, as much of the stormflow reaches streams through subsurface pathways. The effect of groundwater on Clarks Creek instream DO concentrations also depends on whether groundwater enters the stream through the tributaries, bank seepage, or channel seepage. The net influence of groundwater inflows on instream DO concentrations was estimated during model calibration as discussed in the Relationship between DO and Baseflow section and Appendix B.

Waste and other organic matter in undisturbed, natural areas may contribute to background nutrient loading. Erosion of upland soil, streambanks, and stream channels also occurs naturally during storm events.

Goals and Objectives

Project goals

The goal of the TMDL project for Clarks Creek and its tributaries is to address low DO and sediment problems in the watershed so that water quality is improved and beneficial uses are restored. More specifically, the goal is for Clarks Creek and its tributaries to comply with the water quality standards for DO and sediment.

Ecology's objectives:

1. Develop DO and sediment TMDLs.
2. Equitably distribute the TMDL allocations.
3. Develop a WQIR to document the study and guide future actions.

The goal of the planning phase of the project is to develop an implementation plan for actions needed to meet DO and sediment water quality standards.

Study objectives

The TMDL project was developed to support the project goals by achieving the following objectives:

1. Determine the loading capacity of Clarks Creek for sediment and oxygen-demanding pollutants using water quality and hydraulic models, including the development of implementation-ready wasteload and load allocations and actions assumed to meet the allocations.
2. Allocate pollutant loads among pollutant sources in an equitable manner.
3. Develop appropriate control measures so that water quality standards will be achieved. As appropriate, natural background, seasonal variation, and margin of safety are taken into account.
4. Develop a WQIR that includes all of the elements of a TMDL, implementation targets assumed to achieve the TMDL allocations, and an implementation plan for achieving the TMDL project goals.

These objectives provide the data, information, and implementation steps that can be used to meet water quality standards for DO and sediment for Clarks Creek and its tributaries.

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Analytical Approach

This WQIR is designed to reflect the unique processes affecting DO and sediment loading in the Clarks Creek watershed. DO concentrations in Clarks Creek result from complex physical, chemical, and biological processes that are influenced by temperature, salinity, atmospheric pressure, stream flow, and the ambient DO concentration itself.

A key focus of the analytical approach was to analyze DO problems in terms of the DO deficit (DOD), which is the difference between the saturation DO concentration and the ambient concentration. It is also a measure of the sources and the amount of DO they deplete. A positive DOD indicates a shortage of DO, while a negative DO indicates a surplus, as may occur during active photosynthesis by algae. DOD simulations were used to test the sensitivity of DO to variations in source contributions. The loading capacity and allocations are expressed in DOD.

The major sources of sediment loading in Clarks Creek, as outlined previously, include upland sediment in stormwater runoff and streambank and channel erosion. The analytical approach for sediment involved evaluating the degree to which sediment loading exceeds rates or patterns that impair aquatic life. By quantifying the impairment as total sediment load, the approach accounted for the highly variable nature of sedimentation processes and the geomorphic characteristics of the watershed, whose soils have particular sensitivity to land disturbance.

Collectively, the analytical approaches for DO and sediment involved the use of historical data, data collected to support TMDL development, and application of modeling tools. The following sections outline the data, tools, and methods used to study DO and sediment processes.

The following section defines the study area, describes the general modeling framework, and provides documentation for the data used. The Study Results and Discussion section details the results of these data collection and analysis efforts.

Study area

The study area encompasses the entire drainage area of Clarks Creek, from the headwaters to the confluence with the Puyallup River. The study area includes the drainage area of the four major tributaries to Clarks Creek: Meeker Creek, Woodland Creek, Diru Creek, and Rody Creek.

Water quality, flow, and habitat monitoring of Clarks Creek and its tributaries has been ongoing since 1983. The following agencies sponsor monitoring efforts: city of Puyallup (7 stations, 1993), PTI (10 stations, 1998-2012), PTI Stormwater (4 stations, 2011-2012), Pierce County (3 stations, 2008-2010), Ecology (10 stations, 2002-2003), Western Washington Fairgrounds (WWF) (8 stations, 1998-1999), and the USGS (one continuous flow gage, flow 1995-2008, water quality 1983-1984; two field observation flow stations, 2006-2008; four water quality stations, 1983-1984; one additional water quality station, 2006-2007; limited flow observations were also available at the USGS water quality stations).

Table 4 and Figure 7 provide a list and show locations of all the monitoring stations, classified by the monitoring source. As evident in the figure, the highest density of monitoring locations is concentrated in the southern half of Clarks Creek, with considerable redundancy and overlap among monitoring sources.

The USGS collected water quality data from four stations within the Clarks Creek watershed: near the mouth of Rody Creek, near the mouth of Diru Creek, near the mouth of Clarks Creek, and Clarks Creek at Tacoma Road. The latter was also operated as a flow gage from March 1995 through November 2008. Ecology monitored ten stations within the watershed. These stations include five along the Clarks Creek mainstem, two along Meeker Creek, and one each near the mouths of Diru, Rody, and Woodland Creeks. Pierce Conservation District monitors Rody Creek at Pioneer Avenue, Diru Creek at Pioneer Avenue, and Clarks Creek at 56th Street. The city of Puyallup's Surface Water Management collects samples within the city limits at five locations along Clarks Creek and two on Meeker Creek. PTI monitors six locations along Clarks Creek: three downstream within the Tribal Survey Area, and three upstream near the state hatchery and Maplewood Springs. The Western Washington Fair (WWF), which contributes stormwater runoff from its 160 acres, operates eight stations along the creek, including one at the mouth of Meeker Creek.

Table 4. List of monitoring stations within Clarks Creek watershed

Site ID	Source	Location
CLK-1	PTI	Maplewood Springs
CLK-3	PTI	Pioneer Way
CLK-4	PTI	66th Ave bridge
CLK-4.1	PTI	66th Ave/ 5722
CLK-5	PTI	66th/River Rd
CLK-6	PTI	Pond above state hatchery
CLK-7	PTI	Above state hatchery, 14th Ave
CLK-8	PTI	12th St Bridge
CLK-9	PTI	66th/Stewart
CLK-TR	PTI	Tacoma Rd. (co-located with USGS 12102075)
SW-1	PTI	Pioneer Way
SW-2	PTI	7th Ave.
SW-3	PTI	Meeker Creek
SW-4	PTI	12th Ave.
CCURS-1	Ecology	Clarks at 56th
CCURS-2	Ecology	Clarks below Pioneer
CCURS-3	Ecology	Clarks above 7th
CCURS-4	Ecology	Clarks below state hatchery
CCURS-5	Ecology	Clarks above state hatchery
DURS-2	Ecology	Diru mouth
MDURS-1	Ecology	Meeker mouth
MDURS-2	Ecology	Meeker upstream
RURS-1	Ecology	Rody mouth

Site ID	Source	Location
WURS-1	Ecology	Woodland Mouth
City-1	City of Puyallup	Clarks headwaters
City-2	City of Puyallup	Below Clarks, state hatchery
City-3	City of Puyallup	Meeker mouth
City-4	City of Puyallup	DeCoursey-upstream
City-5	City of Puyallup	DeCoursey-downstream
City-6	City of Puyallup	Puyallup city line
City-7	City of Puyallup	Meeker headwaters
CC1	WWF	Clarks Creek at Maplewood Springs
CC2	WWF	Clarks Creek at state hatchery
CC3	WWF	Clarks Creek at 12st bridge
CC4	WWF	Clarks Creek at 7th bridge
CC5	WWF	Clarks Creek at Pioneer bridge
CC6	WWF	Clarks Creek at 66th
CC7	WWF	Clarks Creek at mouth
H	WWF	Meeker mouth
12102000	USGS	Clarks Creek at Puyallup
12102010	USGS	Clarks at 7th Ave.
12102020	USGS	Diru upstream of Diru Creek tribal hatchery
12102050	USGS	Rody at Pioneer Way
12102075	USGS	Clarks between Diru and Rody
12102100	USGS	Clarks at River Road (mouth)
MS048	Pierce County	Rody Creek at Pioneer
MS074	Pierce County	Diru Creek at Pioneer
MS118	Pierce County	Clarks Creek at 56th

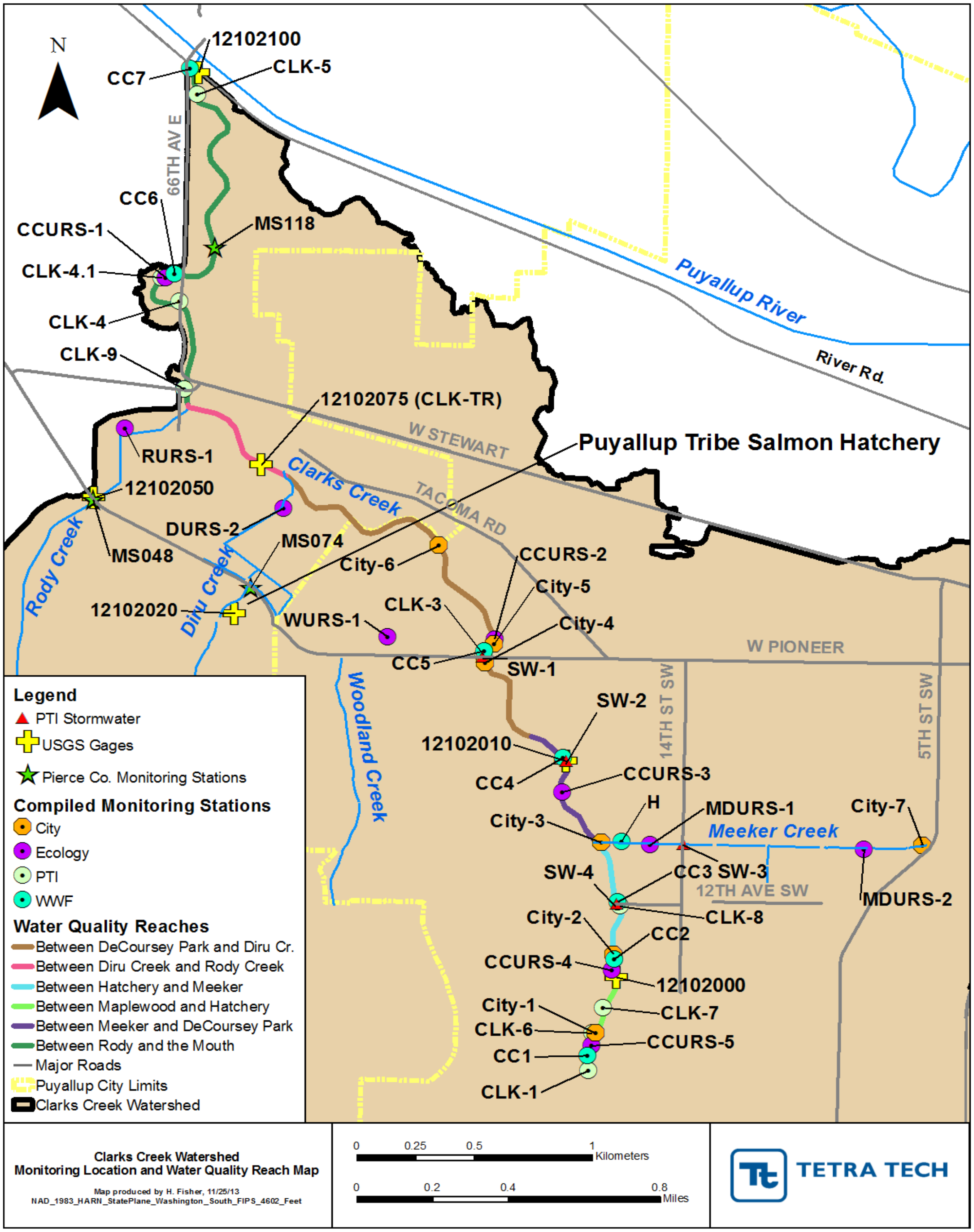

Figure 7. Monitoring station locations and water quality reach designations

In 2011, sediment samples were collected by Brown and Caldwell and PTI staff for the PTI Sediment Reduction Action Plan grant-funded research. Twenty locations were selected and are presented in Figure 8:

- 10 locations on the Clarks Creek mainstem (Clarks-01 through Clarks-10).
- 3 locations in Rody Creek (Rody-01 through Rody-03).
- 1 location in Diru Creek (Diru-01).
- 1 location in Woodland Creek (Wood-01).
- 3 locations in Silver Creek (Silver-01 through Silver -03).
- 1 location each on two unnamed tributaries east of Silver Creek (West-01 and East-01).

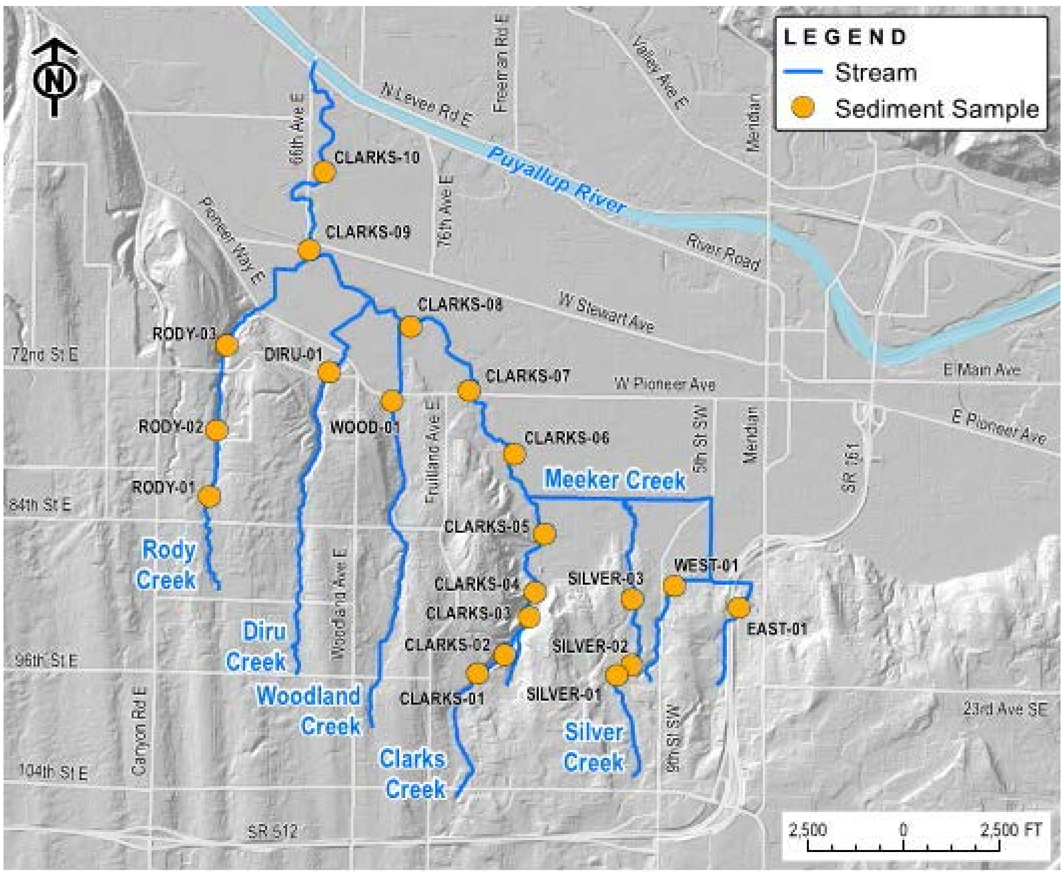

Figure 8. Sediment sampling locations in Clarks Creek watershed (Brown and Caldwell, 2013).

Modeling framework

Two models were developed to support the TMDL analytical approach. Figure 9 summarizes the way each model was used in the analytical approach. First, a watershed model was developed by Tetra Tech (2012a) using EPA's Hydrological Simulation Program FORTRAN (HSPF). This model was developed for PTI as part of a sediment study to support TMDL development and the selection of sediment reduction measures. The HSPF model was used to predict flow and sediment loading to quantify the sediment loading capacity. The HSPF model outputs provide information on the critical storm conditions and the amount of flow each jurisdiction generates. The HSPF model output was also used to allocate both the DOD and sediment loading capacity by jurisdiction based on the proportion of stormflow generated. Second, Tetra Tech (2011a) developed a stream water quality model using QUAL2Kw, a quasi-steady state water quality model created for Ecology (Pelletier and Chapra, 2008; www.ecy.wa.gov/programs/eap/models.html), which is an enhanced version of EPA's older QUAL2E model (Brown and Barnwell, 1987). QUAL2Kw used instream monitoring data, climate data, HSPF outputs, and other data sources to develop the DO mass balance during critical conditions and estimate the loading capacity for DOD. QUAL2Kw was not used to estimate instream sediment results. Appendix B documents the model selection, QAPP, calibration, and validation for the HSPF and QUAL2Kw applications.

HSPF

- Used simulated flow data throughout watershed to analyze water quality observations.
- Described production and transport of sediment and other pollutants as a function of land use and flow.
- Developed overall sediment balance.
- Estimated upland sediment production rates.
- Simulated existing conditions and build-out conditions.
- Generated flow-duration curve to analyze flow regime of storm events with available data and determine critical conditions.
- Provided a line of evidence for the sediment loading capacity.
- Estimated percent of stormwater flow from sources for DOD.
- Determined implementation targets based on stormflow by jurisditction.

QUAL2Kw

- Developed DO Mass Balance during critical conditions
- Explored the system's sensitivity to changes in nitrate, riparian shading, SOD, and flow withdrawals
- Determined the reduction needed from various pollutants to meet DO water quality standards under critical conditions
- Determined loading capacity for DOD; and allocations for DOD and sediment.
- Determined implementation targets based on stormflow by jurisdiction. 2013 +

Figure 9. Clarks Creek modeling framework

Ecology study methods

Water quality data

Water quality data collected by Ecology (2002-2003) were reviewed and analyzed. These data are documented in detail in Tetra Tech (2010a) and are available for download from the EIM database (Project Code: G0100116). Results of this data collection and analysis are discussed in the Study Results Section.

Effective shade and elodea density

Ecology, in partnership with PTI, evaluated the statistical relationship between effective shade and elodea density through data collection and analysis as documented in the Biochemical Oxygen Demand Section and (detailed documentation in Appendix D).

Data quality and data collection

Several studies were used during for the modeling framework and analysis. Data collection and quality assurance methods are explained in detail in the corresponding appendices.

Information and data from sources outside of Ecology

Water quality data collected between 1983 and 2012 were reviewed and analyzed from the following sources: USGS, Pierce County, the city of Puyallup, PTI, and the Western Washington Fair (WWF). These data are documented in detail in Tetra Tech (2010a).

Instream ambient water quality data

For PTI, Brown and Caldwell conducted diurnal sampling of temperature, DO, DO saturation, and turbidity before and after elodea cutting events in 2009 and 2010 (Brown and Caldwell, 2009). The results are discussed in the Effect of Elodea Cutting Section.

Storm event water quality data

The initial modeling analyses indicated that stormwater may be delivering oxygen-demanding sources. In 2011 and 2012, PTI hired Tetra Tech to conduct stormwater sampling in conveyances and receiving waters at four Clarks Creek locations during four storm events between October 2011 and March 2012 (Tetra Tech, 2012d). The investigation was conducted to determine if influent water from storm drains carried pollutants that would diminish DO concentrations in the receiving water. These data are discussed in the Stormwater Monitoring in 2011-2012 Section and (detailed documentation in Appendix E).

Sediment quality data

As part of PTI's sediment reduction action plan, Brown and Caldwell and PTI staff collected samples at 20 locations in the watershed in a one-week period in late July/early August 2011. The samples were analyzed for total organic carbon (TOC), total Kjeldahl nitrogen (TKN, the sum of organic nitrogen and ammonia nitrogen), nitrate and nitrite nitrogen, total phosphorous (TP), biochemical oxygen demand (BOD), fecal coliform bacteria, total solids (TS), and grain size distribution (GSD). More detail on the sediment quality data is provided in the Clarks Creek Sediment Reduction Action Plan (Brown and Caldwell, 2013).

Sediment oxygen demand data

The initial modeling analyses suggested that sediment oxygen demand (SOD) was an important contributor to low DO concentrations. PTI hired HydrO2, Inc. to conduct SOD measurements in the watershed. During September 19-21, 2011, SOD measurements were attempted at three locations along Clarks Creek by HydrO2, Inc. with assistance from Tetra Tech. More detail on the SOD measurement methods and results is provided in HydrO2, Inc. (2011).

Habitat and benthic invertebrate data

Pierce County and PTI collected benthic macroinvertebrate data and calculated the Benthic Index of Biotic Integrity (B-IBI) scores for stations located on Clarks (2001-2004), Diru (2003, 2005, 2010), and Rody (2005) Creeks. The B-IBI scores are composed of ten metrics used to assess stream aquatic health and degradation. In addition, bioassessment studies have been conducted throughout the Puget Sound lowland area since the 1990s. This allows for comparison of biological results from impaired streams and reaches to relatively undeveloped streams. For the Clarks Creek sediment investigation PTI and Brown and Caldwell also conducted a grain size distribution analysis at 20 sites in the Clarks Creek basin in mid-2011, which provides information on substrate characteristics (Brown and Caldwell, 2013).

Geomorphic magnitude-frequency analysis

As part of the PTI Sediment Reduction Action Plan, Brown and Caldwell (2013) evaluated stream stability and mitigation measures for reducing sediment loadings that originate from degrading stream reaches. Stream channel cross-section surveys were conducted at 36 locations along the stream network, primarily in the upper reaches, and added to the existing cross-section data from flood hazard mapping. In total, 54 cross-sections were available for use in the analysis. In addition, LiDAR aerial survey data were used to create preliminary stream profiles. Bed sediment characterization, in terms of size and gradation of the material, was conducted at 20 locations throughout Clarks Creek watershed under the EPA-funded grant awarded to PTI.

These data were utilized to create effective work curves and calculate the geomorphically significant flow range for each reach. The results were compared to regulatory performance standards for flow in Ecology's general NPDES MS4 stormwater permit and to pre-developed conditions to assess the long-term channel-forming effects of a full range of stream flows (Brown and Caldwell, 2013).

Ecology Study Results and Discussion

The initial data review and analyses (Tetra Tech, 2010a), shows that DO concentration in Clarks Creek is affected by several stressors that include sediment erosion and deposition, low oxygen stormwater inflows, nutrient loading, lack of riparian cover, elodea growth, and SOD. Based on literature, higher nutrients contribute to elodea growth, and elodea colonization is promoted by excess fine sediment. In addition, variations in temperature cause variations in DO concentrations because colder temperatures allow higher DO levels in water. Due to these interactions, the data review and analysis includes available data on DO, DOD, and the many related physical, chemical, and biological factors. These data were reviewed and analyzed to develop an understanding of the important processes leading to DO impairment in Clarks Creek and its tributaries.

The degree of sediment impairment within the watershed was also investigated. Brown and Caldwell conducted a sediment study from 2010-2012 to evaluate the sources of sediment loading into the system. The study shows that current sediment loading is approximately sixteen times the loading compared to natural levels of sediment loading. The study confirms the presence of high levels of fine sediment previously observed by PTI. The sediment data in Clarks Creek include TSS data, characterization of the bed sediments, cross-channel surveys, and B-IBI data. The results of the data review are summarized in the following sections, and more detailed results are provided in Tetra Tech (2010a). While the modeling results are largely discussed in the TMDL Analysis Section, a brief exploratory analysis is discussed within this section, which was included in Tetra Tech (2010a)

Quality assurance results

Ecology sources

As part of the Clarks Creek DO study for PTI, Brown and Caldwell collected and analyzed data according to the study's quality assurance project plan (QAPP) (Brown and Caldwell, 2009). Stormwater data from the oxygen-demanding sources investigation for PTI was collected and analyzed according to the study's quality assurance project plan (Tetra Tech, 2011b). Field data collection and hydraulic modeling for the Clarks Creek Sediment Action Plan was completed according to the QAPP designed for the project (Brown and Caldwell, 2011). See Appendix B for a summary of the Model QAPPs for the HSPF and QUAL2Kw modeling.

Sources outside of Ecology

Data collection and quality assurance methods are explained in detail in the corresponding appendices.

Study results

Flow

The USGS monitored flow in Clarks Creek at Tacoma Road at Station 12102075 (drainage area of approximately 13 square miles) from 3/1/1995 to 11/25/2008. The annual average flows are shown in Figure 10. Average annual flows increased from 1995 to 1997, followed by a general decreasing trend through 2005. The period from 2006 through 2008 had flows near average conditions for the period of record.

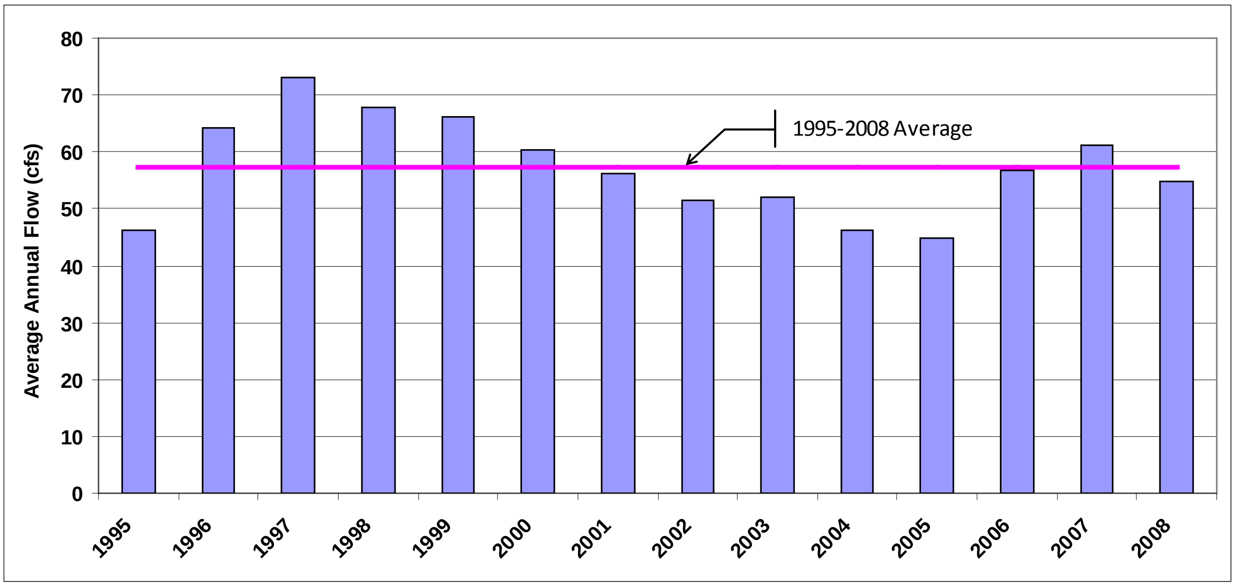

Figure 10. Mean annual average flow rate (cfs) for Clarks Creek at Tacoma Road.

Limited instantaneous flow measurements were taken at other locations. For the period 2006-2008, USGS took nine field measurements on Clarks Creek at Puyallup (gage 12102000, located at the upstream end of Clarks Creek Park; this was also monitored continuously from March 1946 to May 1948) and two field measurements from Clarks Creek at 7th Ave. SW (gage 12102010). Additional instantaneous flow measurements at multiple locations on Clarks Creek and tributaries were taken during the 2002-2003 water quality sampling used to develop the fecal coliform TMDL.

Dissolved oxygen

A thorough analysis of DO impairment required evaluating data collected at multiple temporal scales and flow regimes. In the Clarks Creek watershed, DO concentrations have been measured and analyzed over several decades at a variety of time increments. First, general trends were evaluated based on the long-term data record. Then, data from several focused studies were reviewed. These studies included; 1) the sampling of temperature, DO, DO saturation, and turbidity before, during, and after elodea cutting events; 2) DO monitoring conducted by PTI in 2009 and 2010 with flow, turbidity, and conductivity; 3) comprehensive monitoring of storm drains and instream locations during storm events; and; 4) analysis using QUAL2Kw.

General trends

DO concentrations have been monitored in Clarks Creek since the mid-1980s. Since this time, DO levels have consistently been measured both above and below the water quality standard of 9.5 mg/L in all times of the year, with the maximum DO concentration at 17 mg/L and the minimum DO concentration at 4 mg/L. Historically, the areas with the lowest DO levels in the Clarks Creek mainstem have been in the lower reaches between where Rody Creek enters the creek and where Clarks Creek enters the Puyallup River (Rody Creek to mouth). Meeker Creek, a tributary to Clarks Creek, has the lowest measured DO levels in the watershed. Figure 11 shows the DO concentrations observed in the mainstem of Clarks Creek between major flow inputs such as the state hatchery, Meeker Creek, and DeCoursey Park.

Where aquatic plants or algae are present as in Clarks Creek, DO can increase during the day time when plants generate oxygen in the water during photosynthesis. DO then decreases at night when plants use up oxygen in the night during respiration. The majority of the samples were collected between 10 AM and 2 PM, and thus occurred during periods when photosynthetic activity is expected and DO concentrations are higher. Still, Figure 11 shows consistent violations of the DO water quality standard from 1992-2010 in the mainstem of Clarks Creek. The DO data on Clarks Creek from Rody Creek to mouth represent the highest and lowest data points of DO from 1992-2010, as expected because of excessive elodea growth in this section.

Further analysis of data variability and central tendency (Figure 12) indicates a small decline in DO below the state hatchery, followed by a gradual recovery downstream to Diru Creek, then a decline below Rody Creek. The decline below the hatchery is not necessarily associated with the hatchery itself, but could instead reflect lower velocities and greater macrophyte growth in this reach.

Figure 13 shows DO concentrations on Rody Creek, Diru Creek, Meeker Creek, and Woodland Creek, the tributaries of Clarks Creek. Though limited data were collected, DO concentrations in Meeker Creek violated water quality standards with a minimum of 5 mg/L DO. Data in Rody Creek, Diru Creek, and Woodland Creek were above DO water quality standards.

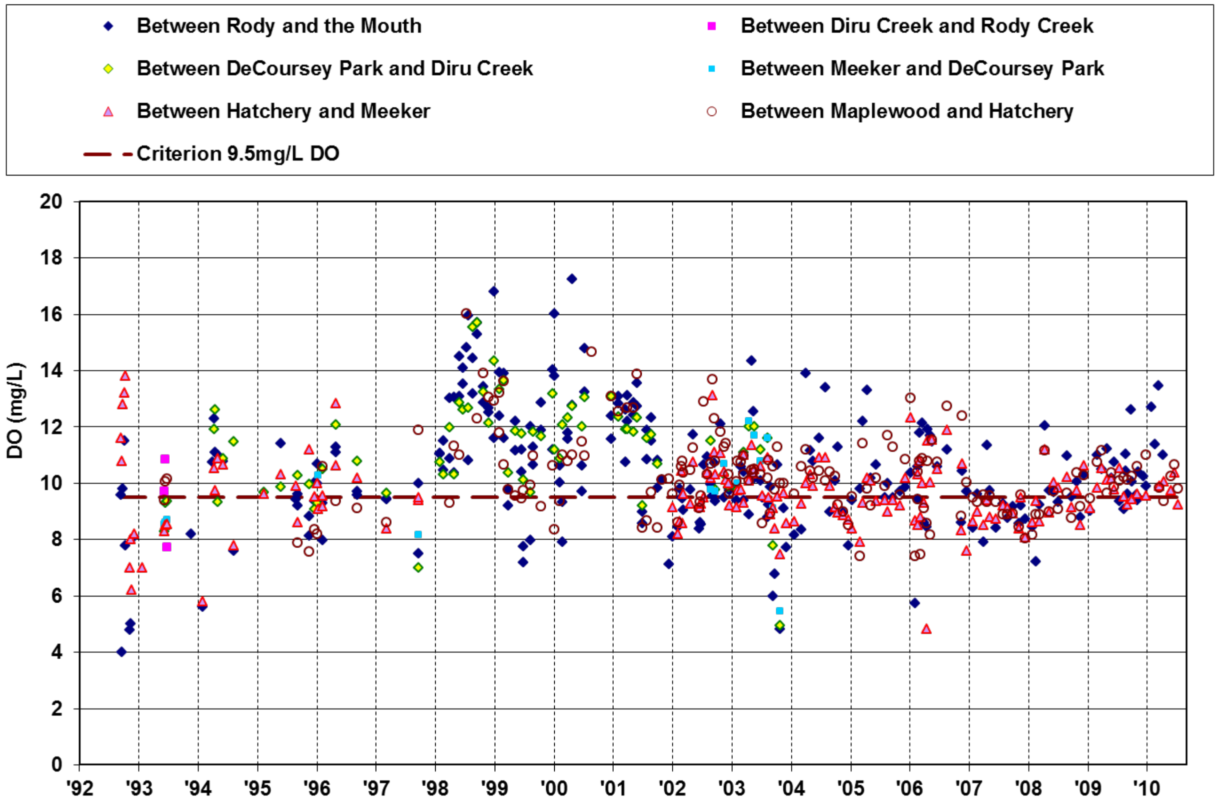

Figure 11. DO concentrations measured in Clarks Creek 1992-2010

Note: ("Hatchery" refers to state hatchery).

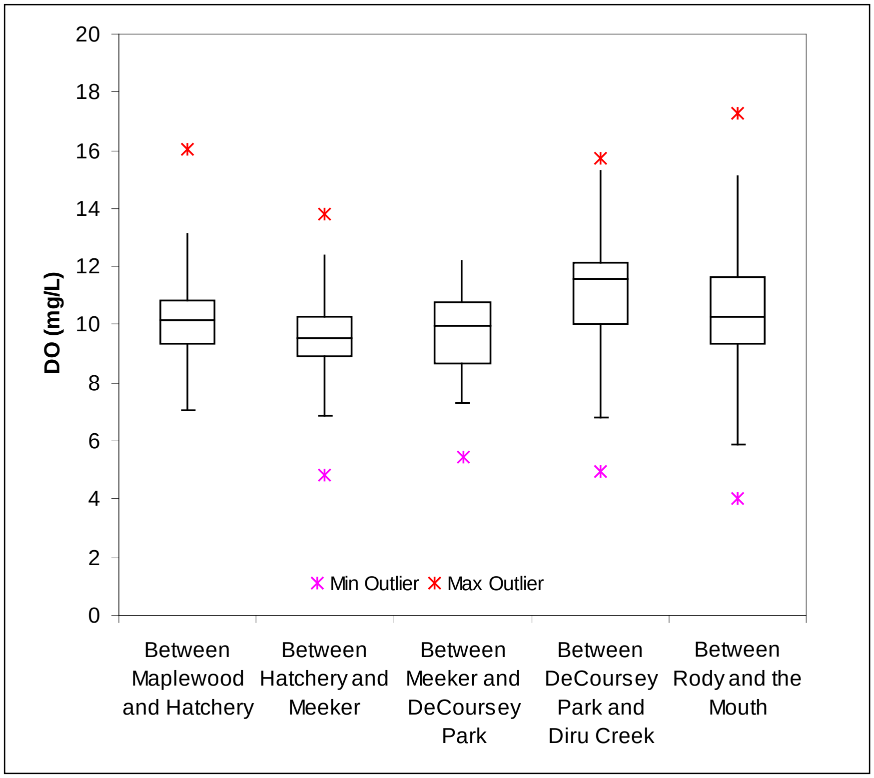

Figure 12. DO concentrations measured in Clarks Creek 1992-2010

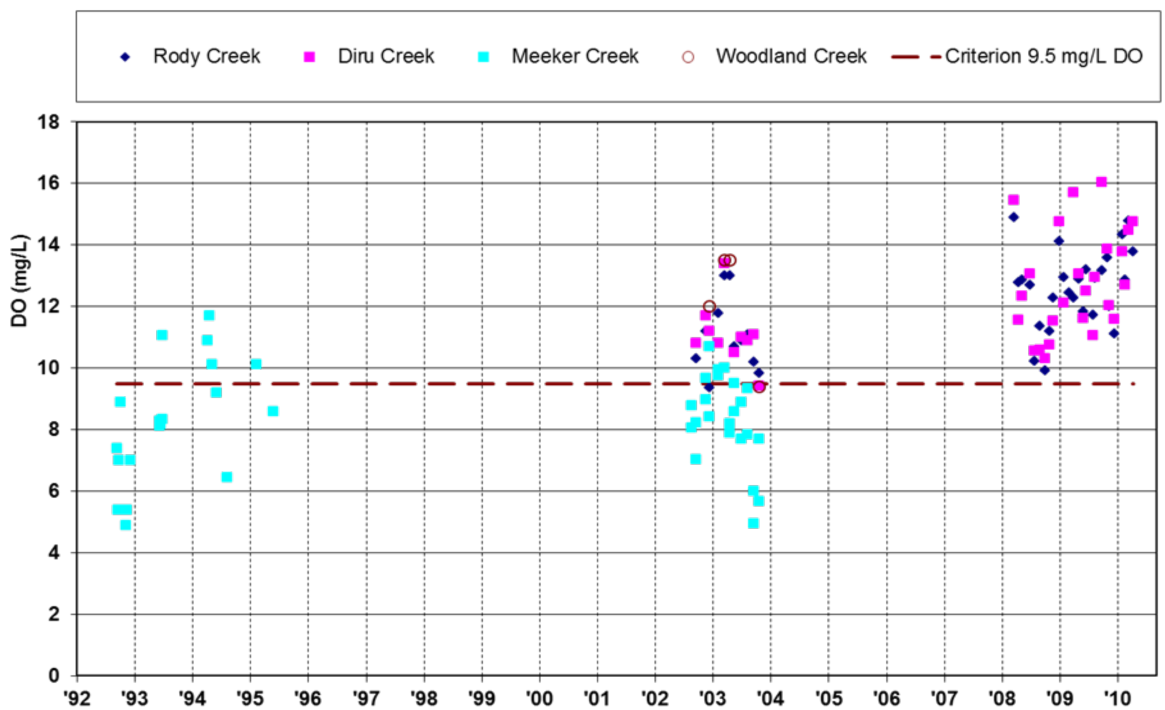

Figure 13. DO concentrations measured in Clarks Creek tributaries.

Effect of elodea cutting

Elodea is a native plant in Clarks Creek that has grown excessively and caused problems in and around the creek for at least 20 years (city of Puyallup, 2013). Elodea presents significant problems in the Clarks Creek watershed. Without elodea overgrowth, Clarks Creek has a maximum depth of 4 feet during non-storm periods. During summer months, however, elodea can grow several feet long, forming dense mats that obstruct flow through the channel. This can increase water surface elevation by 3 feet or more, and increase depths to 7 feet or more (city of Puyallup communications, 2013). From 1991-2012, the city of Puyallup and Pierce County have cut elodea within Clarks Creek as a temporary means to reduce elodea in the system.[2]

The mechanical harvesting of the dense elodea mats has long been a problem for operations at the Tribe's Chinook hatchery near river mile 1.0. The cuttings and fine bed sediments, which were re-suspended during the cutting, clogged the hatchery intake, sometimes necessitating the early release of juvenile salmon from rearing ponds which likely reduced their survival rates. The re-suspended bed sediments also posed a potential barrier for returning adult salmon to the hatchery as well. The elodea re-colonizes quickly after harvesting, as hormones are stimulated and the stems take hold in the fine sediment substrate, which is a preferred habitat of elodea. Thus, the previous methods used to harvest elodea in the creek increased its rate of growth, compounding the problems in the creek.

In 2009 and 2010, PTI and Brown and Caldwell conducted a study of temperature, DO, DO saturation, and turbidity before, during, and after elodea cutting events at CLK-4, CLK-TR, and CLK-8 (see Figure 7 for site locations). These studies provided information to assess the impacts of elodea on the DO balance in Clarks Creek (Brown and Caldwell, 2009). The study design's objectives were to answer the following:

1. Is there DO impairment (low DO levels) in Clarks Creek?
2. If there is a DO impairment, is the condition natural or due to anthropogenic causes?
3. To what extent are dense growths of submerged macrophytes (such as elodea) associated with DO impairment in the creek?
4. Do bottom sediments appear to be contributing to DO impairment in the creek?

The study results, explained in more detail and illustrated in the following paragraphs, showed that the observed dissolved oxygen concentrations in the creek did not meet the DO criterion of 9.5 mg/L for its designated use (core summer habitat). DO patterns observed in the investigation indicated that anthropogenic sources contributed to the DO excursions. Elodea appeared to affect dissolved oxygen concentrations in the creek, with daily minimum dissolved oxygen concentrations increasing after removal of the weed in the creek. Although the sediment investigation component of the study was limited, the observed low dissolved oxygen concentrations in the lower reaches of the creek helped form the basis for further investigation into the influence of sediment oxygen demand. Overall, the study concluded that "elodea

[2] In 2013, the city of Puyallup began Diver Assisted Suction Harvesting (DASH) elodea based on recommendations from the city's Elodea Task Force. The Task Force concluded that DASH would be a more effective, long-term solution to removing elodea, compared to annual cutting which did not remove the roots of the elodea (city of Puyallup, 2013).

appeared to affect DO concentrations in the creek. Daily minimum DO concentrations appeared to increase after the City removed elodea from the creek" (Brown and Caldwell, 2009).

In 2011, the Tribal Council expressed concerns to the city of Puyallup regarding the two decade practice of mechanically harvesting elodea. The Tribe requested a resolution of the issue in a timely manner and indicated status quo management of the creek would no longer be acceptable because of the adverse impacts to the fishery, tribal hatchery operations, and water quality. To resolve the issue, the city of Puyallup initiated an elodea task force forum to identify more effective short-term and long-term methods to manage elodea in Clarks Creek. The Tribe participated in the task force helping to develop an alternative long-term method to harvest elodea in the creek in the winter of 2012.

Table 5 compares the average of the daily minimum DO concentrations and range of percent DO saturation recorded at each station before elodea cutting occurred in an upstream reach (7/7/2009 – 7/13/2009) and after all upstream cutting ceased (7/31/2009 – 8/11/2009) based on continuous sampling between 7/7/2009 and 8/11/2009. Only minimum DO concentrations are listed for comparison to the DO criterion.

The difference between before and after results is not attributable to the cutting alone, as changes in flow, temperature, and other factors also influence DO. The downstream stations in Clarks Creek showed the minima DO increased by 0.5 to 1 mg/L. At the upstream station, CLK-8 (12th St.), elodea cutting had little effect on DO minima.

Table 5 Effects of elodea harvest shown by diurnal studies

Station	Study Year	Average Minimum DO before Cutting (mg/L)	Average Minimum DO after Cutting (mg/L)	Difference in Average Minimum DO (mg/L)	Range of DO Percent Saturation before Cutting	Range of DO Percent Saturation after Cutting
CLK-8 (12th St Bridge)	2009	8.72	8.96	+0.24	75-95	76-91
CLK-8 (12th St Bridge)	2010	10.48	10.49	+0.01	92-95	93-98
CLK-TR (Clarks between Diru and Rody)	2009	8.01	8.50	+0.49	70-134	72-92
CLK-TR (Clarks between Diru and Rody)	2010	6.47	8.31	+1.84	55-132	71-91
CLK-4 (66th Ave bridge)	2009	8.09	8.64	+0.59	71-130	73-91
CLK-4 (66th Ave bridge)	2010	7.38	8.25	+0.87	60-124	69-91

Relationship between DO and baseflow

During baseflow conditions, flow in Clarks Creek is primarily derived from springs (such as Maplewood Springs) that emerge from the base of hillslopes at the edge of the glacial till. The DO concentration in these springs helps determine instream DO concentrations. Measurements are not directly available for DO concentrations in groundwater emerging through these springs. However, their net impact on DO is known to be small based on the relatively high DO concentrations observed during baseflow conditions in monitoring near the state hatchery, in the groundwater discharge zone. These springs are fed by high permeability sand layers in the till, which has a low organic matter content and is likely to maintain well-oxygenated conditions, with additional reaeration occurring at the discharge points.

Shallow groundwater in the alluvial plain further downstream has been noted as having low DO based on monitoring data from groundwater wells (Jones et al., 1999; Brown and Caldwell, 2009). Apparently, this is due to low permeability and incorporated organic peat and muck deposits, although DO concentrations in discharging groundwater in this region have not been directly measured. Groundwater derived from the alluvial plain, however, represents only a small fraction of the total flow in Clarks Creek during baseflow conditions. Calibration of the QUAL2Kw model found that a good fit was obtained by setting the DO concentration in diffuse inflows direct to Clarks Creek downstream of Maplewood Springs to 8 mg/L during summer baseflow conditions. Urban and alluvial plain groundwater may in part account for reduced DO concentrations in water discharged from Meeker Creek and other conveyances. The QUAL2Kw calibration approach is summarized in Appendix B and described in detail in Tetra Tech (2011a).

Relationship between DO and high flow

The interaction of seasonal climatic patterns is important to understanding the influence of stormwater on DO concentrations. Stream flows are high in winter when stormwater runoff is high, and water temperature and plant growth are low. Under these conditions, pollution in stormwater contributes to an accumulation of oxygen-demanding substances over time, as well as acute contributions of low DO concentrations. Stormwater can also contribute additional sediment through instream scouring. The transport of oxygen-demanding substances to slackwater habitat in the winter contributes to additional oxygen depletion during the summer months when productivity increases.

Monitoring data in the Clarks Creek watershed indicate that stormflows and DO impairments have a dynamic relationship that involves acute and chronic effects. Monitoring indicates that stormwater, especially in the lower watershed, is low in DO and contributes to low DO concentrations instream during storm events. Stormwater also delivers nutrients, sediment, and oxygen-demanding substances that can build up in slackwater areas, leading to increased productivity and subsequent DO depletion. The following sections describe; 1) an analysis of DO depletion as it relates to stormflow, and 2) results of recent stormwater monitoring data collected in 2011-2012. The analysis and studies conclude that stormwater depletes DO and needs to be addressed to meet DO water quality standards in the Clarks Creek watershed.

Analysis of DO depletion, flow, and conductivity

The relationship between depressed DO and high flow can be assessed in a variety of ways. Figure 14 shows continuous DO data collected by PTI in the fall of 2010 compared to precipitation levels in the lower watershed from the fall of 2010. Overnight DO minima were consistently below the criterion of 9.5 mg/L. The lowest DO values occurred during high precipitation events.

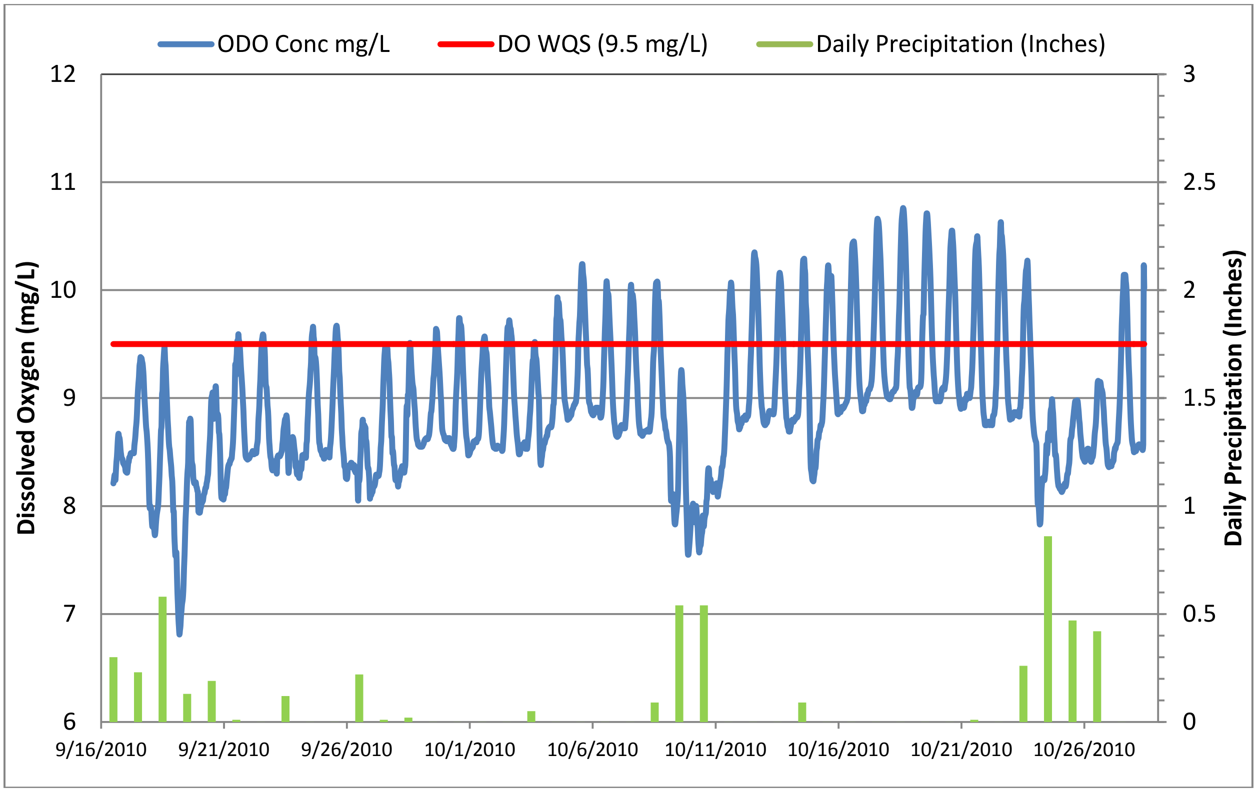

Figure 14. Continuous DO measurements, Sept.-Oct. 2010 PTI monitoring at the Clarks Creek Tribal hatchery (CLK-4).

There is also a strong correlation between DO depletion and low conductivity, an indicator of elevated flow/stormflows in Clarks Creek. The conductivity of water is a measure of its capacity to carry an electrical current. Conductivity increases as the number of ions increase. Therefore, the purer the water, the lower its conductivity will be. Reduced conductivity is associated with rain water and storm events, since rainwater has lower conductivity than surface waters.

From 2009-2010, PTI collected continuous DO, turbidity, and conductivity data. Daily average DO deficits (DOD; defined as the difference between DO saturation and observed DO concentration) are a useful way of expressing how much a given source depletes DO from its natural condition (DO at saturation). A positive DOD shows that DO is being depleted from its natural condition. The TMDL Analysis section provides a more detailed explanation of DO deficit, and greater detail can be found in the data review and model documentation (Tetra Tech, 2010a; Tetra Tech, 2012a).

Plots of DOD versus conductivity under variable weather conditions (not just storm events) clearly show that higher DODs, or a higher deviation from DO under natural conditions, are associated with reduced conductivity, or storm events (Figure 15 and Figure 16). For example, at the Clarks Creek Tribal hatchery station (CLK-4), the highest DODs (above 3 mg/L) occur below a conductivity of 0.16 mS/cm and are associated with known storm events. The data in Figure 15 are plotted at 30-minute intervals and include the full daily range. Lower conductivity (associated with higher surface flow) appears to correlate with consistently elevated DOD, confirming the need to control low DO in stormwater.

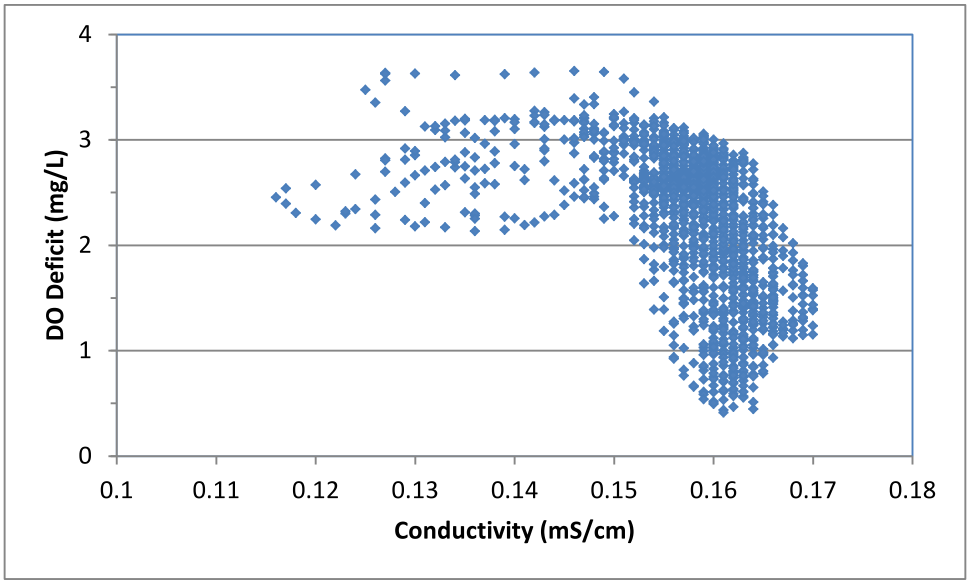

Figure 15. Relationship of DOD and conductivity, Sept.-Oct. 2010 PTI monitoring at the Clarks Creek Tribal hatchery (CLK-4).

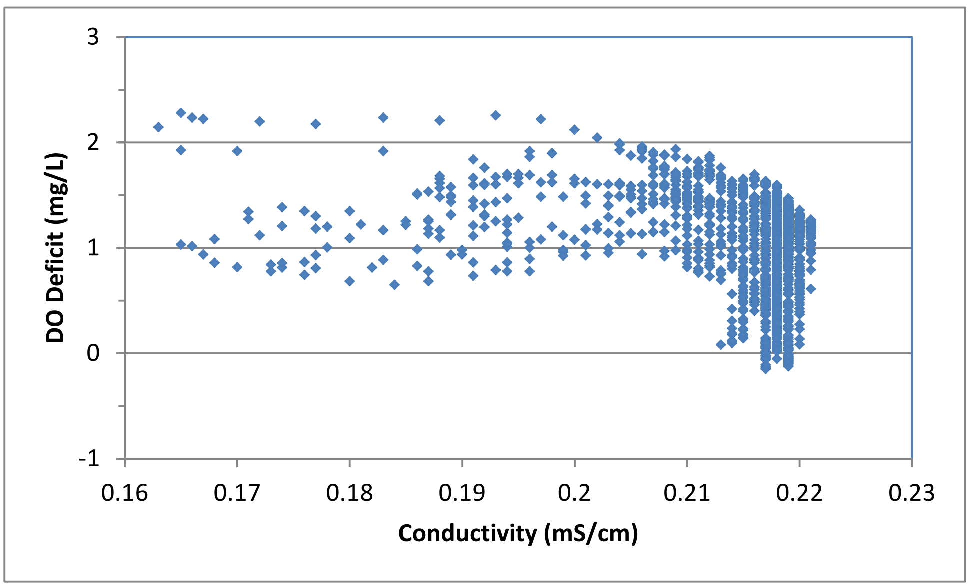

Figure 16. Relationship of DOD to conductivity, Sept.-Oct. 2010 PTI monitoring at Tacoma Road.

Tetra Tech also evaluated simulated flows in Clarks Creek with DOD to see if higher flows corresponded to higher DO depletion. The Tacoma Road flow gauge in Clarks Creek was not operational from 2009-2010. Therefore, Tetra Tech used precipitation, climate data, and existing flow data in Clarks Creek to create a 70-year simulation of flows using the HSPF watershed model. The analysis shown in Figure 17 concluded that higher flows correlated to higher DODs at Tacoma Road (R^2=70%; coefficient $p<0.001$) (Tetra Tech, 2012a).

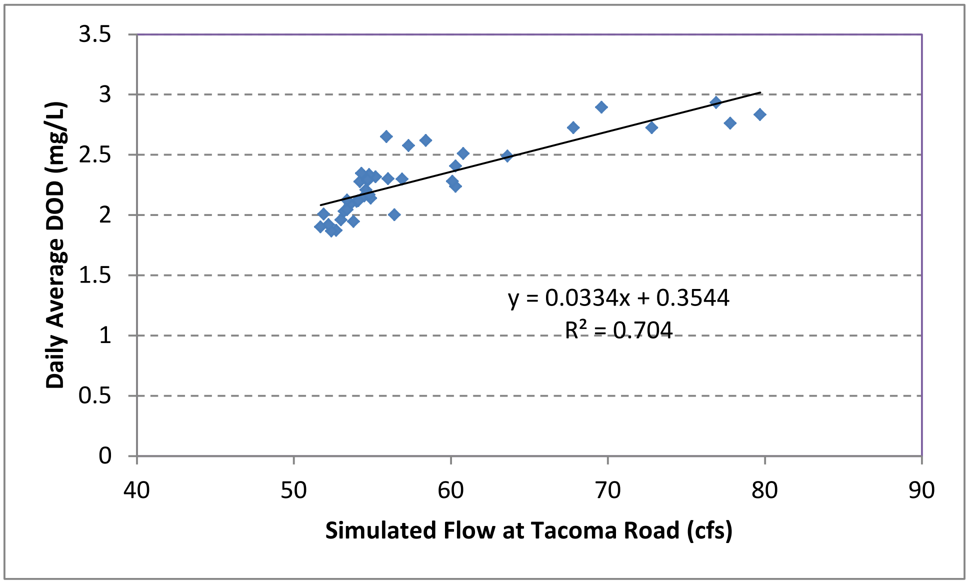

Figure 17. Relationship between DOD at the Clarks Creek Clarks Creek Tribal hatchery (CLK-4) and simulated flow at Tacoma Road, Sept.-Oct. 2010 PTI monitoring.

The analyses of the PTI continuous monitoring indicate that there is a strong association with stormflow and decreased ambient DO concentrations in Clarks Creek. Stormwater further contributes indirectly to DO impairments by increasing sedimentation and elodea growth because excess fine sediment provides substrate for elodea to grow and delivers nutrients attached onto sediment particles. Figure 45 provides a summary diagram of all the parameters and processes that influence elodea overgrowth in the Clarks Creek system.

Stormwater monitoring in 2011-2012

In 2011 and 2012, PTI conducted comprehensive monitoring of storm drains and instream locations during storm events (Tetra Tech, 2012d; Appendix E). The sampling occurred October 1, 2011 through March 31, 2012 and covered four storm events. The events were chosen to represent different magnitudes and durations as follows:

- Minimum of 0.2 inches in >24-hr period; November 11, 2011; 0.41 inches
- Minimum of 0.2 inches in <24-hr period; February 17, 2012; 0.69 inches
- Minimum of 0.6 inches in >24-hr period; March 13, 2012; 0.98 inches
- Minimum of 0.6 inches in <24-hr period; March 29, 2012; 1.12 inches

Stormwater sampling was conducted by PTI on different portions of the hydrograph for each of the storm event types. The intent for selecting different storm types and for sampling on distinct portions of storm events was to adequately describe the range of water quality conditions that occurred in Clarks Creek and Meeker Creek.

Four stormwater outfalls were selected by PTI (SW-1 through 4), and samples were taken upstream and downstream of each outfall and from the outfall discharge itself. The sampling consisted of both grab samples and field meter measurements measuring DO and a variety of water quality constituents. For the outfalls, three to five water quality samples were collected per storm event at each sampling location, and for the creek, six to ten water quality samples were collected per storm event. At all stream locations, stage and discharge measurements were collected as well as several average velocity measurements at the Clarks Creek, West Pioneer Way location (SW-1).

Figures 18 through 21 display the DO results across the four stream sampling locations for each sample date (additional results are documented in Tetra Tech (2012d)). The first storm event (November 16, 2011) was a low intensity, short duration storm (Figure 18). While a few observations met the water quality standard of 9.5 mg/L, most DO concentrations were below the standard. DO concentrations in the SW-3 and SW-1 outfalls were well below the standard and the other instream and outfall locations measured.

During the second storm event (February 17, 2012), which was a low intensity, steady event, none of the DO measurements met the water quality standard (Figure 19). This is a departure from the more than 25% of DO concentrations meeting the criterion in the previous storm event. The same pattern for depression of DO concentrations occurred in the outfalls at SW-3 (Meeker Creek; 6.7 mg/L) and SW-1 (West Pioneer Way; 6.4 mg/L). During both events, these low DO concentrations did not appear to have a noticeable effect on DO concentrations in the downstream receiving water.

PTI found that the DO concentrations were consistently below the water quality criterion (9.5 mg/L) at all sites during the third storm event, which was selected as a storm of relatively high intensity with a duration of greater than 24 hours (March 13, 2012; Figure 20). The low DO from the lowermost stormwater outfall corresponded with high volatile suspended sediment. Stormwater indicators, like fecal coliform bacteria, suggested that substantial runoff was delivered through stormwater conveyances at SW-4 and SW-1. These inputs from stormwater runoff were detected in upstream/downstream samples from SW-3 (Meeker Creek), SW-2 (7th Avenue Bridge), and at SW-1 (West Pioneer Way). The influence of stormwater from upstream was identified at downstream sampling locations using the bacteriological marker.

The fourth storm event (March 29, 2012) represented the highest intensity storm measured occurring within a 24-hour period. PTI found that DO concentrations were relatively uniform among the upper monitoring sites, but slightly declined at SW-1 (West Pioneer Way) (Figure 21). All DO concentrations were lower than the water quality criterion (9.5 mg/L) and did not differ significantly between upstream (SW-4) and downstream (SW-1) during most of the monitoring intervals during the storm event. For most sampling locations, the lowest DO concentrations observed among the sampling intervals occurred at the beginning of the storm event (1-hour interval) with a slow recovery at successive intervals.

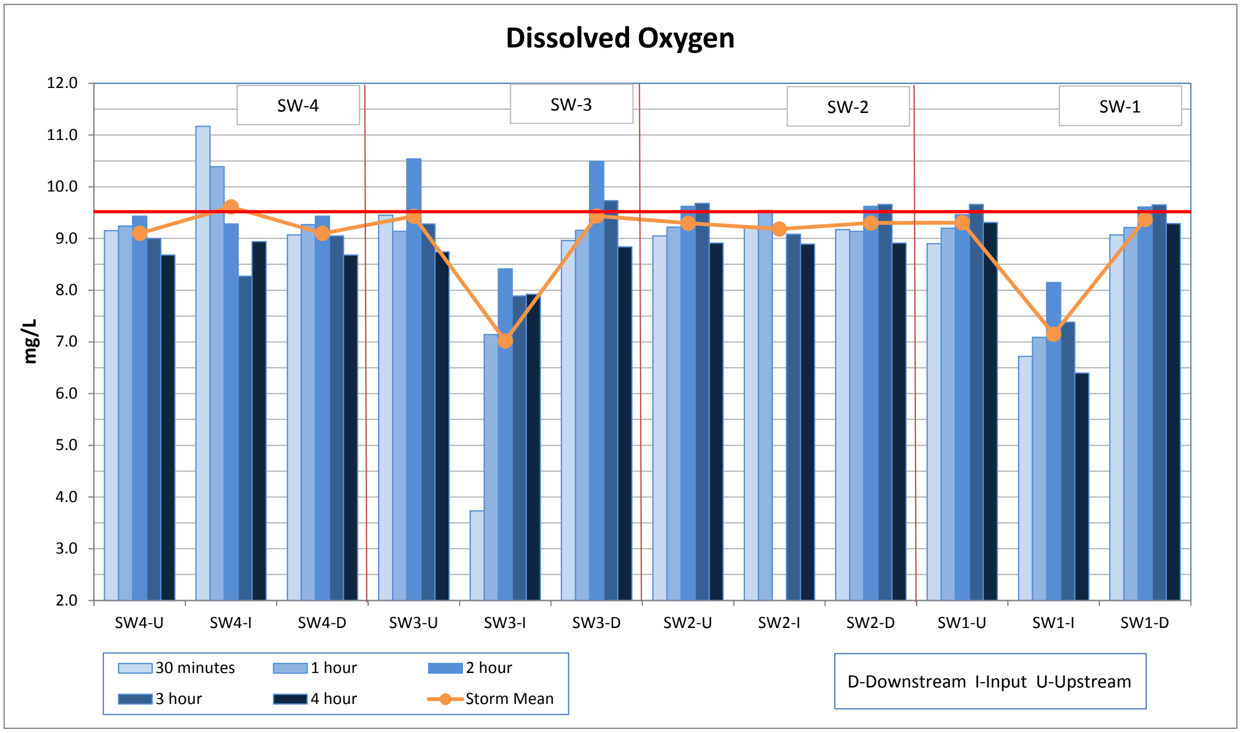

Figure 18. DO concentrations from stormwater sampling at Clarks Creek sites on November 16, 2011; low intensity, short duration event: 0.41 inches in less than 24 hours (red line is the water quality standard; 9.5 mg/L).

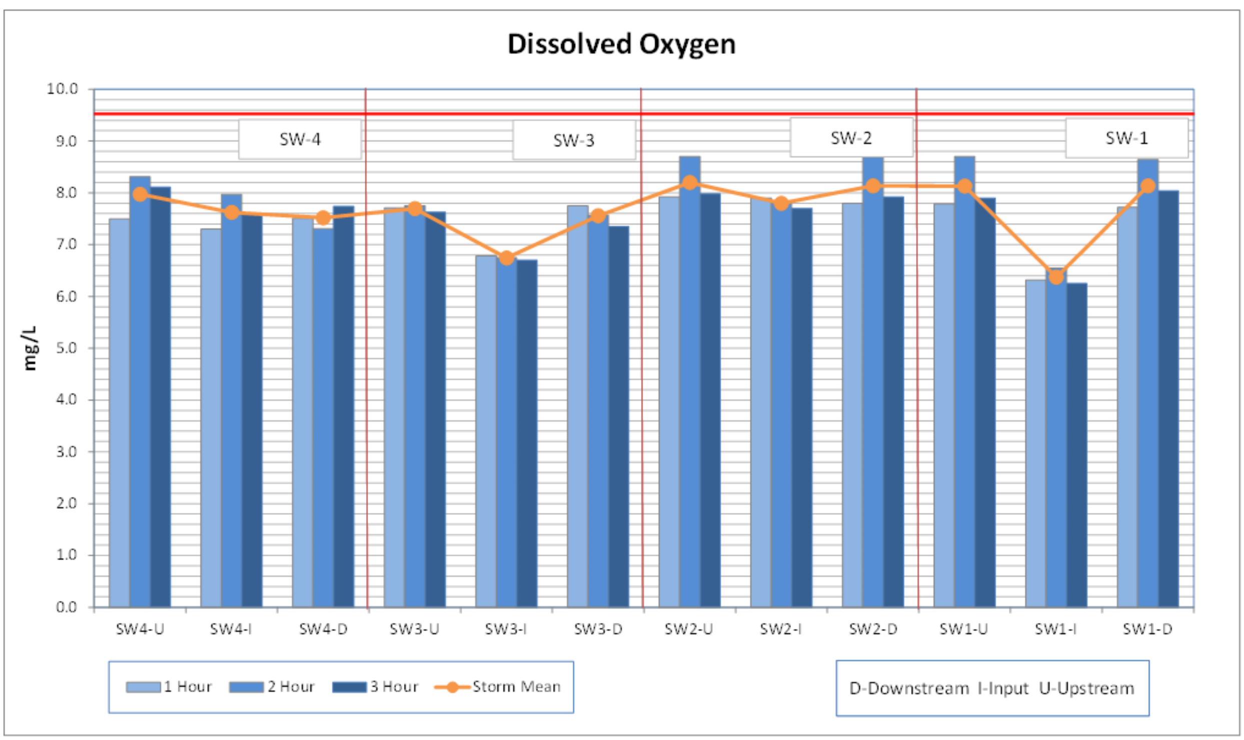

Figure 19. DO concentrations from stormwater sampling at Clarks Creek sites on February 17, 2012; low intensity, steady rainfall event: 0.69 inches in less than 24 hours (red line is the water quality standard; 9.5 mg/L).

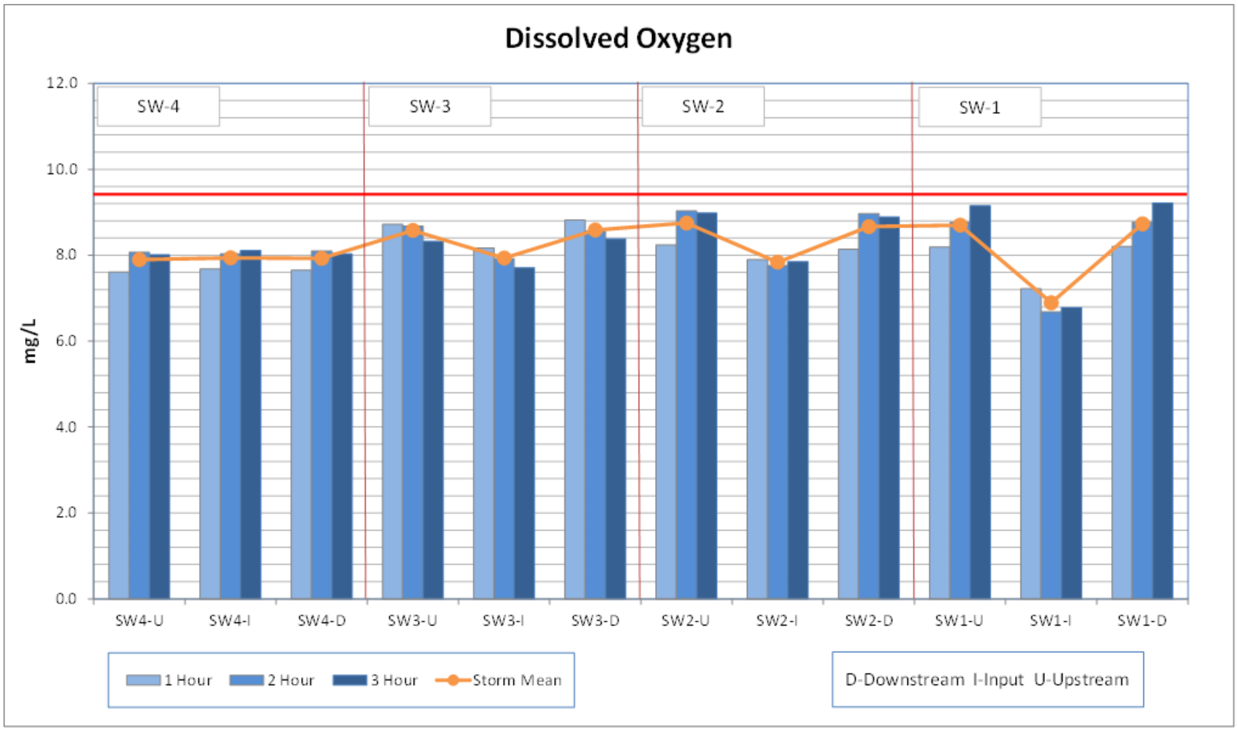

Figure 20. DO concentrations from stormwater sampling at Clarks Creek sites on March 13, 2012; high intensity, longer duration event: 0.98 inches in greater than 24 hours (red line is the water quality standard; 9.5 mg/L).

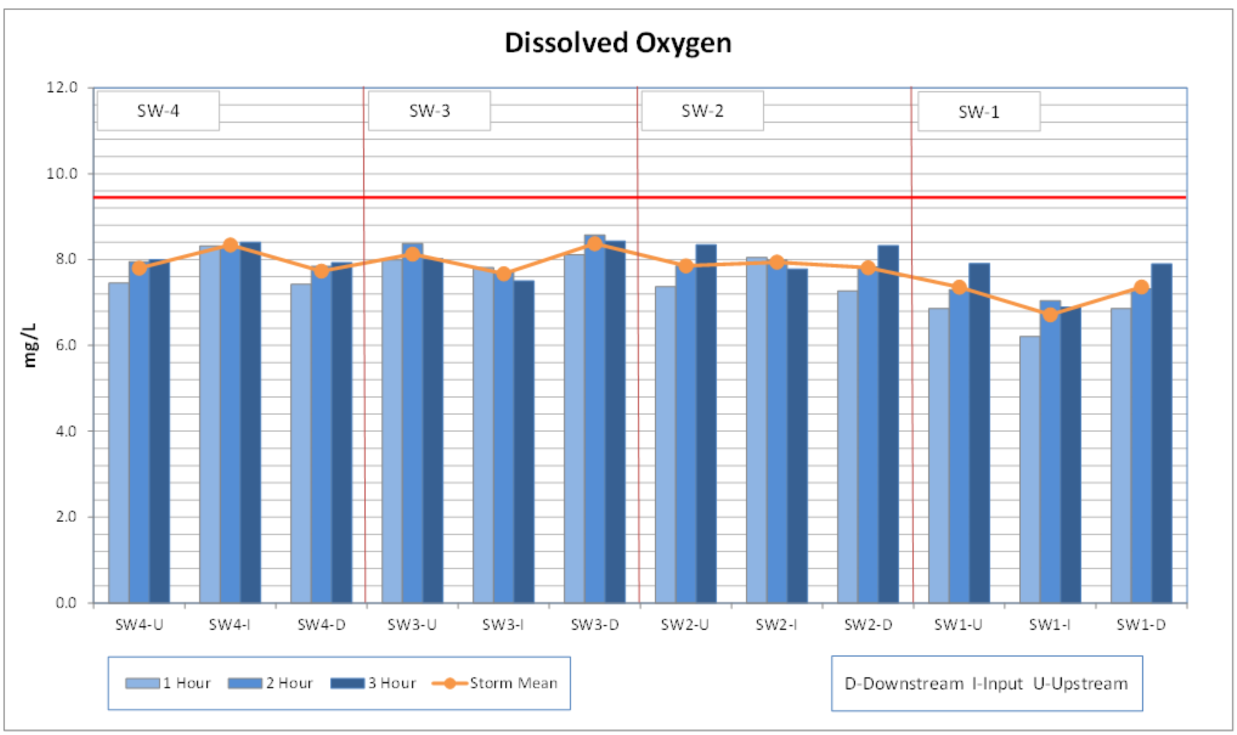

Figure 21. DO concentrations from stormwater sampling at Clarks Creek sites on March 29, 2012; high intensity, short duration event: 1.12 inches in less than 24 hours (red line is the water quality standard; 9.5 mg/L).

The PTI study indicates that stormwater inflows deliver low DO concentrations as well as uniformly high concentrations of sediment and nutrients, contributing to low DO concentrations in Clarks Creek. The Meeker Creek site (SW-3), in particular, contributes much higher concentrations of pollutants compared to the other sites. DO concentrations were highest at the beginning of the wet season and slowly diminished during successive storm events.

The PTI study results indicate that the magnitude of flow in the creek has an influence on DO concentrations, consistent with the 2010 analysis findings (Figure 18). The lowest flows measured during storm event sampling were in November 2011, when some of the highest DO concentrations were observed. The storm events sampled during March 2012 resulted in an increasingly narrow range of DO concentrations observed from all mainstem Clarks Creek sites. The exception was the slightly higher DO concentrations observed from Meeker Creek (SW-3), during the March 29, 2012, storm event.

Through the winter season sampling, PTI found that diminished dissolved oxygen concentrations during higher flows indicated that a combination of pollutants transported into the creek had a measurable effect and may be cumulative over time. The evidence for this observation is the comparison of DO concentrations with the standardized DO saturation threshold. The actual DO concentration trend showed increasing divergence from this standardized DO saturation trend line as the winter storm season progressed (Figure 22).

Low DO occurred at the upstream SW-4 location consistently across the four storm events, and instream DO concentrations were generally lower or similar to DO concentrations in the stormwater output. This location is downstream of a park at 12th Avenue, approximately where the stream meets the alluvial plain. The cause of the low DO concentrations is unclear at this location. Much of the upstream watershed is within the park, which is not expected to be a major source of stormwater; however, other stormwater inputs near SW-4 may have influenced the DO concentrations. The site is also downstream of the state hatchery discharge and could be influenced by groundwater input.

For the locations studied in 2011 through 2012, PTI found that the long-term, cumulative effects of stormwater on instream DO were evident because of increasing levels of pollutants during each storm event. In contrast, individual outfalls with relatively low DO concentrations did not appear to strongly impact instream DO concentrations during storm events, apparently because the incremental flow from individual outfalls was small relative to total flow in the creek. Since only four locations were sampled, it is possible that acute impacts may occur at other locations in the watershed. These findings suggest that management of the long-term effects of stormwater could be more effective at addressing DO impairments. The monitoring data from 2010, combined with this more recent study, provide clear evidence that DO concentrations are consistently low during storm events and a general decline occurs as flows increase throughout the wet season. This indicates that stormwater has a cumulative effect on DO concentrations during the winter.

Model analysis for DO

The QUAL2Kw model was used to explore the system's sensitivity to changes in nitrate, riparian shading, SOD, and groundwater flow withdrawals. A full write-up of the modeling process and results is available in Tetra Tech (2012a). Modeling found that decreases in nitrate loads in Maplewood Springs and other groundwater sources did not reduce the number of predicted DO excursions under baseflow conditions because nitrate levels in the stream are sufficiently high that it is unlikely that nitrogen limitation on elodea growth can be established. Increased flow (modeled as decreased flow withdrawal for potable water use from Maplewood Springs) did not produce a significant effect on DO during baseflow conditions. Increased riparian shading resulted in a small net effect on daily minimum DO due to a combination of reduced water temperature and reduced elodea growth under baseflow conditions. In general, the direct effects of elodea growth are most evident in the daily maximum DO concentration, while the minimum concentrations are less affected by elodea respiration. The most conclusive effect was shown for SOD: a decrease in SOD resulted in a strong increase in DO concentrations under baseflow conditions. While these results do not preclude the direct influence of nitrate, flow withdrawals, and riparian shading, they provide evidence that SOD is an important contributor to DO impairment. However, the SOD is in part derived from elodea overgrowth, and management strategies that reduce elodea growth are likely to result in a gradual diminution of SOD. The results of this analysis are discussed in more detail in Appendix B.

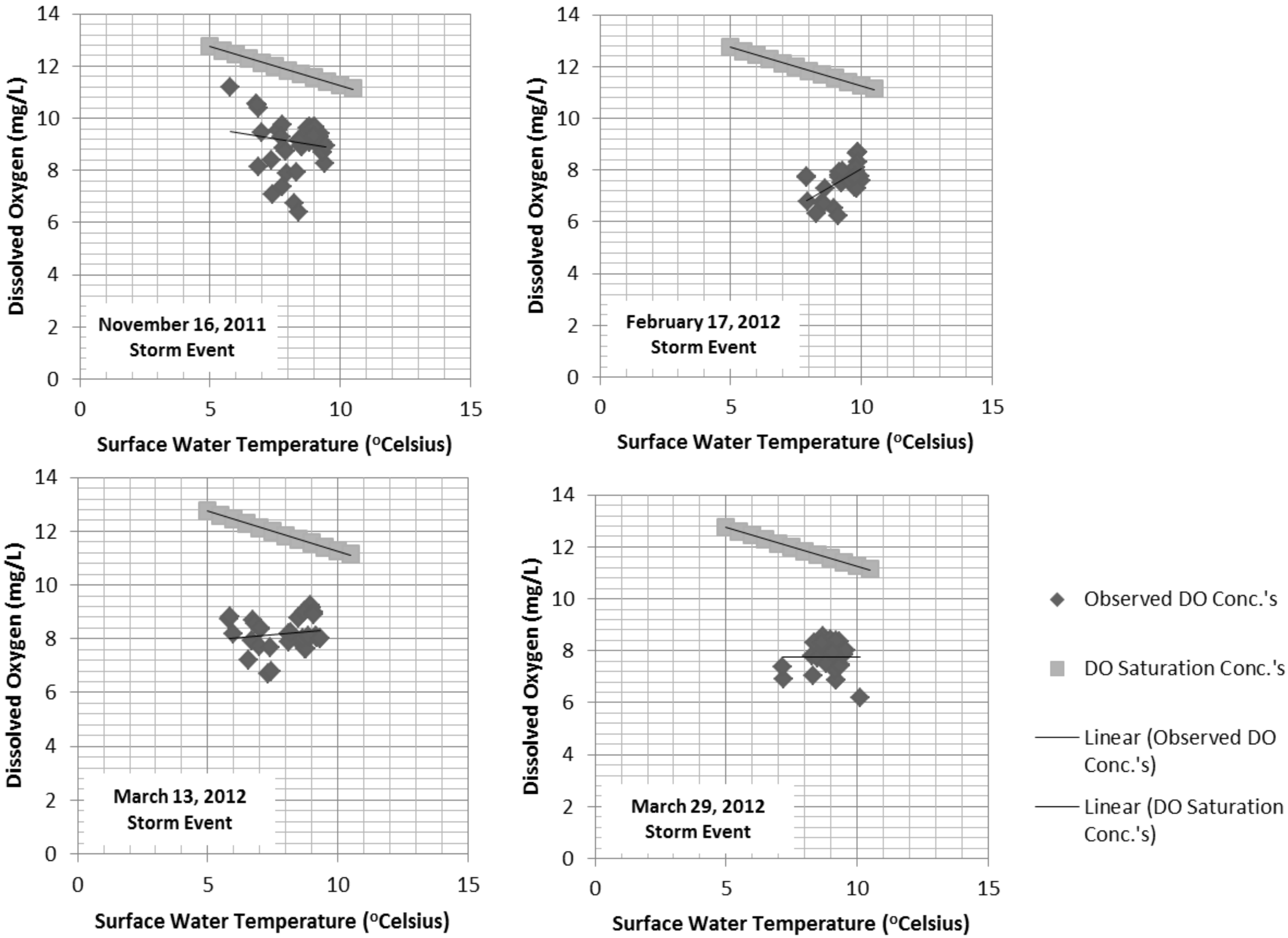

Figure 22. Observed DO concentrations during all time intervals at each site and sample date.

Biochemical oxygen demand

Organic material that is washed into water bodies is gradually consumed by bacteria, fungi, and other organisms. The process of digesting and reducing the organic material and converting it to cellular energy consumes oxygen and reduces DO in the stream. The potential for oxygen reduction by such processes is measured as biochemical oxygen demand (BOD), given in terms of milligrams of oxygen per liter over a given time period. In natural streams, most organic material is present in refractory forms that break down slowly. The total BOD is composed of both carbonaceous and nitrogenous components, where the carbonaceous component represents the oxidation of fixed organic carbon to carbon dioxide and the nitrogenous component represents the oxidation of ammonia to nitrite and nitrate.

Five-day total BOD was measured during a limited number of sampling events in Clarks Creek prior to 2010. Approximately one-half of the samples had concentrations less than the detection limits of 1 mg/L, 2 mg/L, or 4 mg/L, depending on the sampling event. Samples with detectable concentrations ranged from 0.1 mg/L to 4.0 mg/L and averaged 1.51 mg/L. BOD measurements in the tributaries ranged from less than detection to 8.38 mg/L.

In 2011 and 2012, PTI and Tetra Tech conducted comprehensive monitoring of four stormwater outfalls as previously described in the Stormwater Monitoring in 2001-2012 Section (pages 45-49, Tetra Tech, 2012d). Sampling occurred October 1, 2011 through March 31, 2012 and covered four storm events of varying magnitudes and duration. BOD-5 grab samples were collected from the outfall discharge as well as upstream and downstream of the outfall including SW-1 (West Pioneer Way), SW-2 (7th Avenue Bridge), SW-3 (Meeker Creek), and SW-4 (12^{th} Avenue). Figure 23 through Figure 26 display the BOD-5 results for each of the sampling locations for each sample date.

The majority of the samples collected were below detection limits of 2 mg/L. BOD-5 concentrations were consistently below 10 mg/L for the February 17, 2012, March 13, 2012, and March 29, 2012 rainfall events and did not show any distinctive patterns. The November 16, 2011 rainfall event resulted in much higher BOD-5 concentrations at SW-3. This rainfall event was a low intensity, short-duration event which resulted in peak BOD-5 concentrations of 129 mg/L at SW-3 outfall discharge, and 348 mg/L downstream of the outfall. BOD-5 concentrations were also elevated above the SW-3 outfall at a peak concentration of 28.1 mg/L. An elevated BOD-5 concentration was also measured at the SW-4 outfall (10.8 mg/L); however, there were no measurable effects in the stream downstream of the outfall.

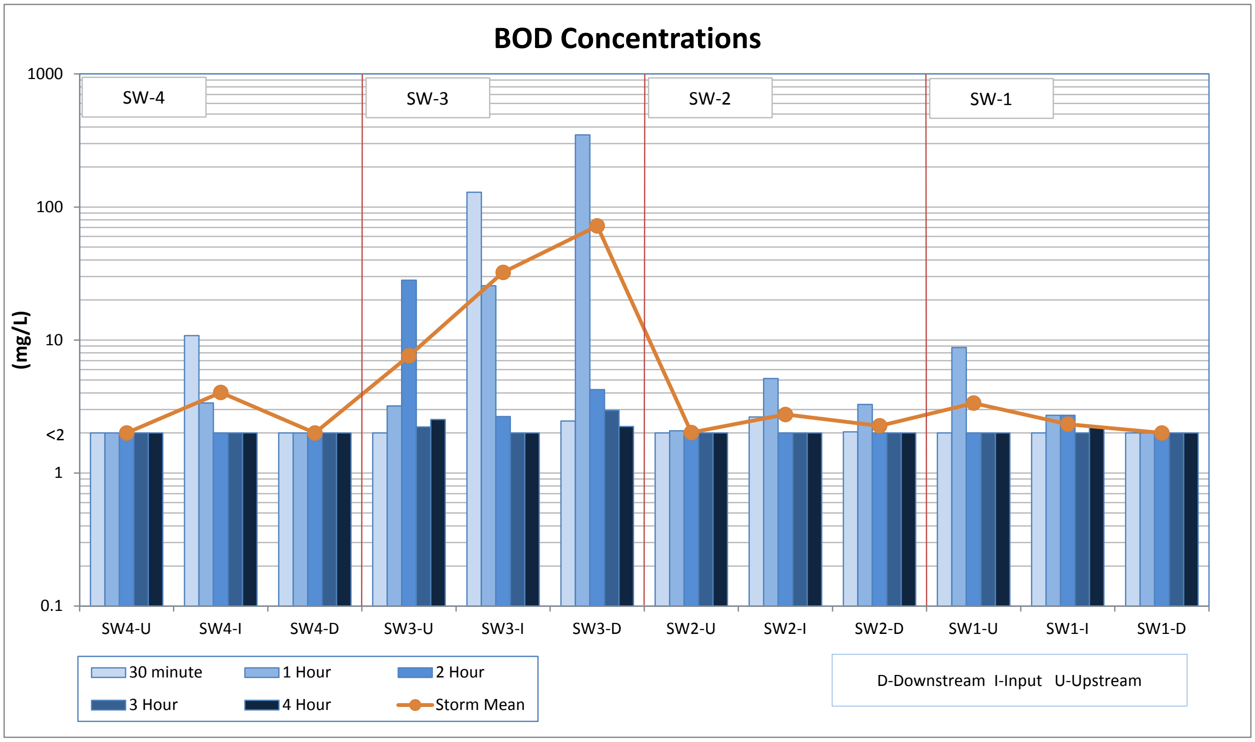

Figure 23. BOD concentrations from stormwater sampling at Clarks Creek sites on November 16, 2011; low intensity, short duration event: 0.41 inches in less than 24 hours (detection limit is 2 mg/L).

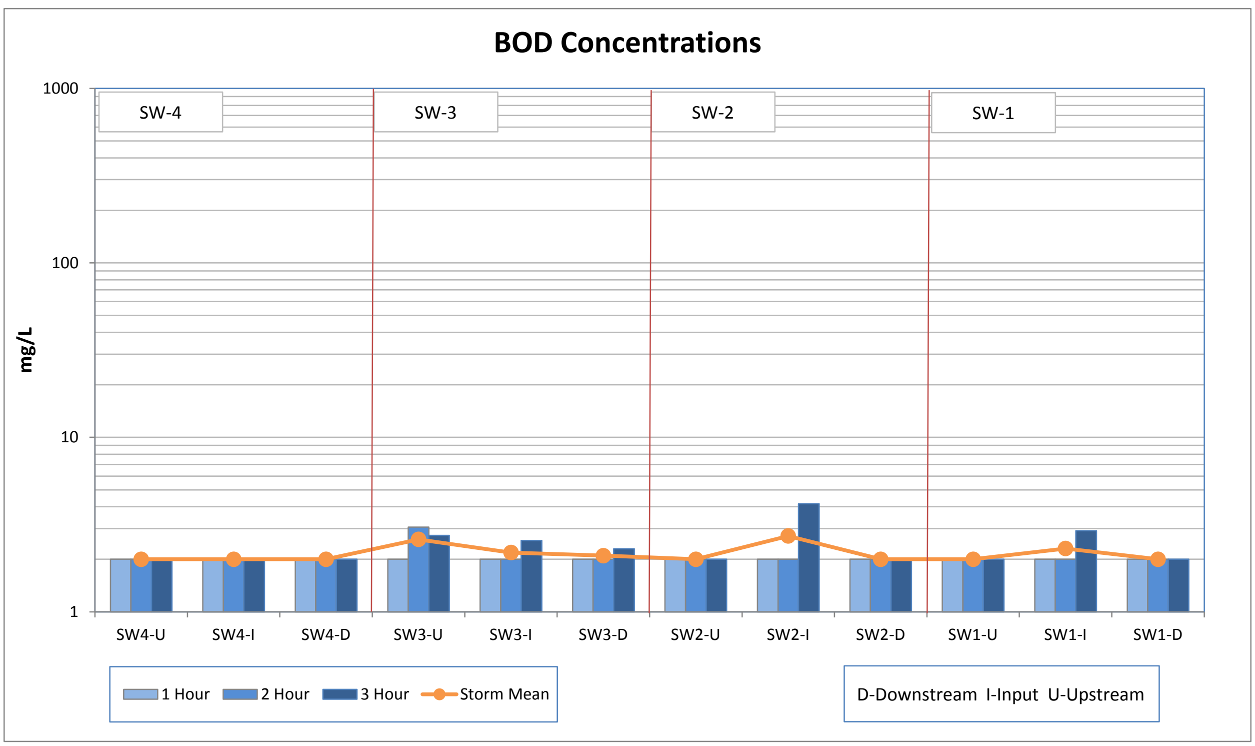

Figure 24. BOD concentrations from stormwater sampling at Clarks Creek sites on February 17, 2012; low intensity, steady rainfall event: 0.69 inches in less than 24 hours (detection limit is 2 mg/L).

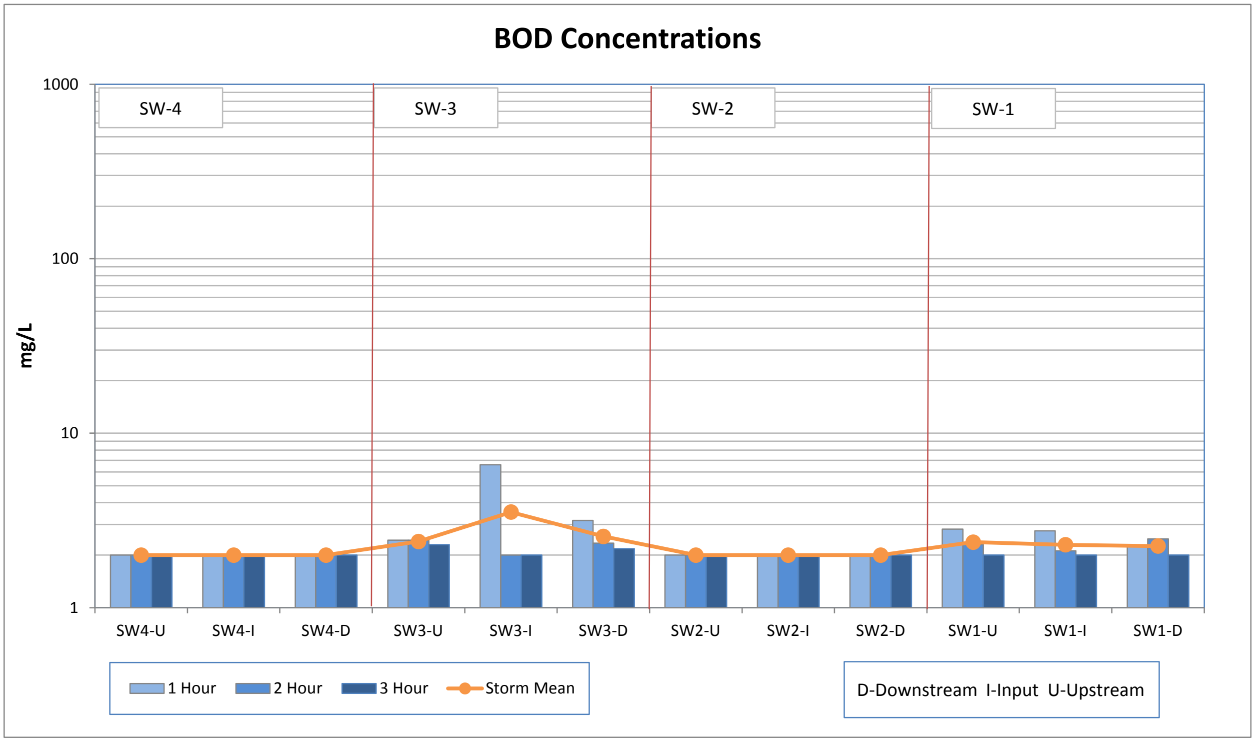

Figure 25. BOD concentrations from stormwater sampling at Clarks Creek sites on March 13, 2012; high intensity, longer duration event: 0.98 inches in greater than 24 hours (detection limit is 2 mg/L).

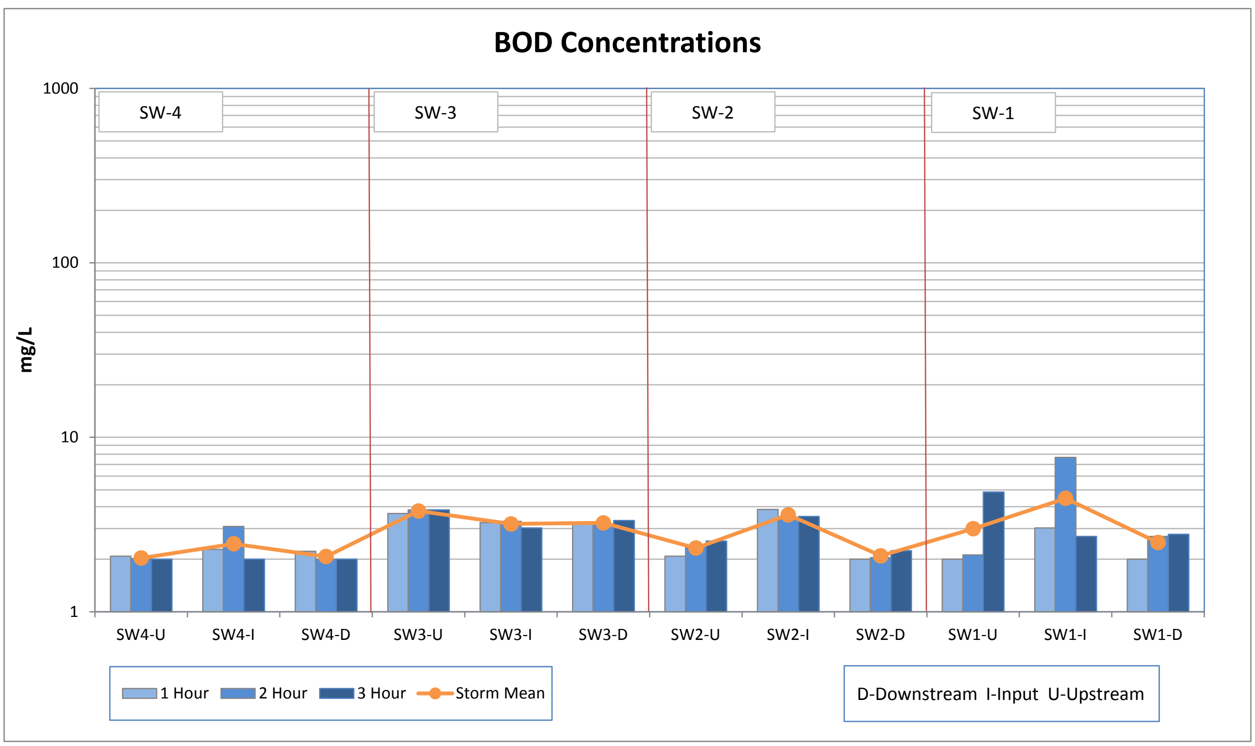

Figure 26. BOD concentrations from stormwater sampling at Clarks Creek sites on March 29, 2012; high intensity, short duration event: 1.12 inches in less than 24 hours (detection limit is 2 mg/L).

Riparian shading and elodea density

As discussed earlier, elodea has a significant effect on DO levels from its respiration and photosynthesis. In addition, when elodea dies, it falls to the bottom of the creek and contributes to the high levels of SOD. In order to meet DO water quality standards, elodea density needs to be reduced. As a result, Ecology conducted a study in June 2012 to investigate whether higher effective shade resulted in lower elodea density. On June 11, 12 and 26, 2012, Ecology and PTI staff conducted field surveys at 21 locations along Clarks Creek between the state hatchery and the 56th Street bridge (Brock, 2012; Appendix D). Effective shade was defined as the percentage of total possible solar radiation blocked from reaching the stream. Ecology and PTI took hemispherical photographs and measured channel geometry and elodea mat data.

Elodea density is defined as the density of the mat of elodea. Ecology's elodea surveys showed that mat density was almost always at 100%. Substrate coverage refers to the percentage of substrate at a given cross section that is covered by elodea. This coverage varies because multiple mats of elodea may be present with space in between where the substrate is free of elodea. Substrate coverage provided the better variable to study how elodea growth is affected by riparian shading. Therefore, the percent of substrate covered by elodea was used to develop the relationship between site effective shade and elodea coverage.

Figure 27 illustrates the relationship between percent effective shade and the percent of the substrate coverage by elodea at each sampling site. The trend line indicates that higher percent effective shade (x-axis) results in lower percent coverage of substrate by elodea (y-axis) on Clarks Creek. That is, more shaded areas result in less elodea in the stream. The square data point is an outlier that was not considered as part of the trend line.

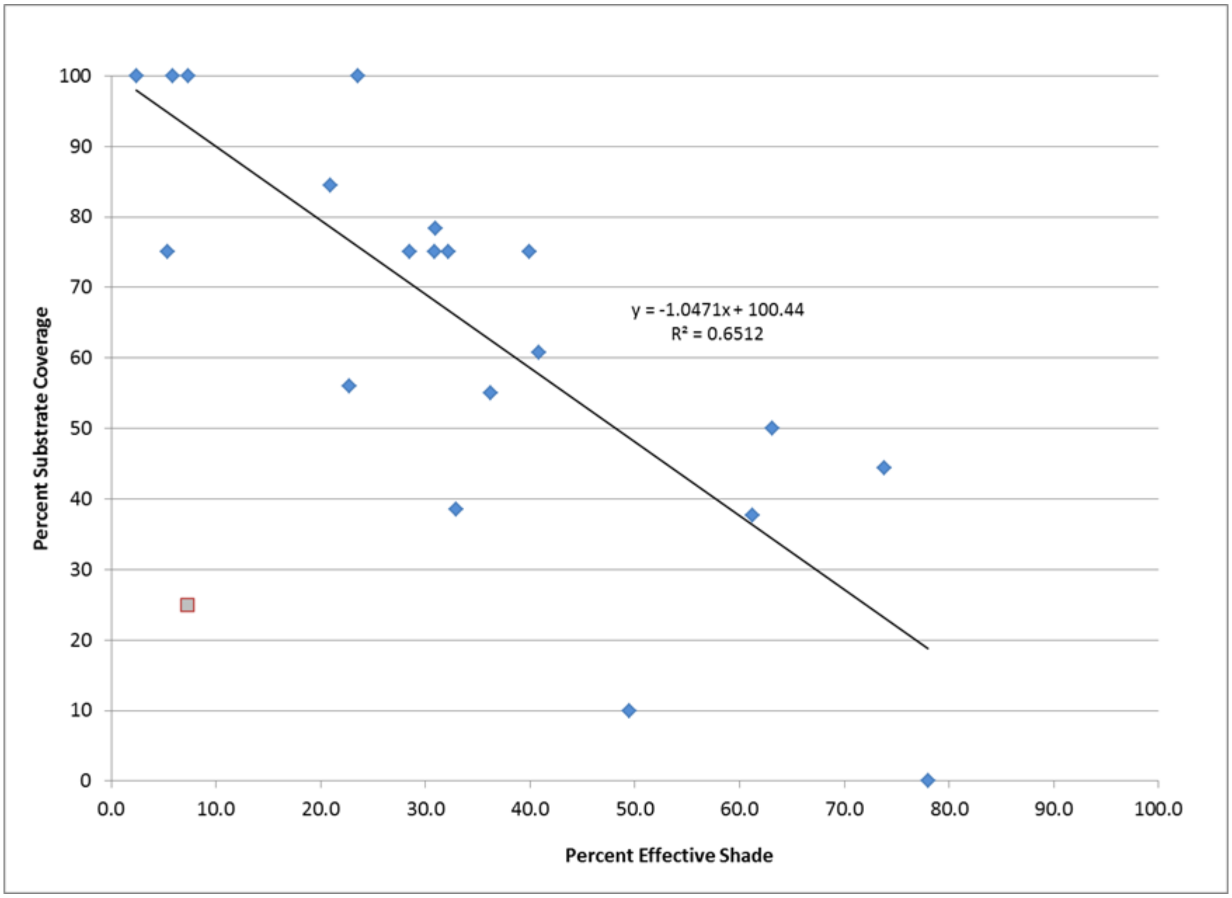

Figure 27. Relationship between percent effective shade and substrate coverage of elodea in Clarks Creek.

The effective shade needed to "shade out" elodea on Clarks Creek was investigated by estimating the effective shade associated with zero elodea growth. At the one sample site with no elodea growth, the effective shade was 78%. Using the regression equation in Figure 27, an elodea density of 0% corresponds with an effective shade of 95.9%. Temperature TMDL studies for other Puget lowland streams, such as Bear-Evans and Green-Newaukum, suggest that based on Clarks Creek's width and vegetation characteristics, an effective shade of 85% is plausible and would "shade out" elodea. The full report is in Appendix D.

Temperature

DO is very sensitive to temperature because water temperature determines the saturation concentration of DO. Water temperatures in Clarks Creek typically range between about 8 and 14 ºC throughout the year and therefore are in compliance with Washington water quality standards. However, they are believed to be elevated over natural conditions due to a lack of riparian shade. At 8 ºC, the saturation concentration of DO in water (assuming conductivity of 100 µS/cm and standard pressure) is 11.8 mg/L, while at 14 ºC this reduces to 10.3 mg/L. Under these conditions, an increase in the deficit greater than 0.8 mg/L will exceed the water quality criterion of 9.5 mg/L. Restoration of natural riparian shade that reduces temperatures will increase the DO saturation concentration and thus reduce the risk of excursions of the DO criterion.

In addition to the diurnal temperature monitoring, temperature measurements have been taken with the collection of most water quality samples (Figure 28). Measurements taken between Rody Creek and the mouth show more variability compared to measurements taken in the upper reaches.

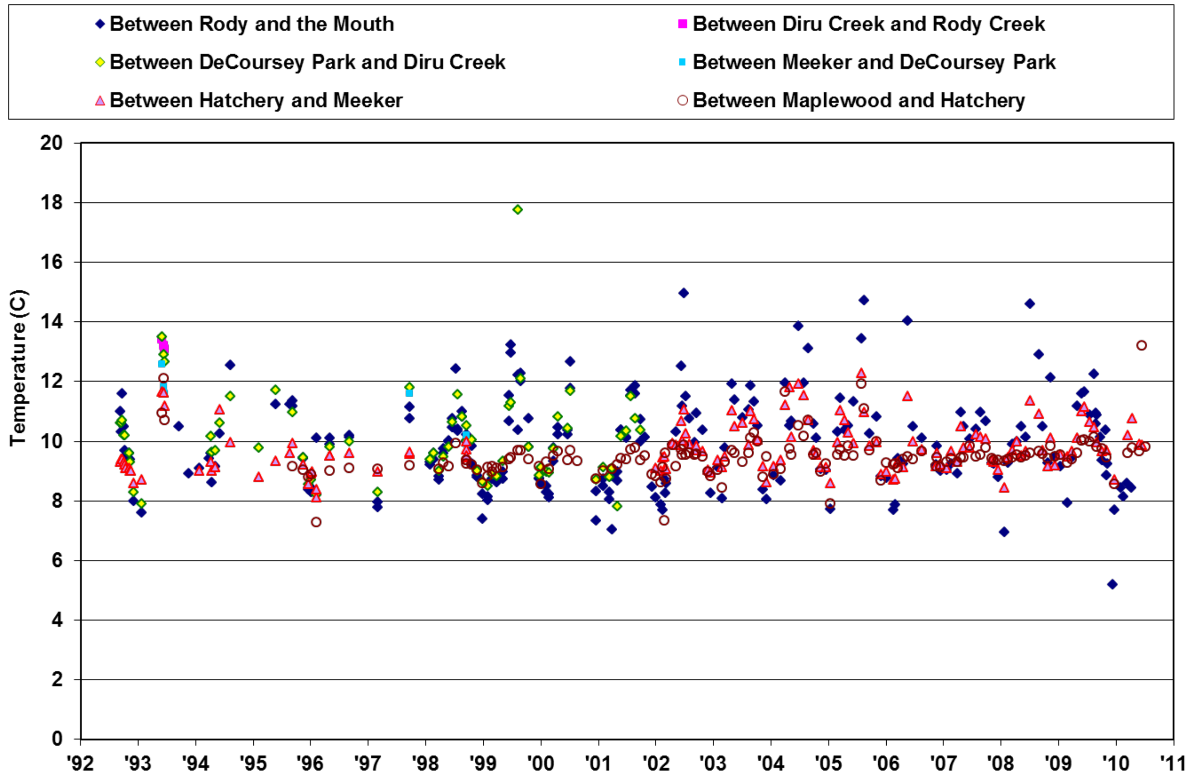

Figure 28. Temperature measurements in Clarks Creek.

Assessment against the water quality criteria for temperature requires continuous monitoring data because these criteria involve 7-day averages of daily maximum temperatures. PTI conducted continuous temperature monitoring at several locations which allowed partial assessment against these criteria. Only station CLK-8 is within the segment of Clarks Creek for which the supplemental spawning/incubation criteria of 13 ºC (as a 7-day average of daily maximum temperatures) applies from September 15 to July 1. The highest 7-day average of daily maximum temperatures observed at CLK-8 during the supplemental period is 11.2 ºC.

pH

As a measure of acidity in water, a pH value of 7.0 indicates neutral conditions, while lower values indicate acid conditions. For DO studies, pH is of particular interest as another line of evidence on photosynthetic production. During photosynthesis, algae and submerged macrophytes remove carbon from the water in the form of bicarbonate ions (HCO_3^-). If bicarbonate is depleted by photosynthetic activity faster than it can be replaced by exchange of

CO_2 from the atmosphere this causes the pH to rise. pH observations above 7.0 are thus usually indicative of strong photosynthetic production.

Based on visual inspection of Figure 29, measured pH values for Clarks Creek appear to have a decreasing trend from August 1992 to April 1996. After 1996, there appears to be a steady increase in pH coupled with an increase in variability (Figure 29). The variability may be due to elodea and other aquatic weeds which during the day, when photosynthesis occurs, create higher pH as carbon dioxide is taken from the water. At night during respiration creates lower pH when carbon dioxide is added to the water. The range of pH measured from 1992 to 2010 for Clarks Creek was 6.07 to 8.83, with an average of 7.20. Several excursions below and above the pH criteria range of 6.5 to 8.5 occurred during the sampling period. Consistent with the recent increasing trend, most of the lower excursions occurred in the earlier sampling period, and most of the higher excursions occurred in the later sampling period.

The Measured pH values for tributaries (Figure 30) range from 6.62 to 7.9. The only pH excursion measured in the tributaries, which was not included in fiqure 29, was a 9.32 measurement at Diru Creek on March 13, 2008. The scale in Figure 30 was kept consistent with Figure 29 for comparison and this excursion was beyond the scale. The tributaries also appear to experience significant photosynthetic activity based on the number of observations above 7.0 pH.

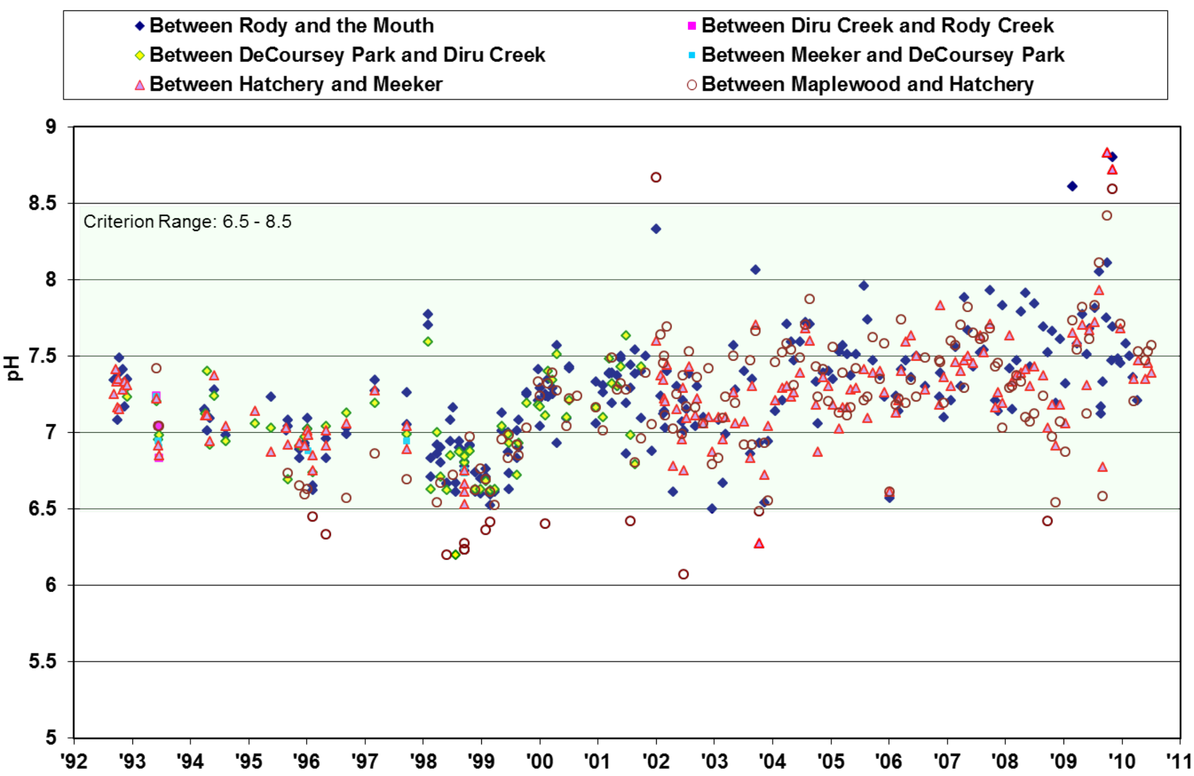

Figure 29. pH measurements in Clarks Creek.

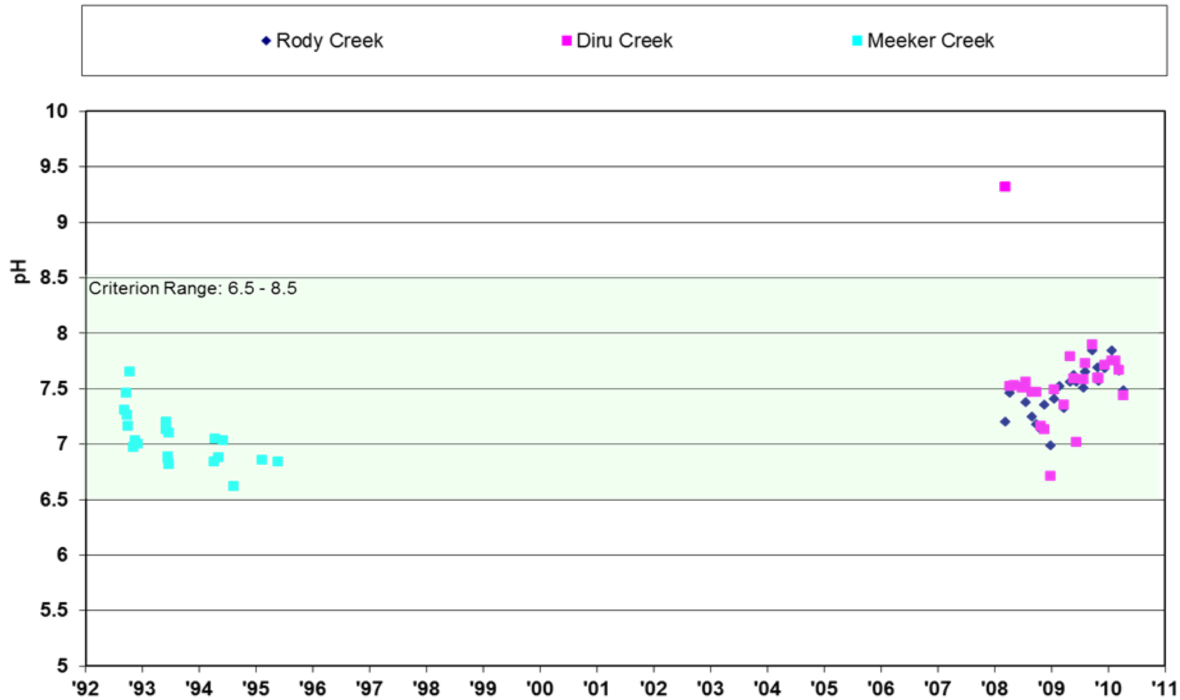

Figure 30. pH measurements in tributaries to Clarks Creek.

Sediment source evaluation

In 2011, PTI received a grant from EPA to develop the Clarks Creek Sediment Reduction Action Plan. To better understand sediment loads and to target effective reduction measures, a sediment source evaluation was completed. Several data collection efforts were utilized to identify and rank sediment sources:

- Brown and Caldwell conducted cross-section surveys at 36 locations along the stream network, primarily in the upper reaches, in addition to utilizing 18 additional cross sections from an existing hydraulic model developed for flood hazard mapping (Brown and Caldwell, 2012) (NHC, 2005).
- Topographic data for the entire Clarks Creek basin, obtained from the Puget Sound LiDAR Consortium, were used to create stream profiles used in calculating the average slope of the stream reaches (Brown and Caldwell, 2012; PSLC, 2011).
- Sediment gradation data, obtained through laboratory analyses of surficial bed sediment samples, were collected at 20 locations along Clarks Creek and its major tributaries (Brown and Caldwell, 2012).
- Brown and Caldwell calculated geomorphically-significant-flows (the range of flow rates over which a substantial portion of the channel-forming work is done) within the basin based on the data previously cited and the application of a magnitude-frequency based methodology. The magnitude-frequency analysis (MFA) was based on the flow duration density, stream channel

hydraulics, sediment gradient, and effective work index using the MFA Spreadsheet Tool developed by Brown and Caldwell (2012).

- Tetra Tech developed the HSPF model, which is a continuous simulation hydrologic model, of the Clarks Creek basin utilizing the existing TSS and flow information (Tetra Tech, 2012a).

For the Clarks Creek Sediment Reduction Action Plan, Brown and Caldwell (2013) estimated volumes and annual loading for the two general categories of sediment sources in Clarks Creek basin: in-channel and upland sources. The estimates were calculated based on the efforts listed previously and were developed specifically to support identification and development of sediment control measures. While the estimates include model output for the upland sources, additional assumptions were made and further calculations completed to reach the final in-channel and upland loading estimates for the Sediment Reduction Action Plan. These estimates vary from the model output, but are within an order of magnitude and thus complement the model estimates. A detailed discussion of model application to the sediment TMDL is provided in the Analysis for Stormflow Conditions section.

In-channel sources from Clarks Creek and its tributaries are primarily from channel instability and degrading stream reaches. Incising and widening channels recruit new material from the bed and banks. Some of the coarser sediment that is mobilized and transported downstream may settle out, but finer sediments are transported to the low gradient reaches where flow velocities are low enough to allow much of the fine sediment to settle out. The volume of sediment from in-channel sources was field-approximated based on visual indicators of the eroded cross-section height and width, multiplied by the length of the eroded segment. This volume was converted to an annual erosion rate by assuming that the period over which the erosion occurred is 95 years, based on when the Puyallup River was channelized. In total, Brown and Caldwell (2013) estimated that 211 tons/year of sediment is from in-channel erosion. This is likely to provide an underestimation of the actual erosion rate, as it is highly likely that the observed erosion has occurred over a much more recent time frame.

Figure 31 shows the eroded channel reaches in the Clarks Creek basin. Clarks, Diru, Rody, Silver, and Woodland Creeks all exhibit some signs of head-cut erosion, which are step-changes in bed surface elevation at the head of the channel, stream-bed lowering, and/or lateral- slope instability. Sediment deposition has occurred in the low-gradient reaches of Clarks, Rody, Woodland, and Silver creeks in the form of primarily sands with some silts. The lower reaches of Clarks Creek, near the PTI's Clarks Creek hatchery, contain larger amounts of silts and finer materials. Depositional zones containing sand and gravel were found in some places along upper reaches of Rody, Clarks, and Silver creeks, typically occurring for a short distance downstream of major erosional areas. A low-head dam located near the state hatchery has also contributed to the formation of a large depositional area.

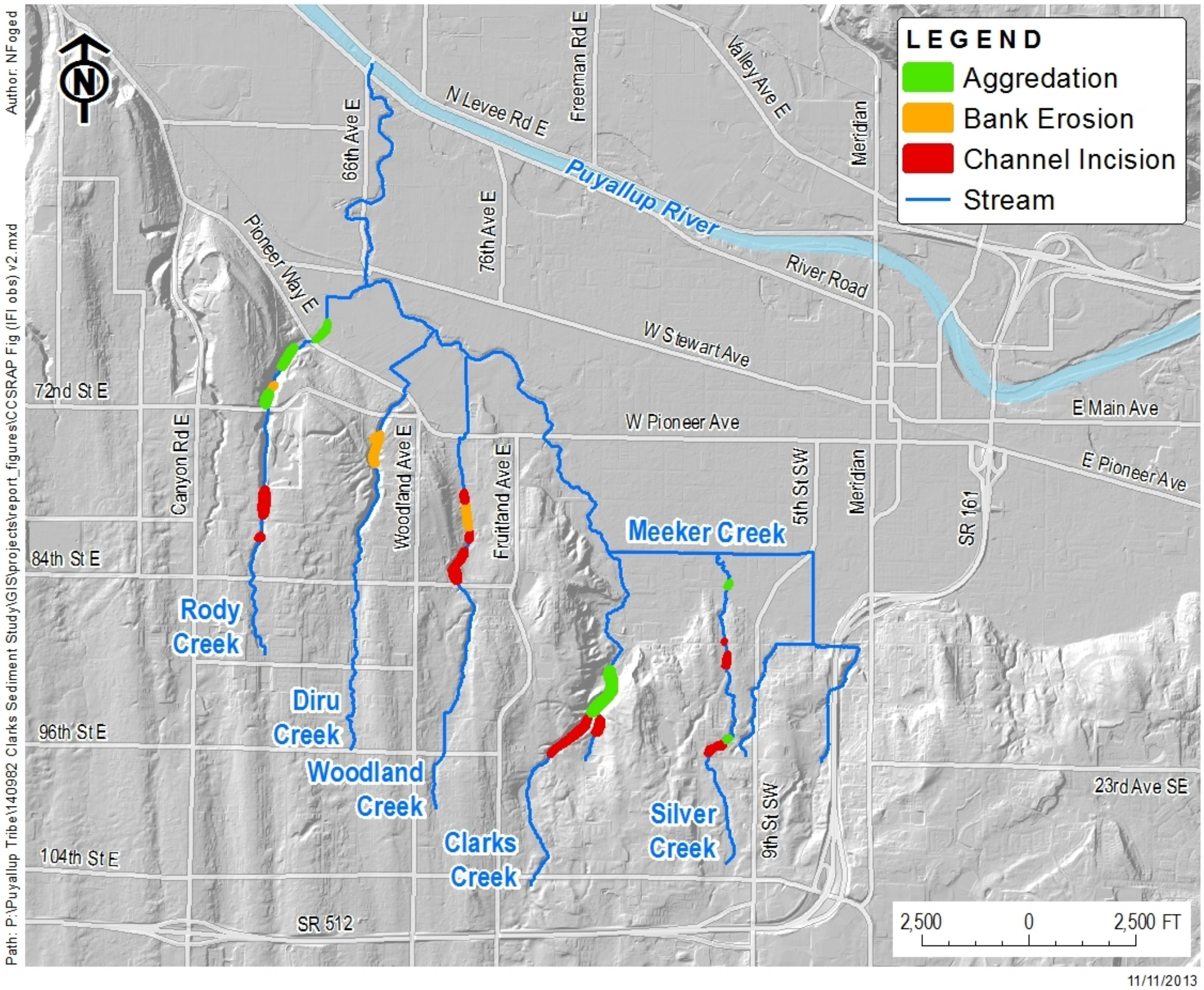

Figure 31. Eroded channel reaches in the Clarks Creek basin.

Upland loads of sediment are generated from pervious land surfaces through soil erosion and from impervious surfaces through the buildup and wash-off of accumulated solids. Brown and Caldwell (2013) used the HSPF hydrologic model to estimate upland sediment production rates. The model uses a variety of input parameters to represent pervious and impervious land surfaces, accounting for slope, soil properties, and land cover conditions.

The HSPF model was calibrated and validated for both hydrology and sediment. The hydrology simulation was calibrated to observed flow gauging data, including the continuous USGS gauge on Clarks Creek and other intermittent measurements of flow. The hydrology calibration and validation indicated a good overall model fit. The sediment calibration approach followed the guidance of EPA (2006) and Donigian and Love (2003). The full sediment model was calibrated through a weight-of-evidence approach including comparison to observed instream total suspended solids concentrations. This insured consistency with observed data on channel incision and aggradation, and evaluation of upland sediment load-generation rates relative to analyses reported for similar streams in the Seattle area. Once calibrated, the model was validated using an earlier time period of observed data. The instream data cover many stations, but only a limited number of total samples are available. Based on the available evidence, the performance of the sediment model is acceptable, and high average relative errors reported for some stations appear to be due to anomalous outliers and small sample sizes. The model reproduces both the temporal and spatial trends in observed TSS. Appendix B provides a more detailed summary of the calibration and validation, and more details are provided in Tetra Tech (2012a).

The basin was divided into sub-drainage areas based on these parameters and flow rates, and sediment production rates were computed. The model estimated that upland sources of sediment contribute about 462 tons of sediment per year. The model output also provided an annual sediment loading rate by sub-area and thus, "hot spots" could be identified. To ground-truth the modeled hot spots, Brown and Caldwell used GIS data and aerial photography to verify the reasonableness of the hot spots and additional field reconnaissance was performed. Once verified, Brown and Caldwell estimated that the total amount of sediment load from in-channel erosion and upland sources for the Clarks Creek basin, under current conditions, is 673 tons/year.

Brown and Caldwell (2013) calculated geomorphically-significant flows for key channel locations in the Clarks Creek basin to estimate the level of flow control that would be needed to reduce channel erosion. The HSPF model, channel geometry data, and particle size data were used to calculate the flows for 83 channel locations on the mainstem and tributaries. The results were compared to two "minimum requirement" flow control criteria contained in the Phase I and Phase II Municipal Stormwater Permits (also known as Municipal Separate Storm Sewer System [MS4] Permits). Minimum Requirements 5 and 7 are intended to reduce the duration of geomorphically significant flows that cause channel erosion and other adverse impacts. Following are summaries of these requirements:

- Minimum Requirement 5: "On-site Stormwater Management," contains a LID performance standard that applies to projects that result in greater than 2,000 square feet of new plus replaced hard surfaces. The requirement reads as follows:

  Stormwater discharges shall match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 8% of the 2-year peak flow to 50% of the 2-year peak flow. Refer to the Standard Flow Control Requirement section in Minimum Requirement #7 for information about the assignment of the pre-developed condition. Project sites that must also meet minimum requirement #7 shall match flow durations between 8% of the 2-year flow through the full 50-year flow.

- Minimum Requirement 7: "Flow Control," contains a standard flow control requirement that applies to projects that result in greater than 5,000 square feet of new plus replaced hard surfaces. The requirement reads as follows:

  Stormwater discharges shall match developed discharge durations to pre-developed durations for the range of pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. The pre-developed condition to be matched shall be a forested land cover unless [specific conditions are met.]

The results of the geomorphically-significant flow calculations indicate that hydromodification, including loss of forest cover, creation of impervious surfaces, and construction of stormwater drainage systems, has contributed to bedload movement and accelerated channel and bank erosion, particularly in upper Clarks Creek and the tributaries. When the lower limit of the flow is less than the minimum flow control requirement (i.e., less than 50% of the two-year forested discharge), it is possible in some cases that sediment transport will not occur. Following are the key findings:

- The boundary flows that likely cause channel degradation in lower Clarks Creek (downstream of 15th Street SW to the mouth) roughly correspond to the flow thresholds of Minimum Requirement 7 in the MS4 Permit (i.e., 50% of the 2-year forested discharge through approximately the 50-year forested discharge).
- The boundary flows that can cause significant amounts of sediment transport in upper Clarks Creek (downstream of 15th Street SW to downstream of 100th Street E) are less than the flow thresholds of Minimum Requirement 7 and range from 5% of the 2-year forested discharge up to about 38% of the 2-year forested discharge.
- The range of flows predicted to cause significant amounts of sediment transport in the tributaries vary widely from reach to reach. The lower bound ranges from as little as 5% of the 2-year forested discharge to greater than 100% of the 2-year forested discharge.
- The lower flow bound was very low for the steepest, most incised stream reaches. This indicates that even small flows can cause bedload movement in these reaches.

Input data for each reach, one-page results summaries, and additional tabulated results are provided in Brown and Caldwell (2012).

After identifying the prominent sediment loading sources, an evaluation of potential sediment reduction measures was conducted. A combination of flow control and capital projects was selected by PTI and the stakeholder group. Twenty-three projects were identified to address in-channel and upland sediment sources utilizing:

- In-channel intervention including channel and bank stabilization.
- Stormwater detention ponds.
- Sediment traps.
- Stormwater diversion.
- Stormwater treatment.
- Low impact development (LID) practices such as porous pavement and roadway bioretention.

The suite of projects was modeled to assess the sediment load-reduction potential. The HSPF model was modified to represent existing conditions and build-out conditions. The build-out conditions, accounting for future regulatory requirements for on-site mitigation and flow controls, were selected as the baseline for project implementation. If all 23 projects were implemented, a 52% reduction in annual sediment loading would be accomplished (Figure 32), primarily due to reduction of in-channel sources.

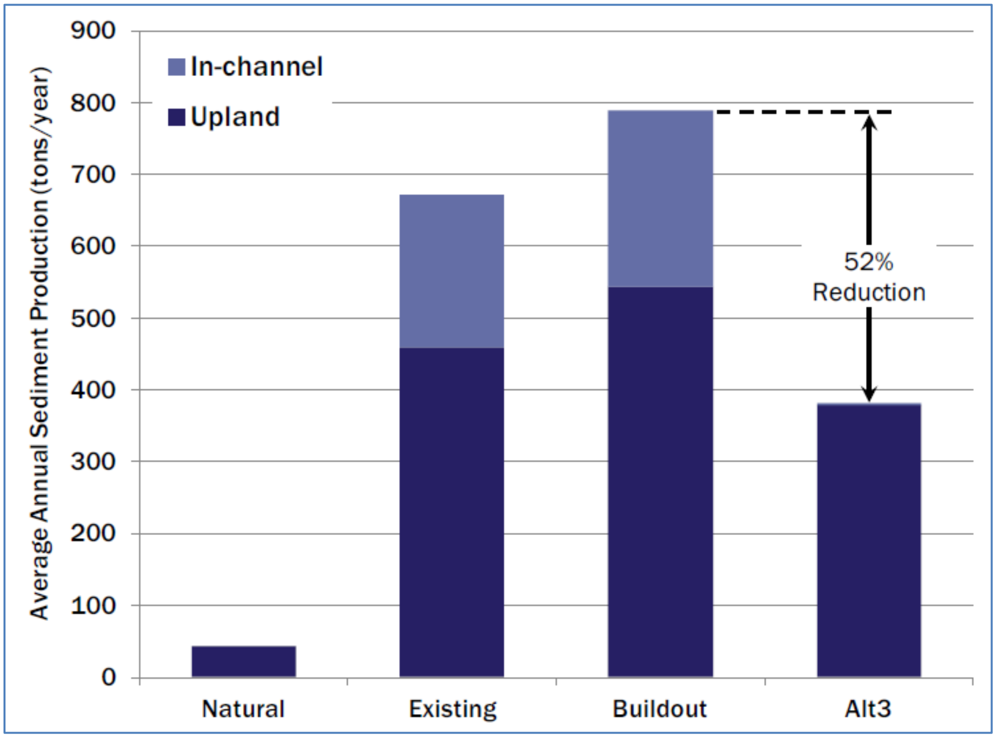

Figure 32. Estimated reduction in average annual sediment load from implementation of the 23 proposed projects (Alt 3) in the Clarks Creek Action Plan (Brown and Caldwell, 2013).

Additional proposed project details, the estimated sediment load reduction per project, and the project benefit-cost index is located in the Sediment Reduction Action Plan (Brown and Caldwell, 2013).

Sediment characterization and analysis

Pollutants such as phosphorus, organic nitrogen, or fecal coliform can attach to sediment particles. When erosion occurs and fine sediments are transported downstream, the pollutants attached to them can also be transported in lower reaches of Clarks Creek. As a result, part of PTI's grants included analyzing sediment samples for certain parameters. Grain size distribution is also very important because it affects the mobility of sediment and how erodible bed sediment may be. As part of PTI's grant focusing on creating a sediment reduction action plan, Brown and Caldwell and PTI staff collected samples at 20 locations within the Clarks Creek watershed during a one-week period in late July/early August 2011. The sampling was conducted shortly after the city of Puyallup and Pierce County completed their annual cutting of elodea in Clarks Creek downstream of sampling site Clarks-04. The full report is provided in the Clarks Creek Sediment Reduction Action Plan (Brown and Caldwell, 2013).

Five surficial sediment subsamples were taken at equally-spaced intervals along each cross-section of the creek. The subsamples were combined to form one composite sample for laboratory analysis. The samples were analyzed for total organic carbon (TOC), total Kjeldahl nitrogen (TKN), nitrate and nitrite nitrogen, total phosphorous (TP), biochemical oxygen demand (BOD), fecal coliform bacteria, total solids (TS), and grain size distribution (GSD). Sediment quality results for TN, TP, BOD, and the percent TOC are presented in Figure 33. Grain size distribution results are presented in Figure 34.

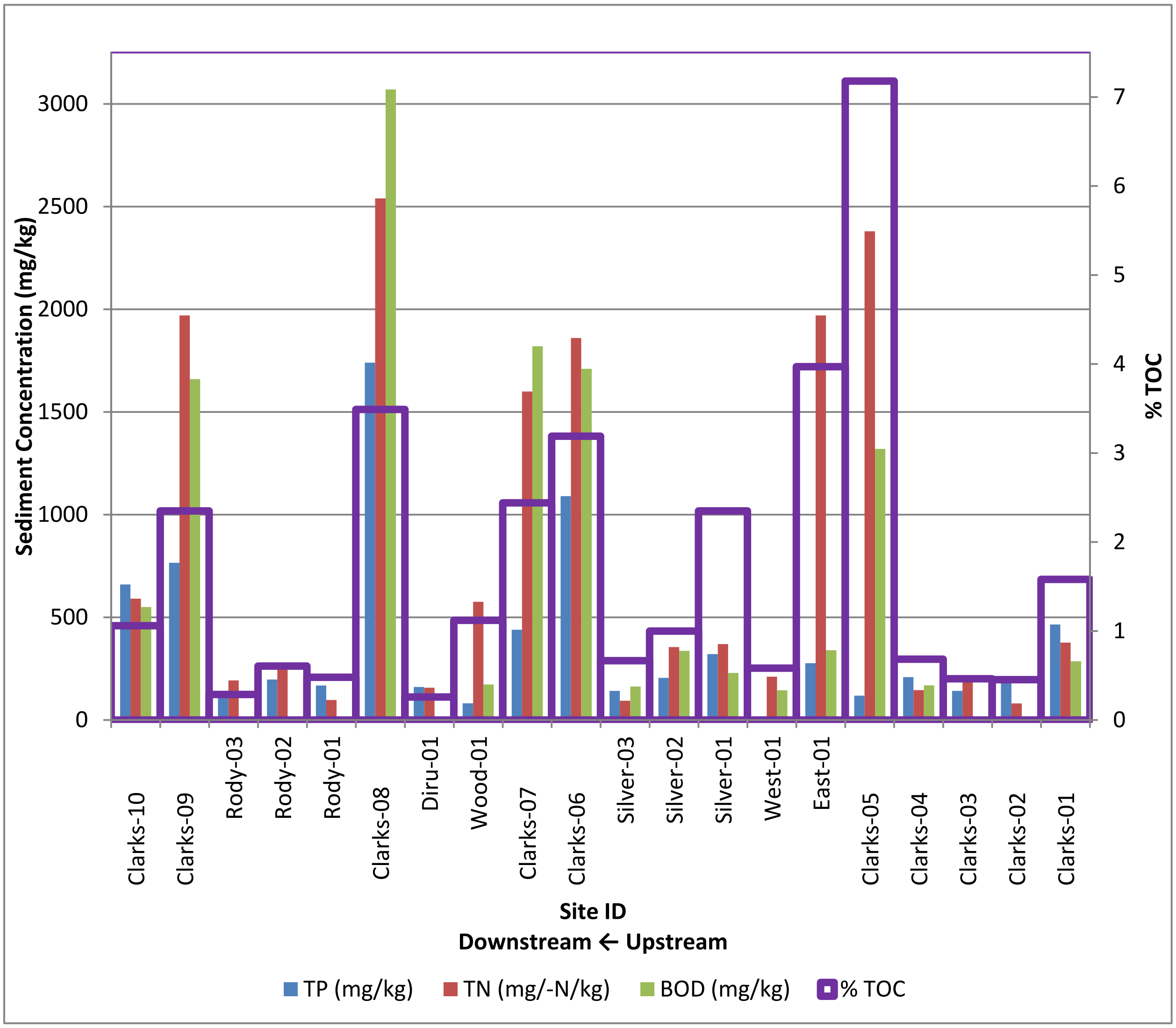

Figure 33. Analytical sediment quality results.

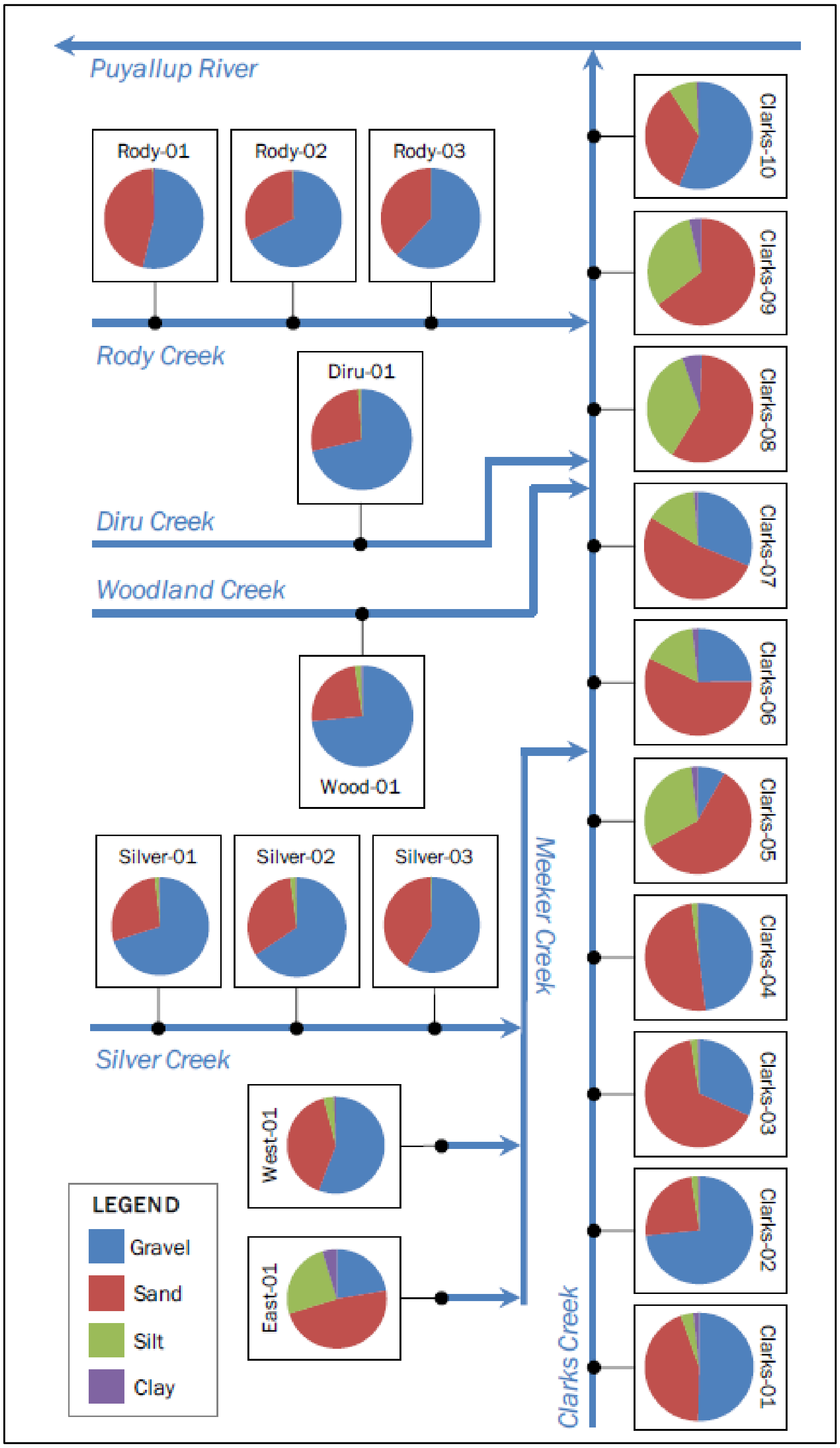

Figure 34. Grain size distribution of bottom sediment samples (Brown and Caldwell, 2013).

Of the samples collected on Clarks Creek, TP, TN, and BOD concentrations were highest in the sediment composite at Clarks-08, located off of Tacoma Road. The grain size distribution analysis at Clarks-08 showed that gravel characterized less than 1% of the composite. The majority of sediment was classified as fine sand and very coarse silt. The highest percent TOC in sediments was found at Clarks-05 near the Clarks Creek Park south entrance parking lot. Also at Clarks-05 there is an increase in silt and clay content. This is likely attributed to the change in hydraulic characteristics. Downstream of the site, Clarks Creek widens and the slope decreases as it enters the Puyallup River Valley. In addition, elodea growth starts approximately 200 feet upstream of this site. Clarks-05 and Clarks-08 were two of the three sites where percent fines were greater than 25% of the grain size distribution. Clarks-09, the next site downstream of Clarks-08, also had these results.

The percentage of sand and fine materials in the samples collected was greater than 25% at all sites within the watershed with 14 out of 20 sites exceeding the 90th percentile of fines and sands in Puget Sound lowland reference streams supporting healthy aquatic life (37%) (Table 6). These sites ranged from 38% to 100%.

Table 6. Percent Fines and Sands Data Compared to Puget Sound Lowland Reference Streams

Monitoring Location ID	Monitoring Location Name	Monitoring Location Latitude	Monitoring Location Longitude	% Sand and Fines	90% Reference for sand and fines
Clarks-01	Clarks Creek Monitoring Site 1	47.17	-122.323	49.6	36.5
Clarks-02	Clarks Creek Monitoring Site 2	47.1717	-122.32	26.5	36.5
Clarks-03	Clarks Creek Monitoring Site 3	47.1744	-122.3178	68.2	36.5
Clarks-04	Clarks Creek Monitoring Site 4	47.176	-122.3176	51.9	36.5
Clarks-05	Clarks Creek Monitoring Site 5	47.181	-122.316	91.7	36.5
Clarks-06	Clarks Creek Monitoring Site 6	47.186	-122.32	75.1	36.5
Clarks-07	Clarks Creek Monitoring Site 7	47.19	-122.3246	68.8	36.5
Clarks-08	Clarks Creek Monitoring Site 8	47.195	-122.33	99.3	36.5
Clarks-09	Clarks Creek Monitoring Site 9	47.2	-122.3411	100.0	36.5
Clarks-10	Clarks Creek Monitoring Site 10	47.206	-122.3406	44.0	36.5
Rody-01	Rody Creek Monitoring Site 1	47.1825	-122.3515	46.3	36.5
Rody-02	Rody Creek Monitoring Site 2	47.1873	-122.3509	32.3	36.5
Rody-03	Rody Creek Monitoring Site 3	47.18257	-122.3515	38.1	36.5
Silver-01	Silver Creek Monitoring Site 1	47.17	-122.308	29.9	36.5
Silver-02	Silver Creek Monitoring Site 2	47.1719	-122.3068	34.3	36.5
Silver-03	Silver Creek Monitoring Site 3	47.1758	-122.307	41.2	36.5
Diru-01	Diru Creek Monitoring Site 1	47.19177	-122.339	28.7	36.5
Wood-01	Woodland Creek Monitoring Site 1	47.189	-122.3328	26.5	36.5
West-01	Silver Creek Tributary Monitoring Site 1	47.17688	-122.3027	44.1	36.5
East-01	Silver Creek Tributary Monitoring Site 2	47.175	-122.2959	77.5	36.5

The two most upstream sites were the only locations on the mainstem that had 50% or more of gravel. Conversely, only Meeker Creek had less than 50% gravel in the sediment composition, while the other locations on Rody, Diru, and Woodland Creeks had more gravel and almost no fines. In general, concentrations of TP, TN, BOD, and TOC appeared to be higher in samples with higher percentages of fine-grained material.

Total suspended solids

Total suspended solids concentrations have been monitored along the length of Clarks Creek. Between Maplewood Springs and Meeker Creek, concentrations are typically less than or around 10 mg/L; some measurements as high as 70 mg/L have been observed, and the average TSS is 5.5 mg/L. Measurements exhibit more variability in the downstream direction, although limited sampling has occurred in the reach from Meeker Creek to Rody Creek. Central tendencies suggest an increase in TSS concentrations below Meeker Creek, then again toward the mouth of Clarks Creek. Between the state hatchery and Meeker Creek the median is only 3 mg/L; between Rody Creek and the mouth, concentrations are often higher with a median of 10 and an average of 12.7 mg/L.

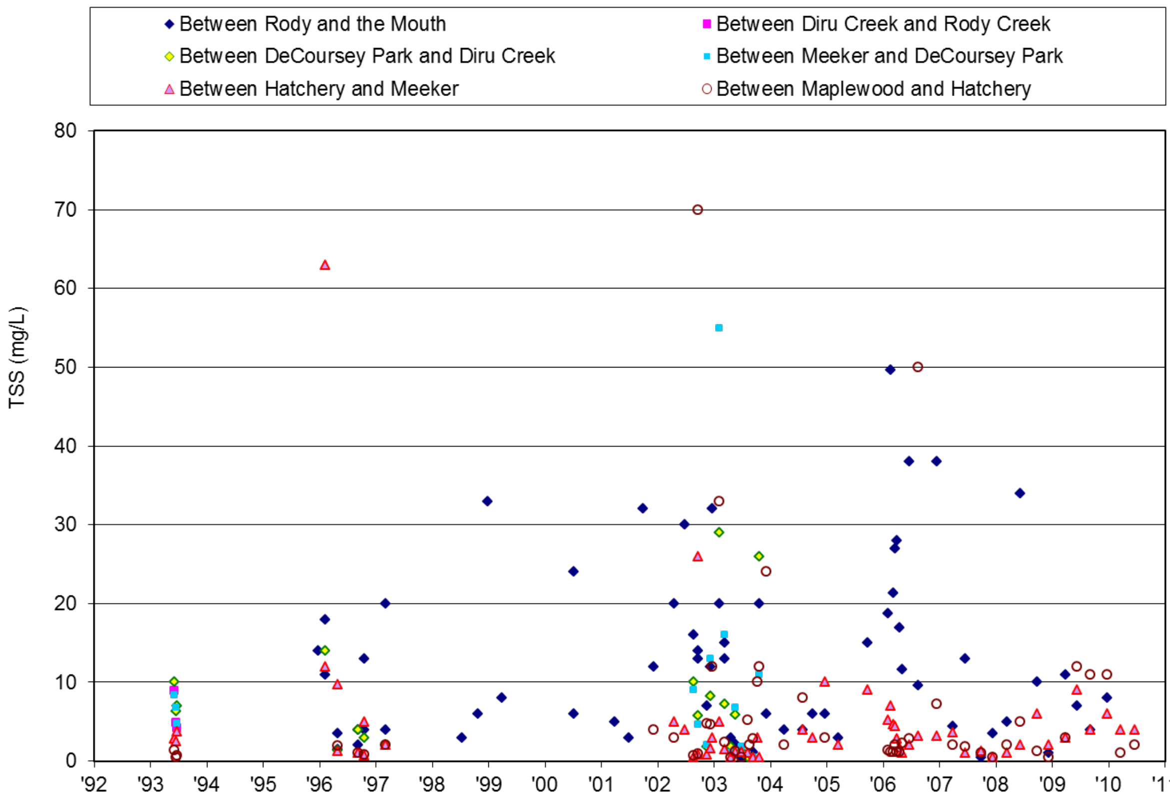

Figure 35. TSS measurements in Clarks Creek.

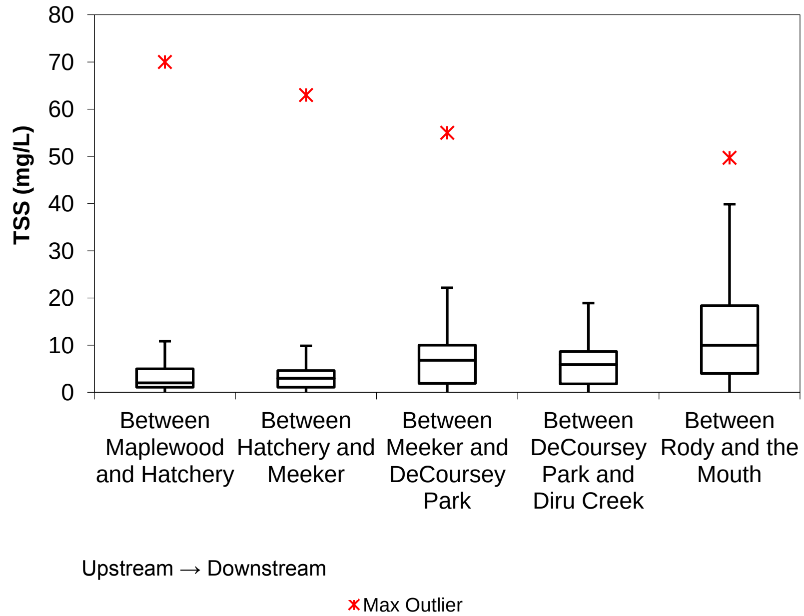

Figure 36. Box plot of TSS measurements in Clarks Creek.

The largest TSS dataset is between Rody Creek and the mouth of Clarks Creek, and this reach is also near the stream gauge. A plot of TSS compiled from all of the stations in the segment versus daily flow measured at the gauge shows a negligible relationship due to higher TSS concentrations often occurring at lower flows. The lack of a clear relationship to flow is likely due to heterogeneity in site characteristics within the stream segment, including macrophyte beds which modify velocity and promote settling of solids. Figures 36 and 37 show the relationship of TSS and flow at four stations between Rody Creek and the mouth. Limited data are available for the tributaries. TSS concentrations as high as 326 mg/L have been observed.

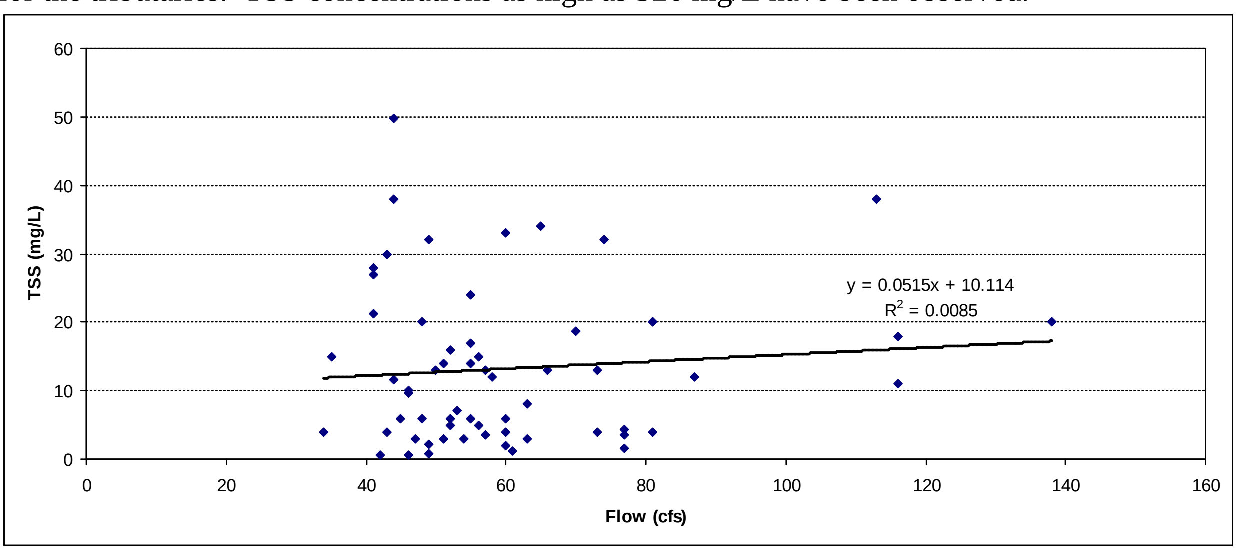

Figure 37. Relationship of TSS and flow, Clarks Creek between Rody Creek and the mouth.

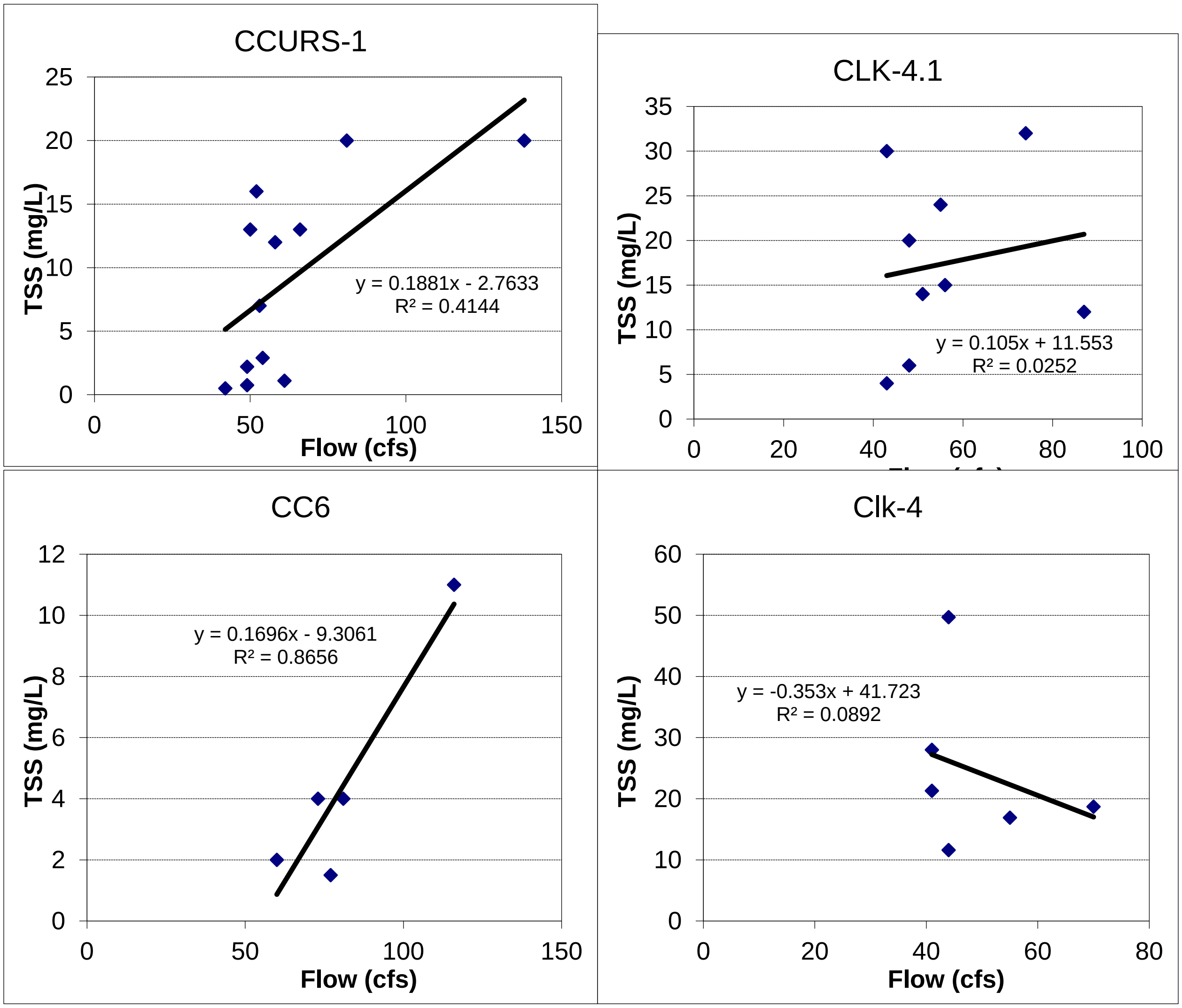

Figure 38. Relationship of TSS and flow at four stations between Rody Creek and the mouth.

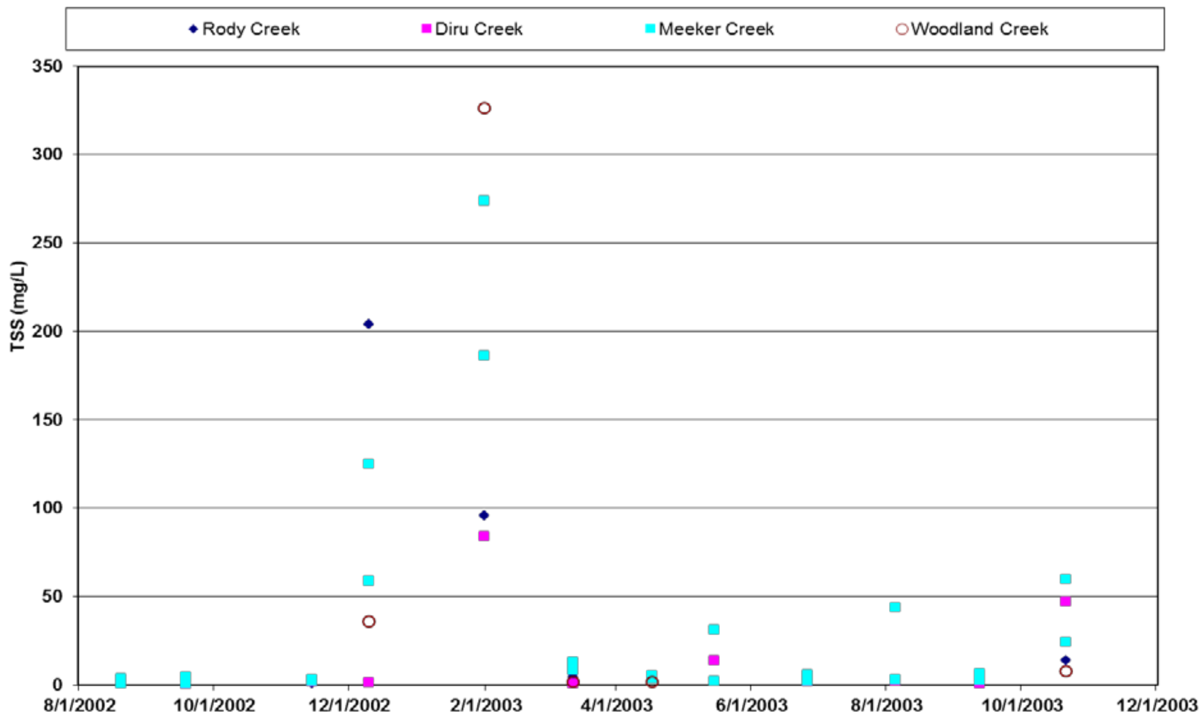

Figure 39. TSS measurements in tributaries to Clarks Creek.

Additional TSS samples were obtained in the winter of 2011-2012 by Tetra Tech for PTI to evaluate water quality during storm events from stormwater conveyances (Tetra Tech, 2012d), as described in the Stormwater Monitoring in 2011-2012 section and Appendix E.

Figure 39 presents the summary statistics for TSS analysis for the mainstem locations, Meeker Creek, and the stormwater conveyance system samples. The average and median TSS concentrations in the mainstem were below 3 mg/L. The average and median concentrations in Meeker Creek were above the average and median concentrations of all of four of the stormwater conveyance systems. These data confirm that suspended sediment concentrations are not well correlated with flow, and that Meeker Creek appears to be a key source of suspended sediment to Clarks Creek.

Table 7. TSS concentrations from stormwater sampling between 2011 and 2012.

	TSS (mg/L)		
	Clarks Mainstem	Meeker Creek	Stormwater Conveyances
Number of Samples	84	28	56
Minimum	0.2	0.6	0.2
Maximum	24.5	79	120
Average	2.5	15.0	10.9
Median	1.4	10.5	5.1

Suspended sediment impacts on salmonid populations

Potential effects of elevated suspended sediment on fish communities were analyzed using the methods of Newcombe and Jensen. Newcombe and Jensen (1996) analyzed 80 published documented reports on fish responses to suspended sediment in streams and estuaries to yield a predictive model for six data groups that relate biological response to duration and exposure and suspended sediment concentration. The six groupings varied by combinations of the following four attributes: taxonomic group, life stage, life history, and particle size of suspended sediment. The group with the largest dataset included juvenile and adult salmonids and particle sizes between 0.5 and 250 µm (group 1) and was used for the assessment on Clarks Creek. The severity of impact on fish of various life stages and species are reported semi-quantitatively from 0 to 14 points as follows (Newcombe and Jensen, 1996):

- A score of 0 indicates no effect.
- Scores between 1 and 3 indicate behavior effects:
  - Alarm reaction: 1
  - Abandonment of cover: 2
  - Avoidance response: 3
- Scores between 4 and 8 indicate sublethal effects:
  - Short-term reduction in feeding rates; short-term reduction in feeding success: 4
  - Minor physiological stress; increase in rate of coughing; increase in respiration rate: 5
  - Moderate physiological stress: 6
  - Moderate habitat degradation; impaired homing: 7
  - Indications of major physiological stress; long-term reduction in feeding rate; long-term reduction in feeding success; poor condition: 8
- Scores between 9 and 15 indicate lethal and paralethal effects, where a score of 10 and above indicate a designated probability of mortality:
  - Reduced growth rate; delayed hatching; reduced fish density: 9
  - 0-20% mortality; increased predation; moderate to severe habitat degradation: 10
  - >20-40%: 11
  - >40-60%: 12
  - >60-80%: 13
  - >80-100%: 14

Severity scores were calculated for Clarks Creek at 66th Avenue under current conditions using output from the continuous HSPF watershed model developed for PTI. One-, two-, three-, seven-, 14-, and 21-day running TSS concentration averages were calculated for the 51-year dataset. The average TSS concentrations were utilized in the Group 1 Newcombe and Jensen equation for juvenile and adult salmonids and the 50th-, 75th-, and 95th-percentile scores were plotted based on the exposure. The modeled TSS concentrations are generally between 2 and 5 mg/L with a median of 2.9 mg/L, a minimum of 2.3 mg/L, and a maximum value of 393 mg/L. Because these values do not go below 2 and the highest value is averaged to create a chronic value, the corresponding severity scores are generally between 6 and 7 with any long-term exposure. *These scores indicate minor to moderate stress, indicating moderate habitat degradation.*

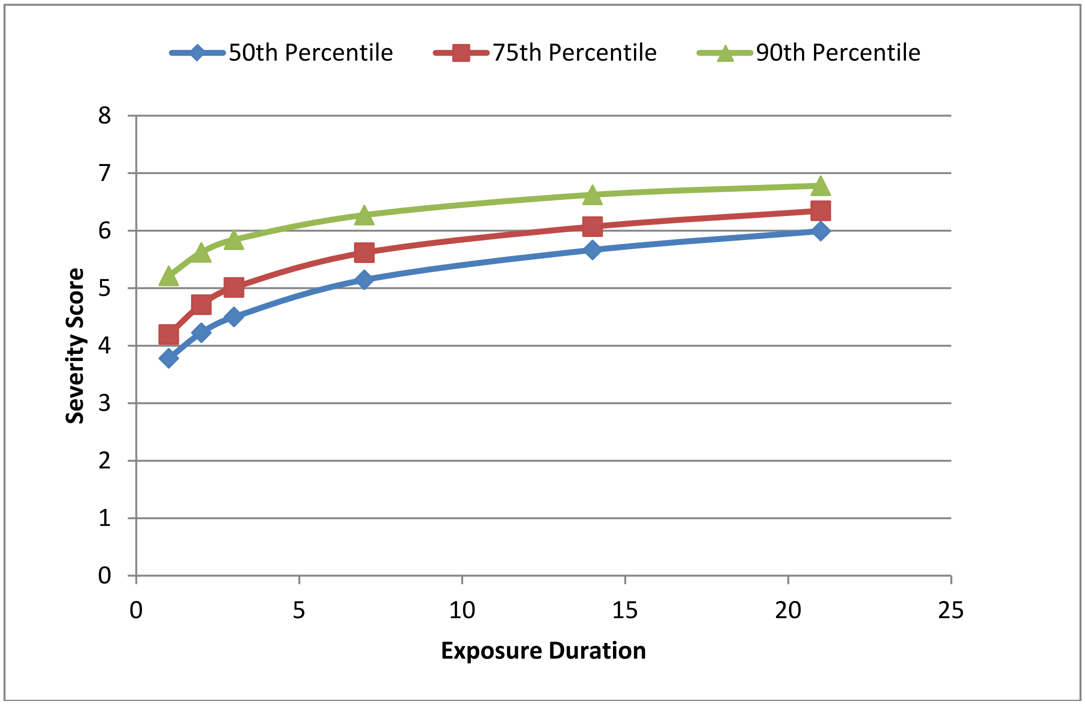

Figure 40. 50th-, 75th-, and 95th-Percentile Severity Scores by Exposure Duration on Clarks Creek at 66th Avenue.

The simulated daily TSS model output for the 50-year period was used as the basis for TSS reduction scenarios. The 21-day running average was used as the basis for the reduction scenarios calculated for the 95th percentile and median severity scores (Table 89). A 75% watershed load reduction was predicted to result in a median severity score less than 5. A 95% sediment load reduction would be required for the 95th percentile score to be below 5. The assessment illustrates that the severity scores are not extremely sensitive to load reductions. The calculation of severity scores is a semi-quantitative method based on streams outside of the watershed and a high degree of uncertainty is associated with these methods.

Table 8. Load reduction required to lower severity scores for a 21-day duration event

Load Reduction	Severity Scores	
	95th percentile	Median
No reduction	6.8	6.0
50%	6.3	5.5
75%	5.8	5.0
95%	4.6	3.8

In Clarks Creek, there are limited suspended sediment data in the watershed. To fit the observed data during baseflow, a default of 2 mg/L TSS was used for spring discharges. This assumption results in a prediction of persistent concentrations at or above 2 mg/L, which in turn, influences the predicted severity scores by increasing them as the Newcombe and Jensen equations are sensitive to low TSS values when they persist over a long period of time.

While suspended sediment data are limited in the watershed, the analysis indicates that a reduction in TSS and sediment load would reduce the adverse impacts of sediment on salmonids. A reduction of the severity scores below 6 would change the effects from moderate to minor, so the analysis does suggest that beneficial improvements occur with a 50% to 75% sediment load reduction.

Turbidity

Turbidity can be one of the ways to measure sediment. Turbidity has been measured less frequently in Clarks Creek in the past relative to the other parameters. This is measured as nephelometric turbidity units (NTU), a measure of light scattering. In the Clarks Creek mainstem, most of the observed turbidity measurements were less than 80 NTU, with an average of 15.5 NTU and several higher observations. Two additional, much higher observations are not plotted, including a sample between DeCoursey Park and Diru Creek measured on January 4, 1996 (at 531 NTU), and a sample between the state hatchery and Meeker Creek measured on September 5, 1996 (at 317 NTU).

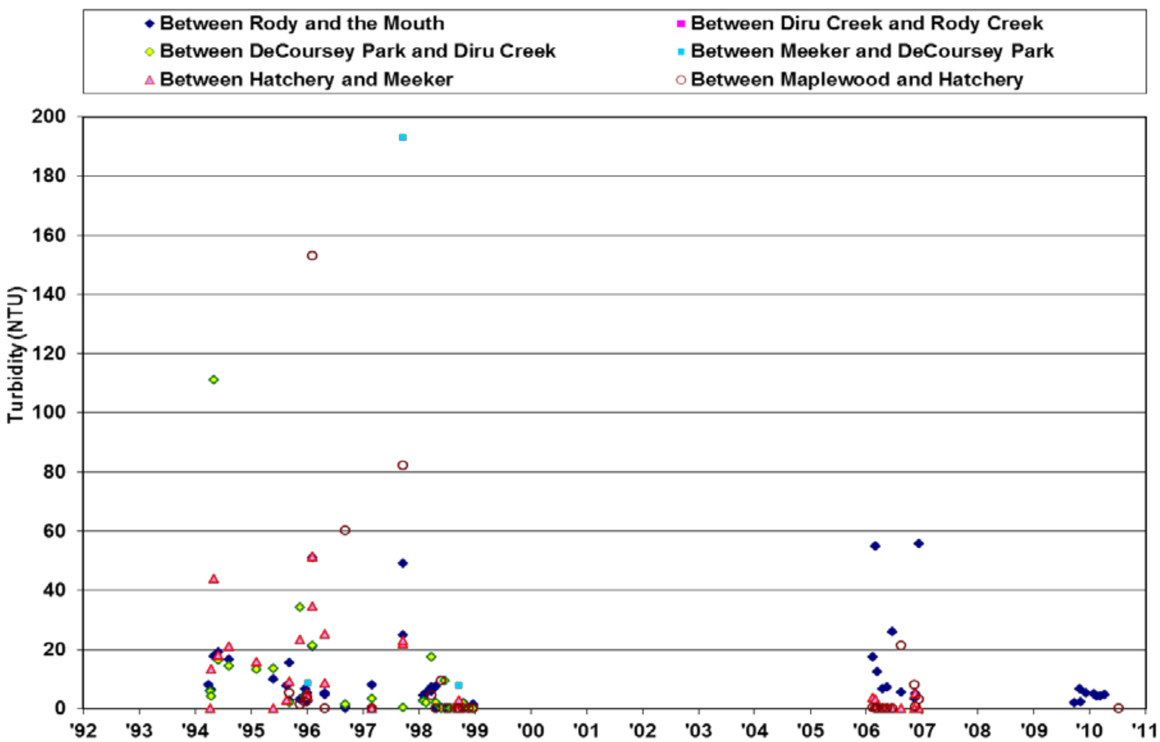

Figure 41. Turbidity measurements in Clarks Creek.

Note: Two turbidity measurements were considered outliers and were not included: 1) between DeCoursey Park and Diru Creek measured on January 4, 1996 (531 NTU) and; 2) between Hatchery and Meeker measured on September 5, 1996 (317 NTU).

In 2009 and 2010, PTI conducted continuous monitoring at three locations in Clarks Creek using automated continuous monitoring equipment, or data sondes. Two stations (near the state hatchery and near the Clarks Creek Tribal hatchery) included monitoring for turbidity. The majority of the sampling was conducted during summer low flow periods, when few storms and minimal erosion are anticipated. Turbidity observations as high as 200 NTU were reported at the state hatchery station near Clarks Creek Park during the summer of 2009. Continued sampling during the fall of 2010 captured several early season storm runoff events. This revealed highly elevated turbidity, above 1,200 NTU, at the state hatchery station, just downstream of the stream reaches identified as at risk of degradation in the geomorphic and sediment simulation analyses and near the state hatchery. It should be noted that the turbidity sensor used in this study cannot measure above 1200 NTU, so it is likely that turbidity levels in Clarks Creek are higher. In contrast, turbidity remained low downstream at the Clarks Creek Tribal hatchery, suggesting most of the sediment settled out in the intervening reaches.

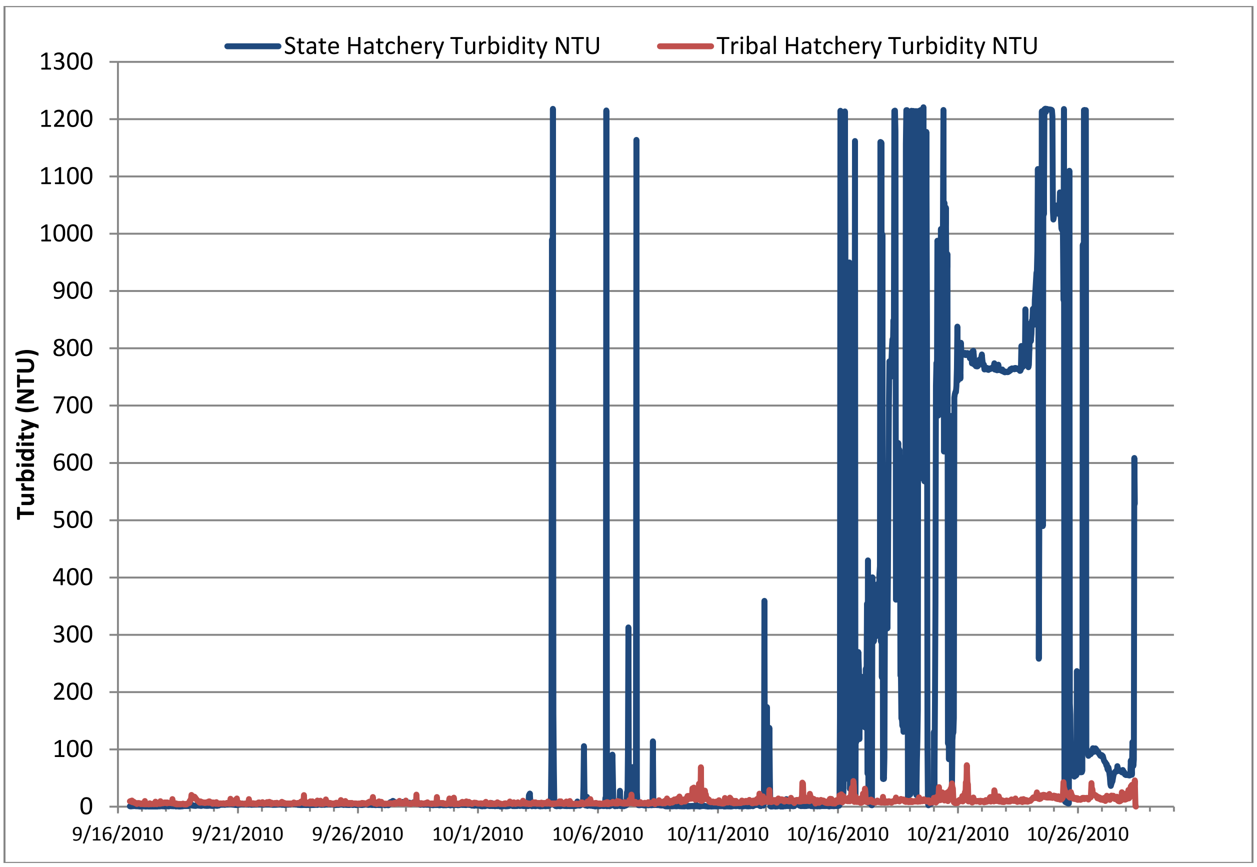

Figure 42. Continuous Turbidity Monitoring in Fall 2010.

Sediment oxygen demand

A study to quantify sediment oxygen demand (SOD) was conducted in 2011 by PTI and HydrO2, Inc. The preferred chamber method of direct measurement of SOD was possible only on open patches of sand/mud or sand/gravel without significant amounts of submerged aquatic vegetation, so these measurements do not include the full SOD that may be exerted underneath elodea mats. According to the data collected at two sites without significant macrophyte coverage, average SOD ranged from 1.58 to 1.99 gm-O_2/m^2/day. These measurements likely underestimate the SOD that is present in areas of fine organic sediments that are typically covered with elodea. To address this issue, HydrO2 also conducted total community substrate oxygen demand (CSOD) measurements. This method involved collecting diel dissolved oxygen measurements and correcting for reaeration and water column respiration. Reaeration was estimated as a function of flow using the method of Langbein and Durum (1967). The resulting CSOD estimates at 3 sites on Clarks Creek ranged from about 2.5 to 4.7 gm-O_2/m^2/day. The estimates do not provide a full measurement of the oxygen demand exerted by the combination of sediment and decaying organic material within elodea mats, and because reaeration was not directly measured they are also highly uncertain. However, these measurements confirmed the importance of both SOD and CSOD in the system and indicated that water column respiration is relatively small, about 0.5 gm-O_2/m^2/day (HydrO2, Inc., 2011).

Biological and physical habitat data

Two assessment tools are available for interpreting benthic macroinvertebrate (BMI) community condition as presented in the Water Quality Standard Section 5: B-IBI and RIVPACS. Both tools use reference conditions as a benchmark and organize sites into classes with a select set of environmental characteristics. The B-IBI index analyzes a broader array of biological signals to define the attributes of living systems that change when exposed to human activity. RIVPACS focuses on recognizing patterns of species composition. Because of the broader nature of the B-IBI, it is not as sensitive to subtle taxonomic changes in the community that may be reflected in RIVPACS scores. However, both provide a direct measure of biota in aquatic systems and thus provide important information on biological endpoints (Jungwirth, 2000). At this time, a RIVPACS analysis is not available for the Clarks Creek basin.

Biological data

Pierce County and PTI have collected benthic macroinvertebrate data and calculated Benthic Index of Biotic Integrity (B-IBI) scores for stations located on Clarks, Diru, and Rody Creeks over the past several years. The B-IBI scores are composed of ten metrics used to assess stream biologic health and degradation. The advantage of doing biological surveys is that actual conditions of aquatic life are evaluated, as opposed to relying alone on chemical water quality indicators. The results of B-IBI show that the biotic index of Clarks Creek is poor. As discussed in the Suspended Sediment, Bedded Sediment and Biocriteria section, based on the Puget Sound Stream Benthos (PSSB), scores ranging from 10 to 16 are ranked Very Poor; 18 to 26 are Poor; 28 to 36 are Fair, 38 to 44 are Good, and 46 to 50 are Excellent.

B-IBI scores for Clarks Creek were measured in 2001, 2002, 2003, and 2004 with respective scores of 34, 28, 32, and 26 (Figure 43). In 2001, 2002, and 2003 the scores rank Fair; in 2004 the score was Poor. Scores in Diru Creek were 18 in 2003 and 24 in 2005, both ranking Poor. B-IBI has been measured once in Rody Creek with a score of 22 (Poor) in 2005. As previously discussed in the Suspended Sediment, Bedded Sediment and Biocriteria section, Washington Water Quality Policy 1-11 guidelines use both RIVPACS and B-IBI to assess biological condition in streams and rivers, and the definition for biotic integrity is "a balanced, integrated, adaptive system having a full range of ecosystem elements (genes, species, assemblages) and processes (mutation, demographics, biotic interactions, nutrient and energy dynamics, metapopulation dynamics) expected in areas with no or minimal human influence (Karr 2000)." The Puget Sound Stream Benthos definition of a poor water is "Overall taxa diversity depressed;

proportion of predators greatly reduced as is long-lived taxa richness; few stoneflies or intolerant taxa present; dominance by three most abundant taxa often very high." Therefore, the poor B-IBI scores in portions of Clarks Creek show that macroinvertebrate populations in those areas are impaired.

Benthic macroinvertebrate populations and B-IBI scores in Clarks Creek are likely limited by overgrowth of elodea and sedimentation. Increasing quantities of fines will smother coarse substrates that support biological communities with larger numbers of species. The space within the coarse substrates fills and reduces the useable area of the hard-bottomed habitat. This stressor commonly appears in urban streams and is the dominant impact that causes strong deviation in biological communities from expected taxonomic structure and function. Direct effects of sediment on aquatic invertebrates include physical habitat changes due to scouring of streambeds and dislodgement of individuals, smothering of benthic communities, clogging of the interstices between substrate components which affect microhabitats, and abrasion of respiratory surfaces and interference of food uptake for filter-feeders (Singleton 1985, CCME 1999). An early response of benthic invertebrates to increases in sediment is that of increased drift. Drift is the means by which aquatic insects colonize streams. Culp et al (1986) showed that as increases in fine sediment occurred, macroinvertebrate drift rates increased and consequently the density and species diversity of the benthic macroinvertebrate community was reduced. Effects on the benthic community then in turn negatively affect salmonids, as they are an important food source for salmonids (Tebo 1955; Rosenberg and Wiens 1978; Cederholm and Salo 1979; Brzezinski and Holton 1983).

Guidance prepared by Jim Muck of the US Fish and Wildlife Service for evaluating the biological effect of sediment on bull trout and salmon and their habitat (Muck 2010) states:

> "*Macroinvertebrates*
> *Sedimentation also alters the habitat for macroinvertebrates, changing the species density, diversity and structure of the area (Waters 1995, pp. 61-78; Anderson, Taylor, and Balch 1996, pp. 14-15; Reid and Anderson 1999, pp. 10-12; Shaw and Richardson 2001, p. 2220). Certain groups of macroinvertebrates are favored by salmonids as food items. These include mayflies, caddis flies, and stoneflies. These species prefer large substrate particles in riffles and are negatively affected by fine sediment (Everest, Beschta, Scrivener, Koski, Sedell, and Cederholm 1987, p. 115; Waters 1995, p. 63). Increased sediment can affect macroinvertebrate habitat by filling of interstitial space and rendering attachment sites unsuitable. This may cause invertebrates to seek more favorable habitat (Rosenberg and Snow 1975, p. 70). With increasing fine sediment, invertebrate composition and density changes from available, preferred species (i.e., mayflies, caddisflies, and stoneflies) to non-preferred, more unavailable species (i.e., aquatic worms and other burrowing species) (Reid and Anderson 1999, p. 10; Henley, Patterson, Neves, and Lemly 2000, pp. 126, 130; Shaw and Richardson 2001, p. 2219; Suren and Jowett 2001, p. 726; Suttle, Power, Levine, and McNeely 2004, p. 971). The degree to which substrate particles are surrounded by fine material was found to have a strong correlation with macroinvertebrate abundance and composition (Birtwell 1999, p. 23). At an embeddedness of one-third, insect abundance can decline by about 50 percent, especially for riffle-inhabiting taxa (Waters 1995, p. 66).*

Increased turbidity and suspended solids can affect macroinvertebrates in multiple ways through increased invertebrate drift, feeding impacts, and respiratory problems (Cederholm and Reid 1987, p. 384; Shaw and Richardson 2001, p. 2218; Berry, Rubinstein, Melzian, and Hill 2003, pp. 8, 11). The effect of turbidity on light transmission has been well documented and results in increased invertebrate drift (Waters 1995, p. 58; Birtwell 1999, pp. 21, 22). This may be a behavioral response associated with the night-active diel drift patterns of macroinvertebrates. While increased turbidity results in increased macroinvertebrate drift, it is thought that the overall invertebrate populations would not fall below the point of severe depletion (Waters 1995, p. 59). Invertebrate drift is also an important mechanism in the repopulation, recolonization, or recovery of a macroinvertebrate community after a localized disturbance (Anderson, Taylor, and Balch 1996, p. 15; Reid and Anderson 1999, pp. 11-12).

Feeding efficiency
Increased turbidity and suspended sediment can affect a number of factors related to feeding for salmonids, including feeding rates, reaction distance, prey selection, and prey abundance (Barrett, Grossman, and Rosenfeld 1992, pp. 437, 440;Henley, Patterson, Neves, and Lemly 2000, p. 133;Bash et al. 2001d, p. 21). Changes in feeding behavior are primarily related to the reduction in visibility that occurs in turbid water. Effects on feeding ability are important as salmonids must meet energy demands to compete with other fishes for resources and to avoid predators. Reduced feeding efficiency would result in lower growth and fitness of bull trout and other salmonids (Barrett, Grossman, and Rosenfeld 1992, p. 442; Sweka and Hartman 2001, p. 138).”

Another potential reason for reduced B-IBI scores may be lack of large woody debris habitat within the stream. Many of the physical effects of wood can alter the biological community. Densities of invertebrates are often found to be greater on wood and leaves than mineral substrate (Hax and Golladay 1993). Woody debris influences invertebrates by changing the structure and abundance of habitat (Gomi et al. 2001).

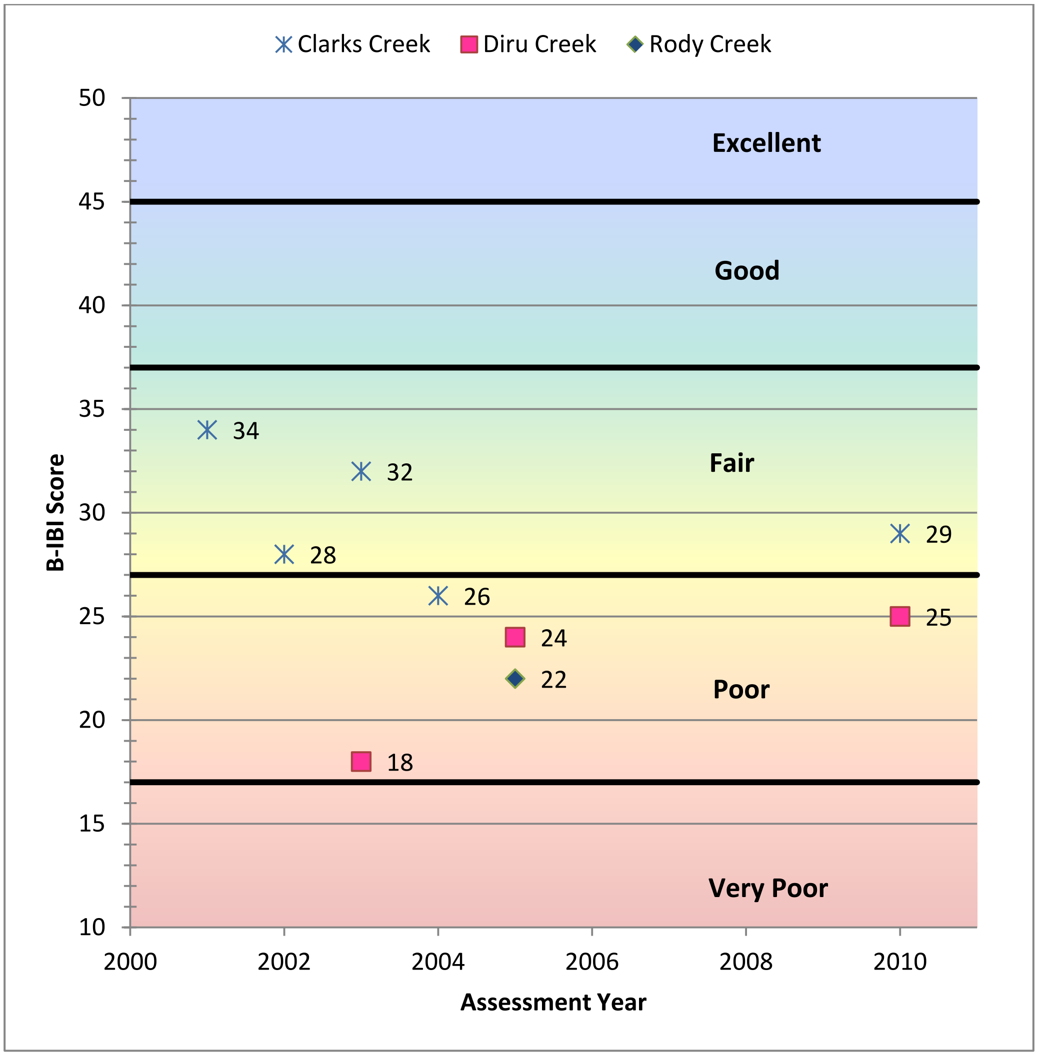

Figure 43. B-IBI Scores for Clarks, Diru, and Rody.

Physical habitat

Physical habitat assessments are commonly conducted together with bioassessment sampling. The assessment can include an evaluation of canopy cover, channel morphology and substrate characteristics, including the percent of fine sediment and/or sands and cobble embeddedness. The grain size distribution analysis conducted by PTI and Brown and Caldwell at 20 sites in the Clarks Creek basin in mid-2011 provides information on substrate characteristics (Brown and Caldwell, 2013).

Figure 34 provides the full grain size distribution while Figure 44 presents the percentage of fine sediments and the percentage of fine sediments plus sand found during the 2011 sampling event. Figure 44 also provides the 90th percentile percentage of fines and percentages of fines and sands in reference streams, which support aquatic life use. The TMDL study used the 90th percentile as a conservative statistic to represent the lower end of sediment values in a reference stream to account for uncertainties and variability in reference sites. Further discussion of the reference stream statistics is presented in the Biological Data section.

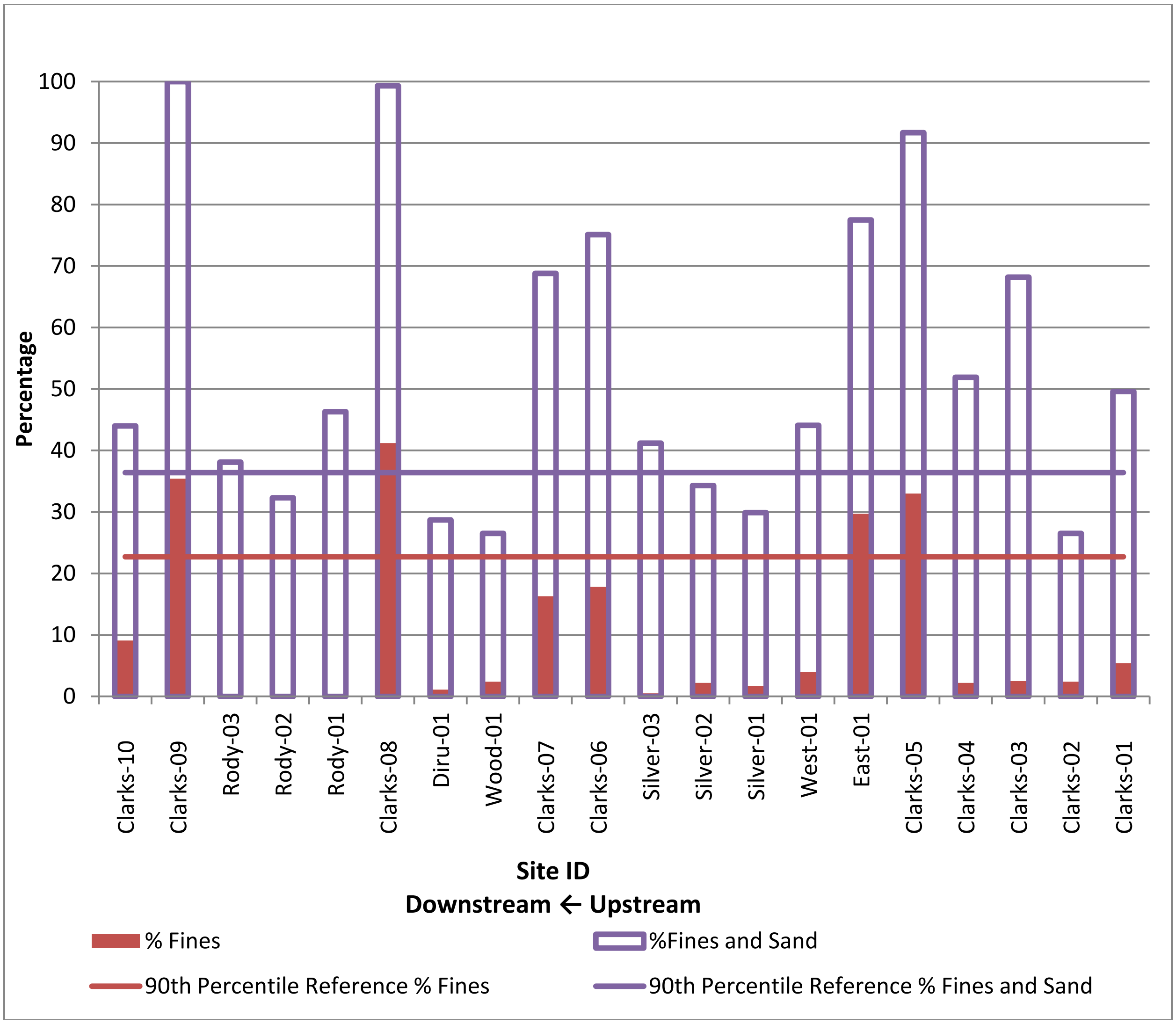

Figure 44. Percentage of Fines and Percentage of Fines and Sands in July 2011 Sampling Event in Clarks Creek Basin.

Three mainstem samples and the eastern unnamed tributary to Meeker Creek exceeded the 90th percentile reference stream value for percent fines. Nine of the ten mainstem locations exceeded the 90th percentile reference streams value for percentage of fines and sand. Since both fines and sands impair fish use, the 90th percentile reference stream values for fines and sands were chosen as the target to meet the aquatic life use for sediment. Clarks-09, the site closest to 66th Avenue, had the highest amount of percent fines and sands. Therefore, to meet the 90th percentile reference stream value at the most conservative locations, the percentage of fines and sands would need to be reduced by 64%.

Reference conditions

Numerous bioassessment studies have been conducted in Puget Sound lowland streams. EPA selected eight of these streams with B-IBI data with similar geological conditions to Clarks Creek that could provide a comparison as a reference condition. Assessing the sites as a group provides more data and accounts for variations even within reference streams. Between 2009 and 2011, 13 B-IBI surveys were conducted on Big Beef, Chuckanut, Coal, Griffin, Surveyor, Dewatto, and Candall Creeks in addition to a Coulter Creek tributary (Hayslip, 2013). The reference data that we evaluated were collected using the *Status and Trends Monitoring for Watershed Health and Salmon Recovery: Field Data Collection Protocol* (Ecology, 2009). The average percentage of urban land uses in the watersheds selected is 2%. The B-IBI scores were all between 38 and 46 with a median of 40, all higher than has been found in Clarks Creek, which according to the PSSB reflect waters that are of "good" or "excellent" quality.

In addition to macroinvertebrate surveys, water quality and physical habitat indicators were measured. Table 9 provides summary statistics for the reference streams, where data was available, for percent fines, percent sand and fines, TSS, and turbidity. Both the average and 90th percentile values of the reference dataset are provided. Several TSS concentrations were reported to be below the detection limit of the laboratory analysis. While not specifically stated, the detection limit was assumed to be 1 mg/L and a non-detect result was calculated for the purpose of the summary statistics as 0.5 mg/L. The average TSS concentration of the 10 samples with available data is 5.5 mg/L. The percent of fine sediments and sand is determined by the stream gradient and native geology. In an alluvial plain, like lower Clarks Creek, the percent of fines and sand would be expected to be higher because of the low gradient. Therefore, the 90th percentile values for percent fines and percent sand and fines are used as a comparison to the Clarks Creek observed data. The 90th percentile value for percent fines is 24% and the 90th percentile value for percent of sand and fines is 37%.

Table 9. Summary Statistics for Reference Stream Data

	Overall B-IBI Score	Percent Fines (%)	Percent Sand and Fines (%)	TSS (mg/L)	Turbidity (NTU)
Number of Samples	13	17	17	10	11
Minimum	38	0.0	8.6	<1	<0.1
Maximum	46	32.9	44.3	36	13
Median	40	8.4	17.3	<1	0.90
Average	41	9.9	21.7	5.5	2.4
90th Percentile	37	23.6	36.5	11.7	4.7

The value assigned to a non-detect concentration for TSS is 0.5 mg/L and 0.05 NTU for turbidity.

Nutrients

Ammonia

Nutrients, such as ammonia and phosphorus, can contribute to the growth of aquatic weeds which in turn deplete DO during nighttime respiration and by building up biomass that later decays. Ammonia concentrations in Clarks Creek are relatively low, and no samples greater than 0.25 mg-N/L have been observed. Samples taken through 2005 had lower detection limits than subsequent sampling; the majority of measurements collected between 2006 and 2010 were less than the detection limits of 0.05 mg-N/L, 0.1 mg-N/L, and 0.2 mg-N/L. No significant differences between stations are indicated by the data; however, ammonia concentration does appear to be elevated at times in the reach below the state hatchery.

Concentrations in Diru, Rody, and Woodland creeks have been consistently less than 0.15 mg-N/L; concentrations in Meeker Creek have been observed as high as 0.82 mg-N/L and are clearly elevated relative to both the Clarks Creek mainstem and other tributaries. However, the dry weather flow from Meeker Creek is small (on the order of 1 cfs during the 2002-2003 sampling) relative to the dry weather flow in Clarks Creek (about 50 cfs at this point), so little change in the distribution of mainstem concentrations above and below the confluence with Meeker Creek is evident.

Nitrate plus nitrite nitrogen

When DO is present, inorganic ammonia oxidizes into nitrite (NO_2) and then nitrate (NO_3). The sum of these two constituents is reported in most of the monitoring data; however, in natural waters nitrite is rapidly converted to nitrate, which constitutes the dominant form.

The majority of the baseflow nitrate load enters the system from groundwater discharges at and near Maplewood Springs, and concentrations decrease in the downstream direction. Recent data support the existence of this trend (Tetra Tech, 2010). Jones et al. (1999) noted an increasing trend over time across historical data, indicating that "land-use activities have affected ground-water quality in the study area." Prior to 2006, the majority of nitrate-plus-nitrite concentrations in Clarks Creek ranged from 1.5 mg-N/L to 3 mg-N/L. This is about ten times the EPA-recommended ecoregional criterion. A return to higher flows in 2006 appears to be accompanied by an increase in nitrate/nitrite concentrations, with mainly observations above 3 mg/L. As aquatic plants need both nitrogen and phosphorus to grow, the high levels of nitrate present in the stream suggest that phosphorus may be the more limiting nutrient. As a result, a more effective way to limit plant growth would be to restrict phosphorus.

Nitrate-plus-nitrite concentrations observed in Meeker Creek are typically less than 2 mg-N/L. Ammonia is elevated in Meeker Creek. Taken together, the ammonia and nitrate/nitrite observations are indicative of reducing conditions in this tributary. Nitrate plus nitrite concentrations in the other tributaries range from 0.6 mg-N/L to 3.5 mg-N/L.

Total phosphorus

Water column concentrations of total phosphorus also are fairly consistent throughout the length of Clarks Creek, and appear to be somewhat elevated relative to natural background. The median observed concentration of about 0.09 mg/l is nearly five times the EPA-recommended ecoregional criterion of 0.0195 mg/L. However, this may be of limited significance in a water body dominated by rooted macrophytes such as elodea, as these plants are typically able to compensate for any shortfall in their phosphorus needs by uptake from the sediment (Angelstein and Shubert, 2008). Among the tributaries to Clarks Creek, Meeker Creek has the highest concentrations with one measurement over 2 mg-P/L. Measurements in the other tributaries are usually less than 0.2 mg-P/L.

Ortho phosphorus

Ortho-phosphorus (PO_4-P) represents the fraction of total phosphorus that is directly available to plants in the water column. Lesser amounts of ortho-phosphorus data are available relative to the total phosphorus data and only three reaches have been monitored. In the past few years, detection limits were lowered and a greater number of lower concentrations are reported. For the 86 samples in which both total phosphorus and ortho-phosphorus were reported, ortho-phosphorus was on average 67% of the total phosphorus concentration.

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Conclusions and Recommendations

Dissolved oxygen

The data review and analyses conclude that dissolved oxygen (DO) concentrations in Clarks Creek are affected by low reaeration, sediment oxygen demand (SOD), tributary and groundwater inflow DO concentrations, and algal photosynthesis and respiration. The following factors were highlighted as important contributors to DO impairment:

- Oxygen consumption within elodea mats, inferred from the 2009 and 2010 monitoring before and after elodea cutting events.
- SOD, inferred from the model sensitivity analyses as well as direct measurements.
- Low DO in tributary and stormwater flows, based on observed concentrations.

Excess elodea growth is promoted, in turn, by elevated nutrient concentrations (in the water column and in the sediment), and elodea colonization is promoted by excess fine sediment, which provides a favorable substrate for elodea colonization.

The evaluation concludes that the most significant risk pathways, interlinked with one another, are:

- Urban runoff associated with impervious areas carries sediment and organic solids loads that increase SOD and reduce DO in storm drainage, reducing the average DO.
- Nutrient (nitrogen [N] and phosphorus [P]) loads in urban runoff increase nutrient concentrations in the water column and sediment.
- Increased nutrient (N and P) concentrations in the water column and sediment pore water help promote elodea nuisance growth, which in turn contributes to SOD, causes diurnal depression of DO, and reduces reaeration.
- Elodea nuisance growth enhances siltation, amplifying the impacts of SOD and reduced reaeration. Sediment loads also promote elodea growth because they provide a substrate for elodea to grow. Control of sediment loading will also result in a reduction in the loads of sediment-associated nutrients.
- Hydromodification, including loss of forest cover, creation of impervious surfaces, and construction of stormwater drainage systems, has contributed to bedload movement and accelerated channel and bank erosion. This was found particularly in upper Clarks Creek and the tributaries causing sedimentation and an increase in the percentage of sand and fines in the sediment bed in lower Clarks Creek. Even small storms contribute to bedload movement, and thus year-round stormflow is an important contributor to sediment loading, which exacerbates elodea nuisance growth as well as SOD.
- Lack of riparian cover increases solar radiation that promotes elodea growth and also elevates water temperature, resulting in decreased DO saturation concentrations and reduced DO.

Sediment

The interaction between sediment and dissolved oxygen led to the conclusion that while DO data provided the basis for the 303(d) listing, there is ample evidence that sediment itself is also impairing designated uses as well as contributing to the DO impairment.

- The sediment data and studies illustrate excess sedimentation in Clarks Creek, the sources of sediment loading, and the impacts to aquatic life use and habitat. The sediment reduction project concluded that significant amounts of excess sediment enter Clarks Creek each year. The current, modeled average annual sediment load (673 tons/year) is over 16 times greater than the sediment load that would naturally occur (41 tons/year).
- Major sources of sediment in the Clarks Creek basin are channel instability and bank erosion.
- Even low flows can cause bedload movement, particularly in the steepest, most incised stream reaches.
- The percentage of fine sediment and sand in Clarks Creek is double to triple the percentage of fine sediment and sand found in reference streams that support a healthy aquatic community.
- While fine sediment transport is expected in a basin with glacial till in the uplands, the amount of fine sediment and sand (versus gravel) in the lowlands is double to almost triple the 90th percentile of percent fines and sand in reference basins of similar slope (37%). At two sites, Clarks-08 and Clarks-09, sand and fines make up almost 100% of the bed composition, thus requiring a 63% reduction to meet reference conditions. At the same two sites, the percentage of fine sediment (silt and clay only) is 50% to 80% greater than the 90th percentile for reference basins: 41% at Clarks-08 and 35% at Clarks-09. A 63% (or 64%) reduction in sediment is needed to meet the reference conditions.
- Benthic invertebrate assessments of Clarks Creek indicate stream health that is "poor" to "fair." Clarks Creek benthic index of biologic integrity (B-IBI) scores range between 26 (poor) to 34 (fair), indicating that macroinvertebrates are impaired. In contrast, some reference streams in the Puget Sound lowlands ecoregion, which support a healthy aquatic habitat, have B-IBI scores that range from 38 (good) to 46 (excellent).
- According to an analysis using Newcombe and Jensen's method, TSS concentrations would need to be reduced by 50% to 75% to decrease adverse impacts to fish from low levels of exposure to fine sediment.
- Fine sediments tended to have higher concentrations of total phosphorus (TP), total nitrogen (TN), biochemical oxygen demand (BOD) and total organic carbon (TOC), which add to the DO impairment. When eutrophication occurs in a water body, shifts in the benthic community can occur, such as a shift toward dipterans. Dipterans have rapid life cycles, and can dominate in the community. This type of response to nutrient-rich environments will increase the "taxa dominance" metrics, lower the "long lived taxa" metric and increase the abundance of the "tolerant taxa" metric. These three metrics (of the ten that make up the B-IBI score) deviate from the reference condition into the "poor" condition category and cause an overall decline in the B-IBI score (Plotnikoff, 2013).

The simplified conceptual model shown in Figure 45 summarizes the key contributors to the DO impairment, and the conceptual model shown in Figure 46 summarizes the key contributors to the sediment impairment. A more detailed conceptual model is provided in Appendix F. The conceptual model diagrams show the linkage between stressor sources (at the top), instream processes (middle), and impacts (at the bottom). Each pathway through the diagrams can be regarded as a risk hypothesis that describes a cause and effect relationship.

For DO, the highest loading of low DO in stormwater and oxygen demanding substances occurs during storm events. In addition, the loading that occurs during storm events contributes to DO impairments both during wet and dry conditions through the loading and accumulation of oxygen-demanding substances. The effects of elodea growth occur year-round, but have particularly strong impacts on DO during the summer months, corresponding with the dry period, when baseflow conditions exist, temperatures are at annual highs, and solar radiation is at its peak. The DO TMDL analysis addressed baseflow and stormflow conditions separately. While baseflow conditions were considered important, stormflow conditions were selected as the critical conditions for achieving the DO criterion due to the year-round and cumulative impacts of these events.

For sediment, the key stressor source is hydromodification, especially increased impervious surfaces on the landscape which increase stormwater velocity and discharge volume. This causes both increased upland sediment washoff and in-channel and streambank erosion. Much of this mobilized sediment is deposited in lower gradient reaches where it impairs habitat and becomes a source of nutrients and SOD, encourages elodea growth, and contributes to reduced DO.

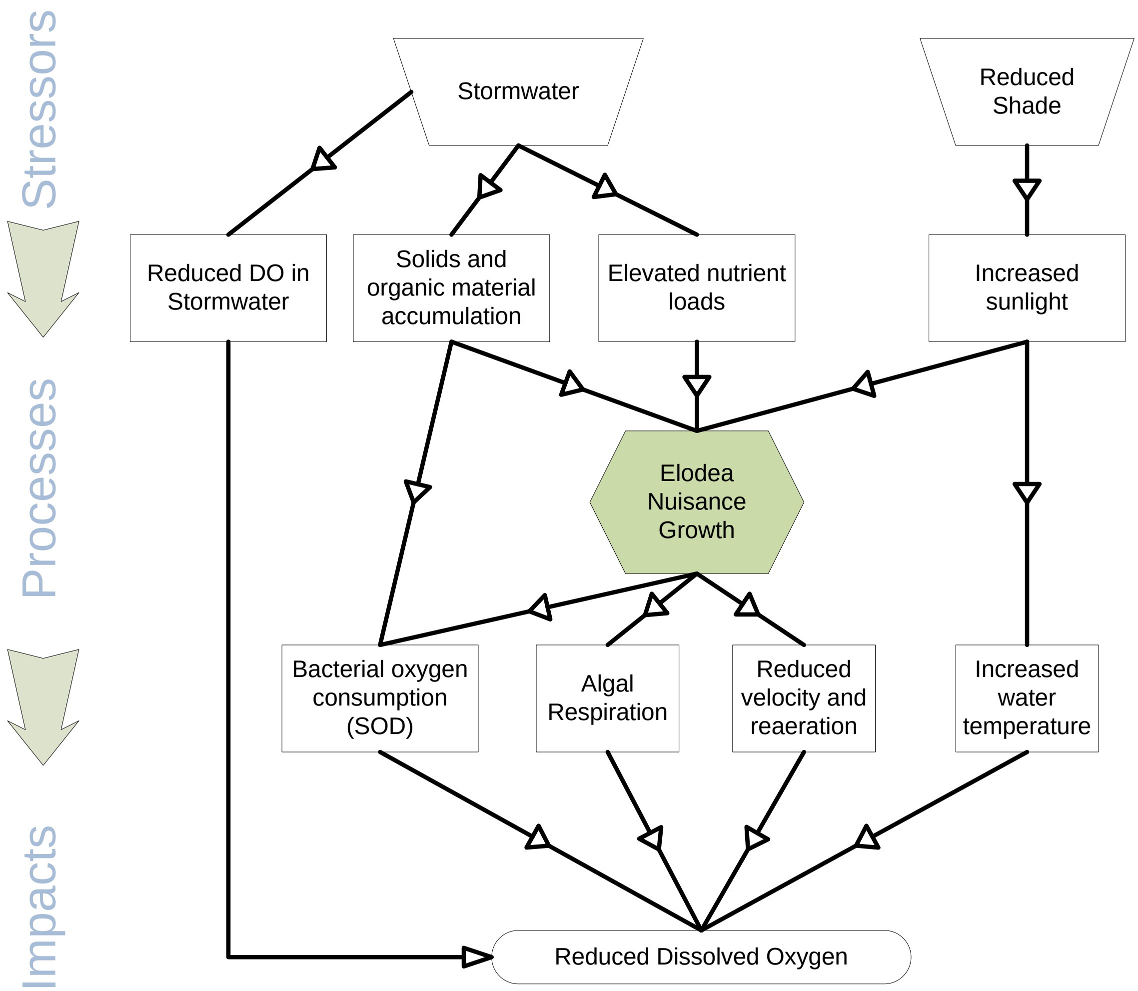

Figure 45. Conceptual Model for DO Impairment in Clarks Creek.

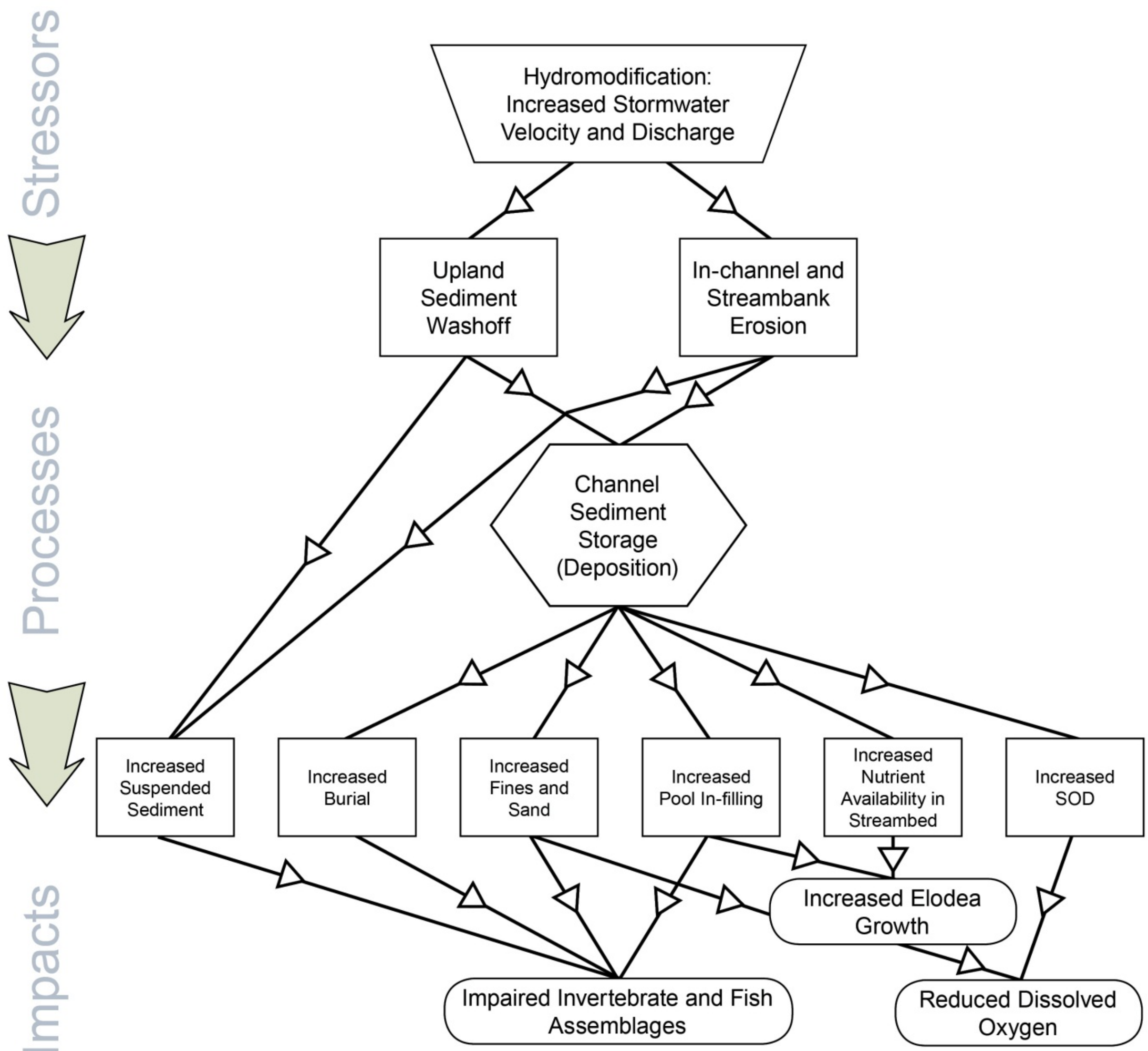

Figure 46. Conceptual Model for Sediment Impairment in Clarks Creek.

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TMDL Analysis

Dissolved oxygen

Analytical framework

The DO loading capacity and allocations are the allowable amount of loading from all sources that can deplete DO in Clarks Creek from its natural state compared to the DO water quality standard of 9.5 mg/L. This is expressed as the dissolved oxygen deficit, (DOD, see Appendix G for a detailed definition). The TMDL uses QUAL2Kw and HSPF to calculate the pollutant loads that can meet the DO and total dissolved gases criteria.

DOD is a measure of the impacts of all DO-depleting sources and also has units of mg-DO/L. It is the difference between the DO saturation concentration (DO_{sat}) and the actual DO concentration. DO_{sat} is the DO concentration that would naturally occur when DO is in equilibrium. A high DOD indicates high amounts of DO-depleting sources. A negative DOD indicates that DO concentration exceeds DO_{sat} and is supersaturated, which can occur during periods of active photosynthesis in dense algal mats. Supersaturated DO concentrations (negative DODs) can harm aquatic life when sufficiently elevated, as defined by the total dissolved gases criterion. The ideal situation is for DOD to be zero or close to zero. This would indicate the smallest deviation from the natural equilibrium level of DO_{sat}.

The loading capacity for DO is the difference between DO_{sat} (a function of temperature) and the water quality standard of 9.5 mg/L, expressed as DOD. This is the allowable amount of loading from natural conditions that is acceptable to meet applicable water quality standards that protect beneficial use. DOD allocations are the amount of loading sources can discharge and meet applicable water quality standards.

DO_{sat} varies with temperature and salinity. In Clarks Creek, temperature affects DO_{sat}. Colder temperatures result in more DO being present in water instead of going into the air. Therefore DO_{sat} concentrations are higher in cooler waters, and there is more assimilative capacity for sources to discharge oxygen-demanding substances or water already depleted in DO and still meet the water quality standard.

Like DO itself, DOD can be converted to a load by multiplying times flow:

$$DOD\ (kg/d) = (DO_{sat} - DO) \times Q\ (cfs) \times 2.447$$

DOD is useful as a common metric to look at different sources affecting DO in Clarks Creek in both the short-term and long-term. It is particularly useful for simultaneously comparing directly translatable sources, such as biochemical oxygen demand (BOD) in stormwater and indirect, long-term sources such as sediment oxygen demand (SOD).

The DOD load that meets the DO standard can be calculated for a steady-state condition using QUAL2Kw. As introduced in the Modeling Framework section, the QUAL2Kw stream water quality model was selected for the TMDL analysis. It contains detailed routines for "bottom algae" that can be used to simulate submersed macrophytes, such as elodea, when nutrient availability from the sediments is specified (Pelletier and Chapra, 2008). Descriptions of model quality assurance, calibration, validation, sensitivity, and error analysis are in Appendix B.

To calculate the TMDL, DOD concentrations and loads for individual dates were analyzed using the QUAL2Kw model, which evaluates the impact of each of the sources of DOD on the stream DO balance. Note that QUAL2Kw cannot be used to directly determine the relationship between upland pollutant loading rates and instream DO because it is a steady-state model, whereas some of the major DOD components (SOD, elodea) depend on long-term loading and accumulation of organic solids and nutrients, much of which occurs during transient storm events. Full-time series models of macrophyte growth and unsteady sediment diagenesis (including SOD) exist, but are largely experimental in nature and would require extensive data that are not currently available for Clarks Creek.

Compliance with standards

The water quality standards for Clarks Creek and its tributaries allow a minimum of 9.5 mg/L DO. Sampling shows clear evidence of DO excursions along Clarks Creek and its tributaries. Individual daytime grab sample measurements of DO have often been below the criterion throughout Clarks Creek. In addition, continuous monitoring shows frequent excursions of the criterion upstream of Tacoma Road, primarily in the early morning hours when elodea production is absent but elodea respiration is present. These morning excursions combine the effects of continuous lowering of the DO concentration (due to SOD) and increased within-day variability of DO due to excess elodea growth (which in turn is exacerbated by high nutrient concentrations and lack of shade).

Figure 47 shows the percent of DO measurements less than the 9.5 mg/L DO criterion along Clarks Creek for each station and year, based on daytime grab samples for the last two decades. High excursion frequencies prior to 1997 may be attributable to the low number of observations. Following this period, there is an increasing trend in the frequency of excursions. The years 2007 and 2008 have some of the highest frequencies of excursions, even between Maplewood Springs and the state hatchery. Figure 48 shows the percent of DO measurements less than the 9.5 mg/L DO criterion for the tributaries. Meeker Creek represents the majority of excursions among the tributaries.

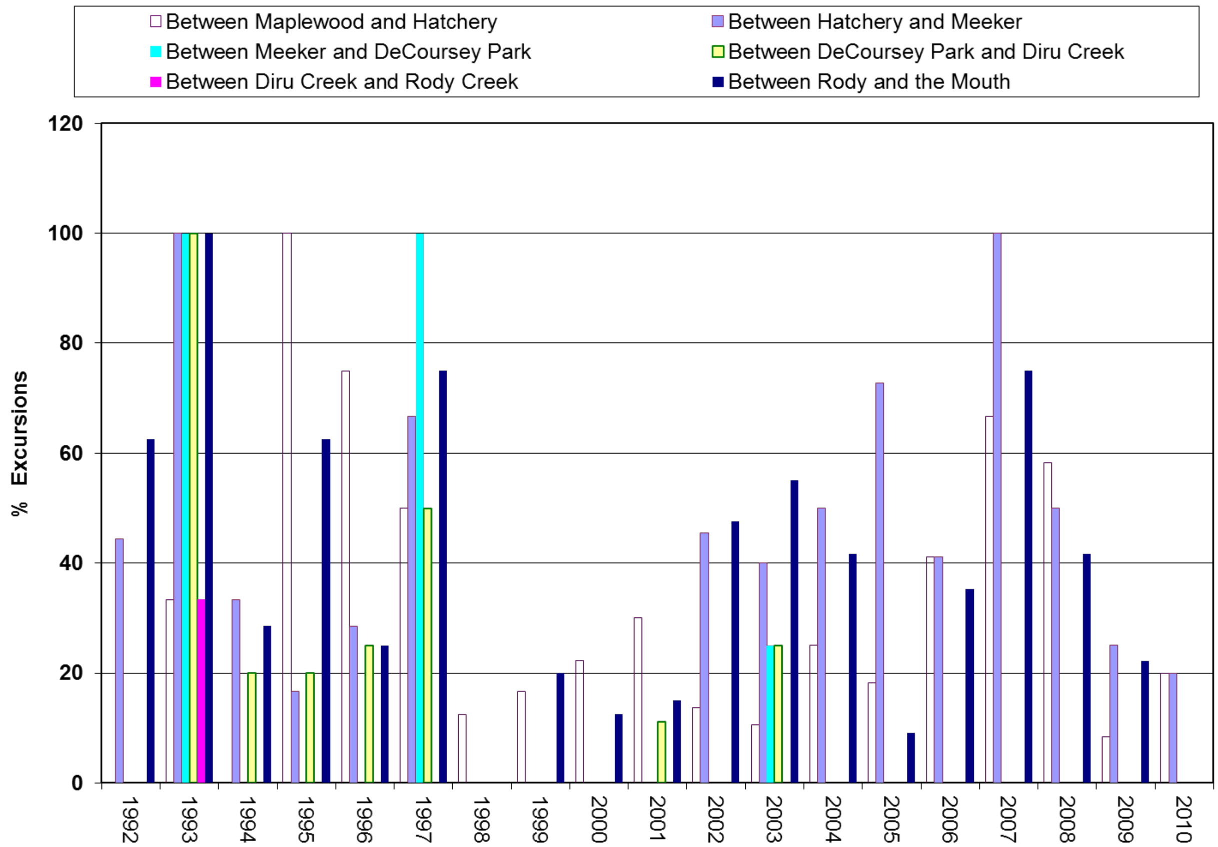

Figure 47. Frequency of Excursions of the DO Criteria in Clarks Creek (DO < 9.5 mg/L).

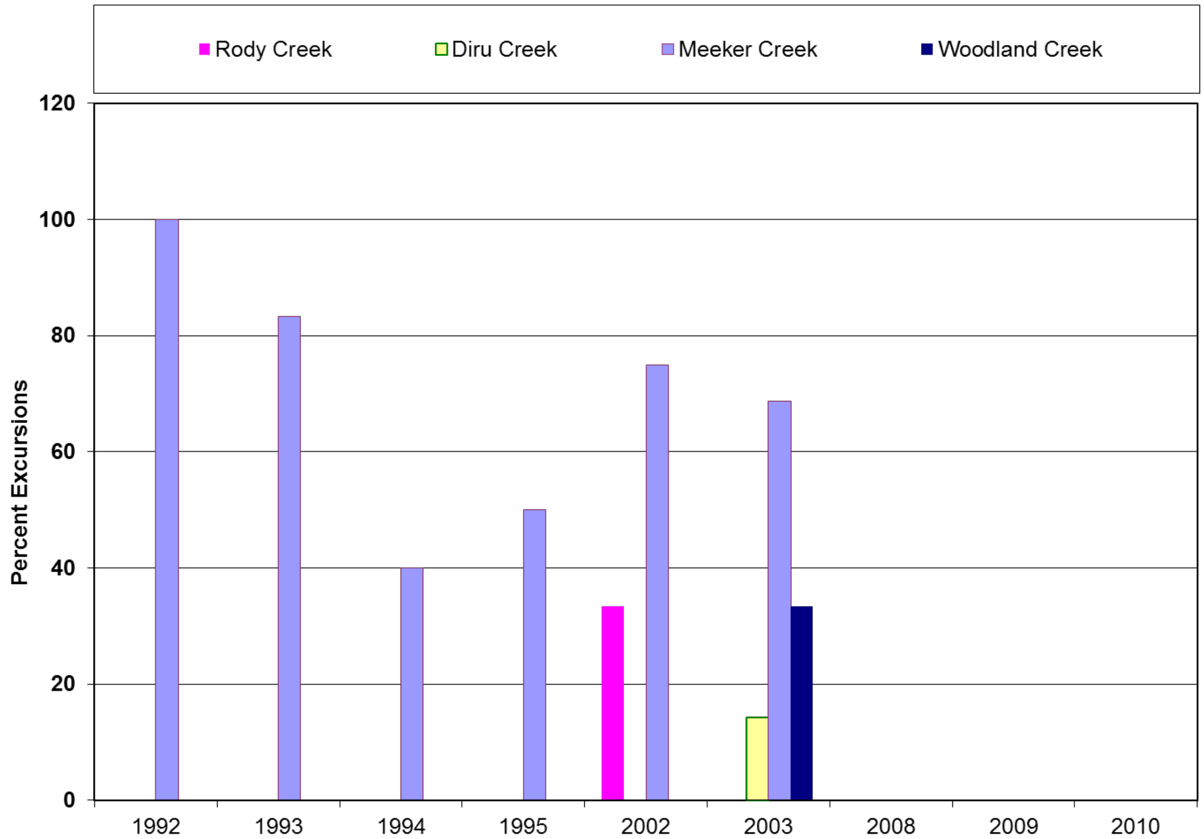

Figure 48. Frequency of Excursions of the DO Criteria in Clarks Creek Tributaries (DO < 9.5 mg/L).

For the Clarks Creek watershed, the wet season generally occurs from October through April, and the dry season occurs from May through September. Table 10 lists percent excursions of the DO criterion by season for the last five years. Excursions occur during both the wet and dry seasons across these years, which illustrate the importance of assessing compliance with the criterion year round.

Table 10. Percent DO excursions for wet and dry seasons along Clarks Creek (2006-2010)

	2006		2007		2008		2009		2010	
Reach	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Between Maplewood and hatchery	46	25	57	80	57	60	17	0	50	0
Between hatchery and Meeker	54	0	100	100	57	40	17	33	0	33
Between Rody and the Mouth	46	0	71	80	57	20	22	22	0	-

Limited data and information are available on natural background concentrations of DO in the Clarks Creek watershed. Previous studies have indicated that background concentrations are above the 9.5 mg/L DO criterion based on measurements along Clarks Creek upstream of the state hatchery (WA ECY, 2008). This location provides the least altered measurement of natural background conditions, but it may not be an accurate reflection of background conditions due to flow withdrawals and urban development within its drainage area. Therefore, natural background concentrations may be higher than 9.5 mg/L. Nonetheless, this segment provides the best available benchmark to assess whether background conditions are above the criterion, which confirms the applicability of the 9.5 mg/L DO criterion.

Water quality standards for Clarks Creek also contain criterion for total dissolved gases, which "shall not exceed 110% saturation." Daytime DO monitoring of Clarks Creek shows occasional high DO saturation levels that violate applicable water quality standards during the day when elodea and other plants undergo photosynthesis. Although low DO levels cause problems in Clarks Creek, DO saturation that is too high can also be harmful to aquatic life. As a result, elodea density levels must be reduced to address both occasional exceedances of the DO saturation water quality standards and DO levels that are too low, both of which harm aquatic life.

The relative importance of various processes affecting oxygen levels varies according to flow condition. During baseflow conditions, the relative influence of SOD and elodea respiration is greater for lowering DO levels. In contrast, during storm events, the relative influence of reduced DO in storm drainages is greater. Storm events also contribute sediment and nutrients to the system, which exacerbate DO depletion.

The calibrated QUAL2Kw model was used to assess the contributions of DOD under both dry and wet conditions (Figure 49). Under dry, baseflow conditions, DOD is derived from approximately equal contributions of internal sources (mostly SOD and elodea respiration) and tributary and groundwater sources (primarily DO below saturation inflows). Under wet conditions (Figure 49, right) the tributary sources of DOD become dominant (mostly stormwater with reduced DO).

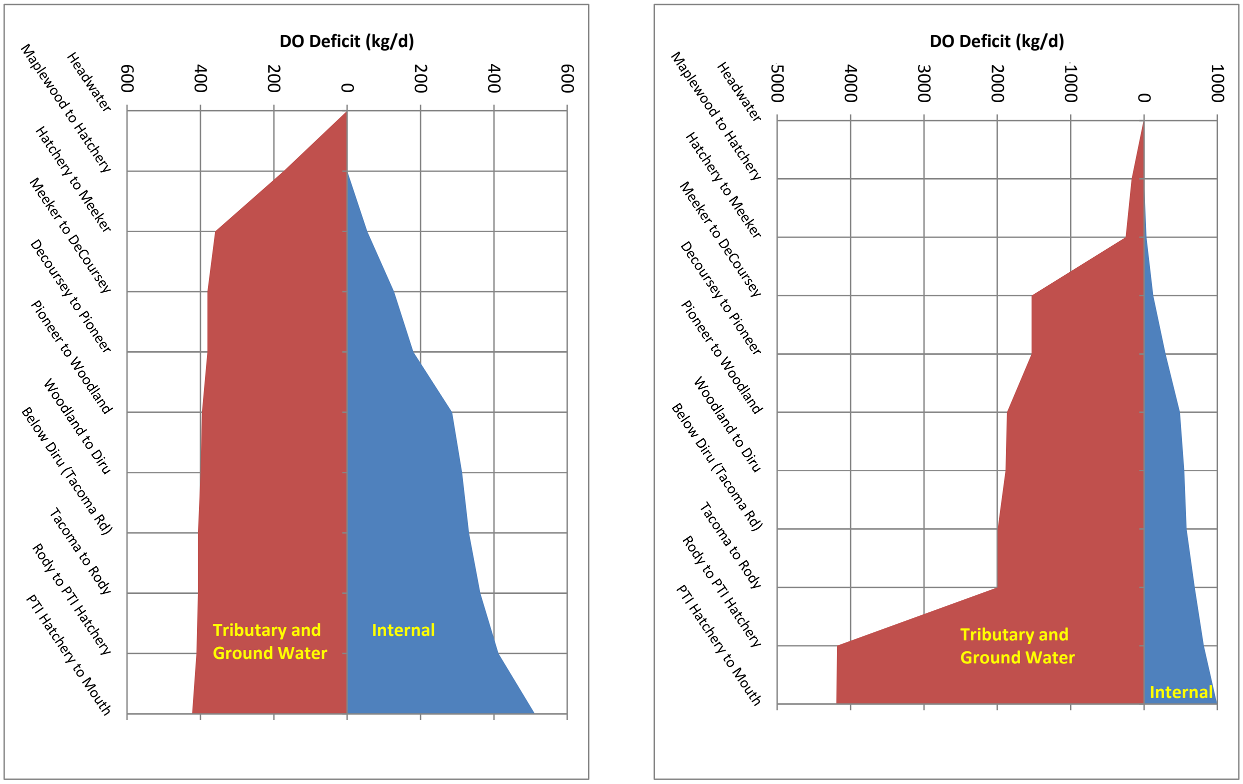

Figure 49. Longitudinal Contributions to DOD under Dry Conditions (7/10/2009, Left) and Wet Conditions (10/21/2003, Right) Estimated with the QUAL2Kw Model.

Based on the study discussion in the Conclusions section, stormflow was considered the critical condition for achieving compliance with standards, and, therefore the final loading capacity was based on this condition. Reductions in stressors were analyzed under both baseflow and stormflow conditions, and the results of these analyses are described in the following sections.

Analysis for baseflow conditions

Baseflow is the flow of the creek entering the streams from groundwater. Baseflow conditions were estimated using the steady-state (diurnal) QUAL2Kw models developed for four well-monitored summer dry-weather events in Clarks Creek, with flows around 50 cfs at Tacoma Road. The development, calibration, and application of these models are described in detail in a separate memorandum (Tetra Tech, 2011a; see Appendix B).

The water quality model was used to analyze the scale of improvement necessary to achieve both the DO and the dissolved gases criteria on four different dates. The combinations of improvements that result in the attainment of standards are referred to as "management scenarios."

The QUAL2Kw model indicates that the minimum instream DO at baseflow conditions is most sensitive to SOD, while the dissolved gases criterion is most sensitive to elodea growth rate. Meeting both criteria simultaneously requires large reductions in both SOD and elodea growth. SOD is thought to be ultimately a result of the elodea growth (see the Conceptual Model presented in Figure 45) To determine the necessary reduction in elodea growth to meet the DO and total dissolved gases criteria, the model was first adjusted to achieve the DO criterion without active elodea growth and respiration. A second application was then used to determine the level of elodea density reduction needed to meet both the DO and dissolved gases criteria during baseflow conditions. The conditions that achieve the DO criteria *without* active elodea growth and respiration are documented in Appendix B.

With these assumptions in the model, the model scenario was run to determine the level of reduction in elodea density needed to meet water quality standards for DO and total dissolved gases throughout the diurnal cycle for all four dates. The results indicated that DO and total dissolved gases criteria would be met if elodea coverage were reduced to a maximum of 33% of existing (pre-TMDL) coverage between the state hatchery and Tacoma Road, and to a maximum of 25% of existing coverage between Tacoma Road and the mouth of Clarks Creek.

Overall, the baseflow condition modeling indicated the need for a total reduction in DOD of 49%. For example, the model for July 10, 2009 requires a reduction in DOD from 933 kg/d to 475 kg/d (Figure 50). Most of this is accomplished by a reduction of 68% in the amount of DOD caused by SOD and a 27% reduction in DOD in tributary inflows (i.e., an increase in DO concentration in these inflows).

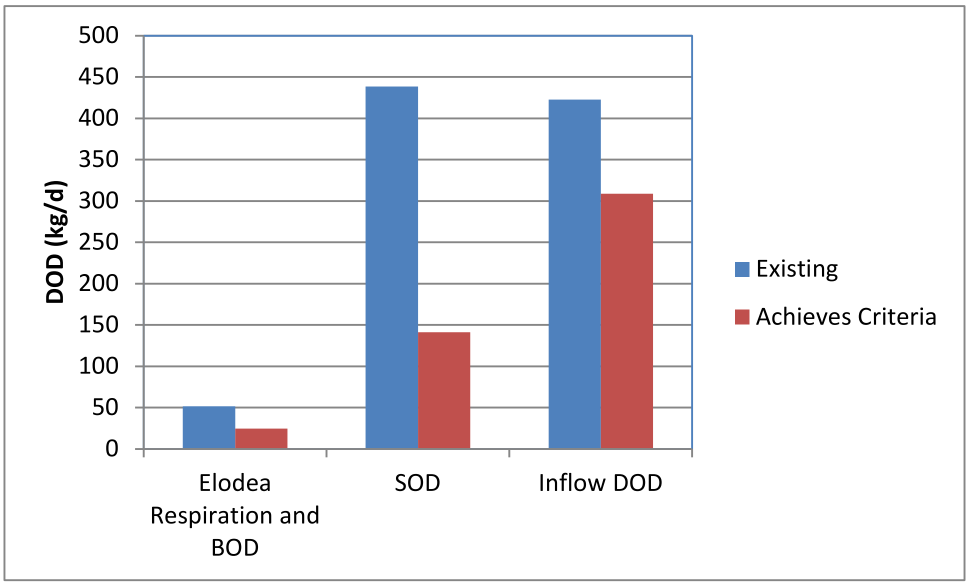

Figure 50. DOD Loads That Would Achieve DO and Dissolved Gases Criteria under Baseflow Conditions (7/10/2009).

To estimate the proportion of the DOD attributable to the state hatchery, QUAL2Kw was rerun with the hatchery flow present but the BOD and nutrient loads removed. The DOD attributed to the state hatchery was less than 1% of the total DOD under both existing and allocation conditions. Due to this small percentage, no reductions are proposed for the state hatchery. They are, however, receiving allocations in their Individual NPDES Permit.

Analysis for stormflow conditions

As shown in the simple conceptual model (Figure 45), urban runoff that occurs during stormflow conditions is a significant water quality stressor in Clarks Creek. Urban stormwater runoff contributes to nutrient and solids loading, which can lead to elodea nuisance growth and high levels of SOD, both of which are identified as major sources of DO problems in Clarks Creek.

Two calibrated QUAL2Kw model applications (for September 12, 2003 and October 21, 2003) are available for stormflow conditions, and are described in Tetra Tech (2011a) and Tetra Tech (2012c). DO was measured well below the standard during both storm events (6 mg/L and < 5 mg/L respectively), and low DO was especially pronounced on October 21, 2003, which was approximately a 2-year runoff event. More details on both storm events are provided in Appendix B. The October event was selected to represent critical conditions for achieving the DO criterion, as it represents the greatest measured impact to DO during stormflow conditions which results in DO impairment.

In addition to the data used to develop the QUAL2Kw models, DO data were collected from four stormwater conveyances during four storm events in the late fall of 2011 through the spring of 2012, as discussed in the Dissolved Oxygen section (Tetra Tech, 2012d). A DO concentration of less than 4 mg/L was measured in one stormwater outfall, and a majority of the outfall samples had average DO concentrations lower than the DO standard of 9.5 mg/L for all stations in all four storm events. Individual outfall samples ranged from 6.2 to 11.2 mg/L, with averages for all outfalls of 8.5, 7.1, 7.6, and 7.7 mg/L on 11/16/2011, 2/17/2012, 3/13/2012, and 3/29/2012, respectively. These data confirm the presence of low DO levels (and high DOD) in stormwater conveyances. The DOD in the stormwater conveyances is driven by elevated CBOD in stormwater.

Data from 2011-2012 (Tetra Tech, 2012d) also confirm the presence of high levels of nutrients, total suspended solids, and volatile suspended solids in stormwater conveyances. These results indicate that urban stormwater runoff delivers nutrients, solids, and organic materials to the system, which can increase both elodea density and SOD.

During storm runoff conditions it is reasonable to suppose that a greater fraction of tributary flow is delivered by surface rather than groundwater pathways, and could thus potentially achieve greater DO concentrations because the flow remains in contact with the atmosphere. To determine the loading capacity for DOD during stormflow conditions, the following TMDL assumptions were made in the model:

- Discharges from the mouth of Meeker Creek and Pioneer Way achieve a daily average DO concentration of 9.5 mg/L (with reduced diurnal variability of ± 0.5 mg/L).
- Diffuse inflows achieve a DO concentration of 9.5 mg/L.
- SOD is held to 2.5 mg/m^2/day.

With these assumptions, the model scenario was run to evaluate the flow reduction needed from stormwater conveyances to meet DO criteria for both the critical storm event on October 21, 2003 as well as additional event on September 12, 2003. Based on QUAL2Kw model runs, if the flow volume from the Meeker Creek, 7th Avenue, and Pioneer Way storm drains, and Rody, Diru, and Woodland Creeks is reduced by 50%, the DO standard is predicted to be met for both the September and October 2003 storm events. Note that SOD, which arises from bacterial and fungal decomposition processes, is likely to be naturally reduced during high flow events when turbulent flow disturbs the biofilm at the sediment-water interface.

The changes that result in attainment of both the DO and dissolved gases criteria also reduce total DOD from 5,189 to 719 kg/d (Figure 51). These conditions are achieved through a 50% reduction of stormwater volume (flow from 138 to 69 cfs) or treatment of 50% of untreated stormwater. Note that net elodea respiration increases slightly under this scenario, despite reduced elodea coverage, due to the greater water velocity that occurs with the reduction of elodea biomass.

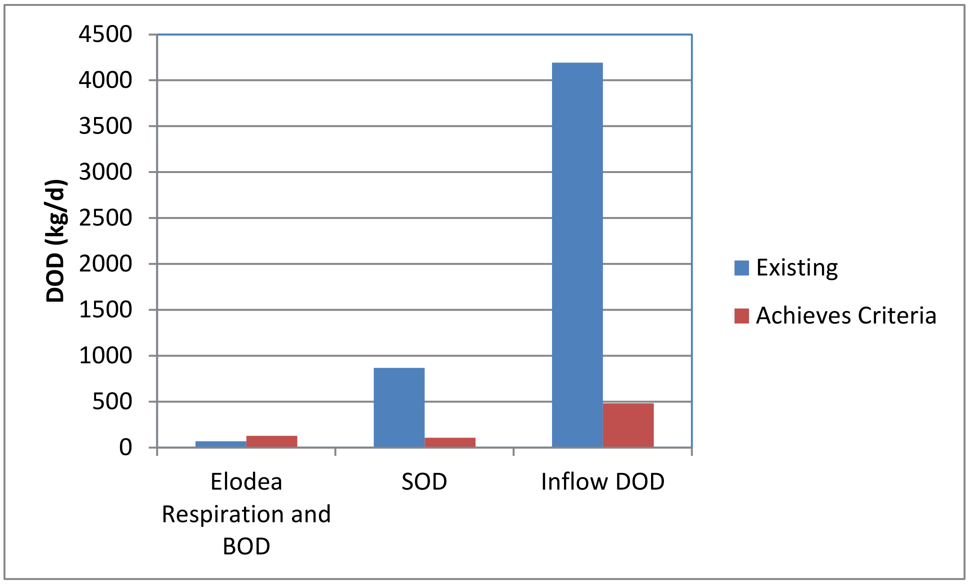

Figure 51. DOD Loads That Would Achieve DO and Dissolved Gases Criteria under Wet Conditions (event of 10/21/2003).

Loading capacity

As explained in the DOD section, the loading capacity (LC) for DO is the load of DOD that achieves the DO and total dissolved gases criteria. For DO, the LC can be determined by calculating the DOD (DO_{sat} – 9.5) (or zero if the temperature rises to a point at which DO_{sat} becomes less than 9.5). The DO saturation concentration, and thus the LC, varies as a function of temperature and salinity (Figure 52). For total dissolved gases, the LC is equivalent to conditions under 110% DO saturation.

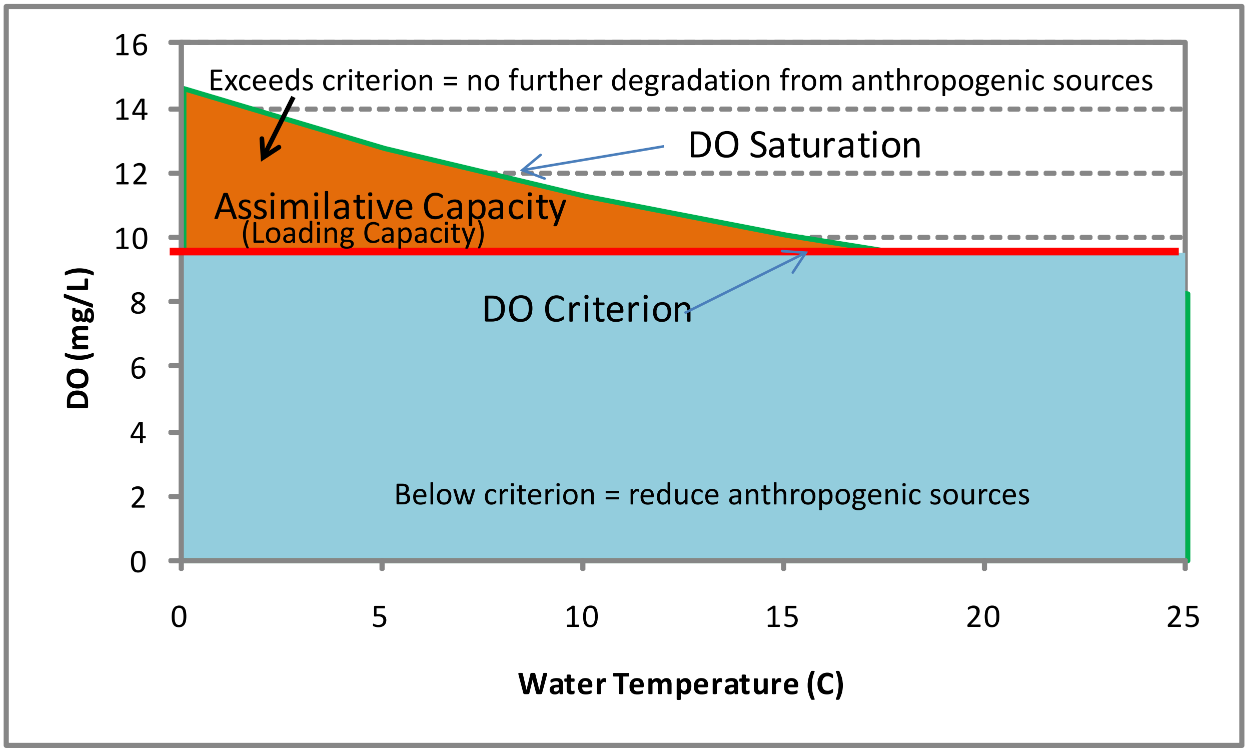

Figure 52. Loading Capacity as a Function of DO Saturation

DOD can be expressed in mass per time units (e.g., kg of DOD per day), and is therefore an appropriate quantitative expression of a TMDL. For any given temperature condition, the TMDL is equal to the LC. As explained in the Compliance with Standards section, the LC during the critical storm event (10/21/2003) is a DOD of 719 kg/d, which is estimated to be achieved through a 50% reduction of stormwater volume or treatment of 50% of untreated stormwater. These conditions are also estimated to achieve compliance with the total dissolved gases criterion as documented in the Analysis for Stormflow Conditions section and Appendix B.

Sediment

Analytical framework

Sediment monitoring and modeling in the Clarks Creek basin indicates that existing development has substantially altered the natural hydrology and sediment dynamics of Clarks Creek, leading to increased peak flows, increased sediment load, degradation of upland stream reaches, and aggradation of reaches in the alluvial plain (Tetra Tech, 2012a; Brown and Caldwell, 2013). Because both suspended and bedded, in-channel sediment sources have been identified as causing impairments, the existing turbidity water quality standard (or an associated TSS concentration) would not be appropriate as an in-stream target because it would not reflect the full range of sediment processes that are impacting the system. Both turbidity and TSS measure the amount of suspended particulates in the water column and, therefore, do not account for heavier sediments that settle out more quickly and sand and gravel transport, which occur along the stream bed.

To reflect the dynamic transport mechanisms that are occurring in Clarks Creek, the loading capacity for sediment is derived from the total sediment load predicted by the HSPF model. The HSPF model has the capability to simulate a variety of processes related to sediment and solids transport. On pervious and impervious upland areas the model simulates the build-up and wash-off of sediment resulting from human influences, naturally occurring land cover, and rainfall. Within the stream network, the model simulates the sediment mass balances in both the water column and stream bed. Solids in the stream are subject to advection, settling, and scour from the stream bed and bank.

While the model provides a reasonable description of the processes contributing to sediment load and transport within the creek, it is based on limited observations of flow and TSS. No small-scale monitoring has been conducted to estimate loads from individual land use areas. The limited TSS concentration data reduces the ability of the model to produce a reliable TSS simulation when such low levels of TSS are present and potentially cause impairment. While field data for water quality, sediment quality, and geomorphic analysis is limited, there is enough data to develop a reasonable loading capacity for the TMDL.

Model application

Two models were used in the simulation of sediment and sedimentation effects. The HSPF model, a dynamic flow and water quality model, was used to simulate flow and sediment loading in the Clarks Creek basin. The QUAL2Kw stream water quality model was used to determine the DO mass balance. A factor in the DO mass balance is SOD, which is increased by sedimentation. The following section discusses the application of both models in the determination of the sediment TMDL.

HSPF model

The Clarks Creek HSPF model was used to simulate an overall sediment balance, which identified upland sediment loads as the main contributor of sediment to the Puyallup River. In addition to a current conditions simulation, a natural conditions and a build-out scenario were simulated utilizing the model. The natural conditions model scenario demonstrated that current sediment loads are much larger than would be expected under natural conditions. Both upland loads and channel erosion are predicted to have increased. However, some erosion of the channel in the steepest segments of the glacial till would be expected even under natural conditions (Tetra Tech, 2012a).

Table 11 provides the simulated total sediment loads for all three scenarios at 66th Avenue. To determine loading capacity, the simulated sediment load at 66th Avenue was chosen, as opposed to the load at the mouth of the creek, because loads tend to decline downstream of 66th Avenue due to additional settling. Use of the sediment load at the mouth would inaccurately represent the amount of sediment that is contributing to the impairment in Clarks Creek.

Table 11. Average Annual Simulated Sediment Load in Clarks Creek at 66th Avenue.

	Model Scenario	Clarks Creek at 66th Avenue
Average Annual Sediment Load (tons/year)	Current Condition	580
	Natural Condition	140
	Buildout Scenario	640

The current and buildout scenarios show similar loads due to the simulation of future BMPs that will be required under the proposed general permit. The natural, forested condition estimates much less sediment loading at 66th Avenue (140 tons/year), so a return to natural conditions would require a sediment reduction of 76% percent relative to current conditions.

QUAL2Kw model

The QUAL2Kw model analyzed SOD in conjunction with the density of elodea, and provides one of the lines of evidence that a reduction in sediment loads would reduce the SOD and improve conditions in the creek. Model runs suggest that the total effective SOD (representing demand from both the sediment surface and from within the elodea mats) needed to be reduced by approximately 60%, while the density of elodea (below Tacoma Rd.) needed to be reduced to 25 percent of the current density compared to 2003 levels (Tetra Tech, 2011a). The stormwater load reduction required to meet these scenarios is utilized as a line of evidence in the determination of the loading capacity for sediment.

Compliance with standards

Ecology developed water quality criteria for turbidity and has begun to include bioassessment data in water-body impairment assessments. Other numeric water quality parameters relating to sediment impairments have not been established. To provide a target that is more reflective of the stream processes and because of the complex dynamics of sediment transport in streams and Clarks Creek, the applicable narrative water quality standards in WAC 173-201A-260(2) was used. Biological assessment measures the integrity of an assemblage of species, incorporating the synergistic effects of multiple stressors on the biota. The collection of species at a given site will be a reflection of the types of conditions the site has been exposed to. Biological assessment can be used to detect the response of resident biotic communities to alterations to the physical habitat resulting from sedimentation from stormwater runoff and physical habitat alterations from dredging, filling, and channelization. In-channel impairments are generally determined through bedload characteristics, while fine upland sediment load can be characterized by both suspended sediment analysis and bedload characteristics. Because both the in-channel and upland sediment sources identified in Clarks Creek basin need to be accounted for, a total sediment load reduction has been identified as a target for water quality improvements. The target to protect designated uses from sediment impairment is a 64% reduction in sediment loading based on comparing the current percentage of fines and sands to those in Puget Sound lowland reference streams that support a healthy fish habitat.

The reduction in sediment loading will also help achieve compliance with DO standards and improve the benthic macroinvertebrate community. The following section discusses all benefits in more detail.

Sediment composition and chemistry

As part of sampling in support of the PTI Sediment Reduction Action Plan, sediment chemistry and grain size analysis was conducted at twenty locations in the Clarks Creek basin. The percentage of fines and sand in mainstem sediment samples increases drastically as the topography and hydrology change from steep slopes to flat lowlands which also coincides with the convergence of Clarks Creek basin's tributaries. Fines and sands impact fish health in Clarks Creek by clogging the interstitial spaces at the bottom of the stream where eggs are laid. The spawning capacity of Clarks Creek is exceeded as gravel substrate is limited to about a 1,600 lineal foot reach below the state hatchery. Downstream reaches are dominated by relatively more fines. A superimposition of redds occurs in this reach, as there are more fish than available substrate to spawn. Coarse and fine sands can also be found in this reach. The primary mechanisms of impact are through increased egg mortality, reduced egg hatch, and a reduction in the successful emergence of larvae. The cause of egg survival rates and egg death are due to reduced permeability of the streambed and from burial by settled particles. Thin coverings (a few mm) of fine particles are believed to disrupt the normal exchange of gases and metabolic wastes between the egg and water. Even if intergravel flow is adequate for embryo development, sand that plugs the interstitial areas near the surface of the stream bed can prevent alevins from emerging from the gravel (Weaver and Fraley, 1993).

Bedded sediments impact the density, diversity, and structure of invertebrate communities as well. Permanent changes in community structure may occur if the sedimentation effects are elevated and sustained. Direct effects on invertebrates include abrasion, clogging of filtration mechanisms that interfere with ingestion and respiration, and potentially smothering and burial, resulting in mortality. Indirect effects are caused primarily from light attenuation leading to changes in feeding efficiency, behavior (i.e., drift and avoidance), and alteration of habitat from changes in substrate composition, affecting the distribution of infaunal and epibenthic species. Sedimentation alters the structure of the invertebrate community by causing a shift in proportions from one functional group to another as well (Staver 1996; Jha 2003; and Griffiths et al 1978).

Similarly, the Clear/Clarks Creek Basin Plan (Pierce County 2006) further discusses the harms to aquatic life caused by excess sediments in the basin:

> *"The sediments increase the turbidity of the water, reduce light and harm the aquatic life by smothering eggs and benthic creatures and filling in spaces between rocks that could have been used as habitat for aquatic organisms. A significant reduction in light penetration can result in lower release of oxygen into the water. Fine particulates can clog or damage sensitive gill structures in fish, decrease their resistance to disease, prevent proper egg development, and interfere with feeding activities. Sediments also carry nutrients into the stream system increasing vegetation growth, especially invasive vegetation. Sediments clog stream channels and fill reservoirs. The increased intensity of floods due to channels clogged with sediments often leads to more pollutants entering the streams as waters over flow their banks. (p. 4-60)"*

Clarks Creek-09, the sediment sampling site closest to 66th Avenue, has the highest percentage of fine sediments and sands (100%), likely due to physical features that cause high amounts of sediment deposition. In contrast, the 90th percentile of Puget Sound lowland reference stream values, which reflect a healthy stream habitat, for percentage of fine sediments and sands is 36%. Therefore, the percentage of sands and fines that would need to be reduced from current conditions is 64%.

The TMDL sets a 64% reduction in overall sediment loading corresponding to the 64% reduction in percent fines and sands needed to meet Puget Sound lowland stream reference conditions that support a healthy aquatic environment. In the mainstem of the Clarks Creek, sediment composition averages roughly 65% fines and sands at 10 sites. Tributaries to Clarks Creek have fines and sands that range from 28%-48%. In addition, TP, BOD, nitrogen, and TOC are higher in samples with higher percentages of fines (see Appendix I, in *Clarks Creek Sediment Reduction Action Plan*, “Geomorphic Assessment and Sediment Analysis”). Since fines and sands comprise the bulk of the sediment composition, particularly in the mainstem Clarks Creek, and since fines and sands are the primary sediment size that harms fish and aquatic life use, reducing 64% of the sediment load will also reduce 64% of fines and sand.

Biological integrity and aquatic use support

Benthic invertebrate assessments conducted on Clarks Creek by Pierce County and PTI between 2001 and 2010 show a range of scores between 26 (poor) to 34 (fair). As a comparison, reference locations in the Puget Sound lowlands have B-IBI scores ranging from 38 (good) to 46 (excellent). B-IBI scores have been calculated for two of the tributaries, Rody and Diru Creeks, and are between 18 and 25 (poor). The multi-metric assessment may indicate impairments from sediment in addition to the 303(d) listed parameters of DO and pH, in addition to other water chemistry or physical habitat parameters.

Suspended sediment and turbidity in the water column

Measured turbidity and TSS concentrations and modeled TSS concentrations based on the observed data were analyzed to indicate the level of impairment caused by suspended sediments in Clarks Creek and its tributaries. There were limited reference data for suspended sediment in the Puget Sound lowland. The modeled TSS concentrations at 66th Avenue, from the HSPF model, were used to calculate a biological response to suspended sediments severity score, according to Newcombe and Jensen’s methods. While suspended data were limited, the results indicated that a sediment load reduction between 50% and 75% was necessary to reduce the adverse impacts of suspended sediment to aquatic life and habitat. This reduction would reduce the impact from moderate habitat degradation and physiological stress to minor physiological stress and short term reduction in feeding success. A more detailed analysis is presented in the Total Suspended Solids section.

Benefits to compliance with DO standard

Fine sediments tended to have higher concentrations of TP, TN, BOD and TOC that also contribute to the DO impairment. Of the chemistry samples collected on Clarks Creek, TP, TN, and BOD concentrations were highest in the sediment composite at Clarks-08, located off of Tacoma Road. The grain size distribution analysis at Clarks-08 showed that gravel characterized less than 1% of the composite. The majority of sediment was classified as fine sand and very coarse silt. The highest percent TOC in sediments was found at Clarks-05 near the Clarks Creek Park south entrance parking lot. Also at Clarks-05 there is an increase in silt and clay content. This is likely attributed to the change in hydraulic characteristics. Downstream of the site, Clarks Creek widens and the slope decreases as it enters the Puyallup River Valley. In addition, elodea growth starts approximately 200 feet upstream of this site. Clarks-05 and Clarks-08 were two of the three sites where percent fines were greater than 25% of the grain size distribution. Clarks-09, the next site downstream of Clarks-08, had similar results.

As discussed in the Analysis for Stormflow Conditions Section, the QUAL2Kw model of DO dynamics in Clarks Creek analyzed SOD in conjunction with the density of elodea. Model runs suggested that the total effective SOD (representing demand from both the sediment surface and from within the elodea mats) needed to be reduced from 8 gm- $O_2/m^2/d$ to 2.5 gm- $O_2/m^2/d$, while the density of elodea (below Tacoma Rd.) needed to be reduced to 25 percent of the current density (Tetra Tech, 2011). The SOD here is called an "effective rate" because it accounts for true sediment interface demand and also the demand exerted by dead matter and detritovores within the elodea mats (exclusive of the respiration of the elodea itself). The HydrO2 study put the true SOD, at sites without elodea mats, at around 2 gm- $O_2/m^2/d$ (HydrO2, Inc., 2011). Therefore, 6 gm- $O_2/m^2/d$ are associated with the elodea mats. Assuming that the 75 percent reduction in elodea density results in a similar reduction in the effective SOD rate within the elodea mats, this 6 $g/m^2/d$ portion would be reduced to 1.5 gm- $O_2/m^2/d$. The remaining net effective SOD would then be 1.5 + 2 = 3.5 gm- $O_2/m^2/d$. Reducing the true sediment SOD rate by 50%, from 2 to 1, would then meet the desired target effective rate of 2.5 gm- $O_2/m^2/d$. A 50% reduction in the true SOD rate is likely to be met by a 50 percent reduction in sediment load.

Achievability of load reduction

The PTI grant-funded analysis has identified priority sources based on the hot spots and potential projects to reduce the sediment load in the basin by about 50 percent. The projects identified are estimated to mitigate channel bank erosion problems and are projected to restore a more natural balance to the sediment transport system.

As discussed in the Model Application section, the HSPF model also provided sediment-loading results based on current, natural, and build-out scenarios. The average annual sediment loading from the model represents both the in-channel and suspended-bedload transport in the basin. Attaining the natural conditions would require up to a 76 percent reduction in existing sediment loads; however, it is likely that uses can be fully supported with somewhat smaller reductions. The results of the PTI and Brown and Caldwell studies indicate that if identified sediment reduction opportunities (hot spots and potential projects) were implemented, a sediment reduction of 390 tons/year could be achieved.

Summary

The sediment reduction needed to protect designated uses for sediment is a 64% reduction in sediment loading, based on the reduction in percent fines and sands needed to meet Puget Sound lowland stream reference conditions that support a healthy aquatic environment (Sediment Composition and Chemistry section). This percent reduction falls within range of several additional lines of evidence discussed previously. The Newcombe and Jensen assessment results suggested that a 50% to 75% reduction in suspended sediment was necessary to reduce suspended sediment impacts to aquatic life. Furthermore, achieving the 64% sediment reduction target would address the SOD target of 50% for DO impairment.

Loading capacity

The loading capacity of the stream is set at 209 tons/year or .57 tons/day, based on a 64% reduction of the current conditions simulated sediment load (580 tons/year or 1.59 tons/day) at Clark Creek at 66th Avenue (monitoring station CLK-4) estimated by HSPF modeling (Tetra Tech, 2012a).

This loading capacity is expected to meet designated uses because; 1) it is equivalent to the reduction necessary in percent sand and fines to meet reference conditions; 2) it is expected that aquatic life will respond beneficially to the sediment reductions (Newcombe, 1996); and 3) the reduction will result in a long-term average flow weighted TSS concentration of about 2 mg/L, which is similar to TSS concentrations in reference Puget lowland systems.

Load and Wasteload Allocations

Wasteload allocations

The entire watershed (with the exception of private property that drains directly to the streams) is subject to MS4 permits for stormwater, held by the city of Puyallup (Permit No. WAR04-5017), Pierce County (Permit No. WAR04-4002), and WSDOT (Permit No. WAR04-3000A). Most of the stormwater impacting Clarks Creek is subject to MS4 permits, and thus receives wasteload allocations (WLAs). However, stormflows that do not discharge through organized surface drainages (primarily wash off from properties adjacent to Clarks Creek) are not covered by the MS4 permits and therefore receive load allocations (LAs). Although the two tribal hatcheries are exempt from permit requirements based on their size and production, both tribal hatcheries receive LAs.

Additional permitted point sources that discharge to Clarks Creek include the state hatchery (Permit No. WA0039748), Ecology's *Construction Stormwater General Permit* discharges (e.g. Lakes Development Stormwater Construction Permit), and discharges associated with Ecology's *Industrial Stormwater General Permit* and Ecology's *Sand and Gravel General Permit*.

There is currently one facility covered under Ecology's *Sand and Gravel General Permit*. The DMR data available for the Northwest Cascade – Canyon Rim Estates Sand and Gravel Permit (Permit # WAG501040) indicates that no surface water discharges have occurred at the facility since the facility began operating in October 2010. Based on this, the facility is considered an insignificant source of pollution in the basin and a narrative wasteload allocation is applicable. If this facility continues to comply with the terms and conditions applied in the Sand and Gravel Permit and specifically in Permit Number WAG501040, then the facility is in compliance with its wasteload allocation and the TMDL.

New *Sand and Gravel General Permit* facilities that propose to discharge to a segment of a water body on the current EPA-approved 303(d) list or an approved TMDL for turbidity or fine sediment must conduct turbidity monitoring in accordance with an Ecology-approved monitoring plan. The plan includes receiving water monitoring to demonstrate the discharge does not cause or contribute to the impairment and will meet wasteload allocations set aside for future growth. The applicant/permittee must contact Ecology before developing a monitoring plan.

There are currently no *Industrial Stormwater General Permits* discharging to Clarks Creek in the watershed. New and future facilities must meet the conditions outlined in the *Industrial Stormwater General Permit condition S6.B*.

B. Limits on Coverage for New Discharges to TMDL or 303(d)-listed Waters
Facilities that meet the definition of "new discharger" and discharge to a 303(d) listed water body are not eligible for coverage under this permit unless the facility:

1. Prevents all exposure to stormwater of the pollutant(s) for which the water body is impaired, and retains documentation of procedures taken to prevent exposure onsite with its SWPPP; or

2. Documents that the pollutant(s) for which the water body is impaired is not present at the facility, and retains documentation of this finding with the SWPPP; or

3. Provides Ecology with data to support a showing that the discharge is not expected to cause or contribute to an exceedance of a water quality standard, and retain such data onsite with its SWPPP. The facility must provide data and other technical information to Ecology sufficient to demonstrate:

- *a. For discharges to waters without an EPA approved or established TMDL, that the discharge of the pollutant for which the water is impaired will meet in-stream water quality criteria at the point of discharge to the water body; or*
- *b. For discharges to waters with an EPA approved or established TMDL, that there are sufficient remaining wasteload allocations in an EPA approved or established TMDL to allow industrial stormwater discharge and that existing dischargers to the water body are subject to compliance schedules designed to bring the water body into attainment with water quality standards.*

Facilities are eligible for coverage under this permit if Ecology issues permit coverage based upon an affirmative determination that the discharge will not cause or contribute to the existing impairment.

The construction stormwater general permit discharges will receive a WLA as part of the Sediment TMDL.

Load allocations

Figure 53 is a diagram of the watershed that shows the locations where the allocations apply for both DOD and sediment. The following sections establish the allocations, seasonal variation, and reserve capacity for growth, separately, for each TMDL.

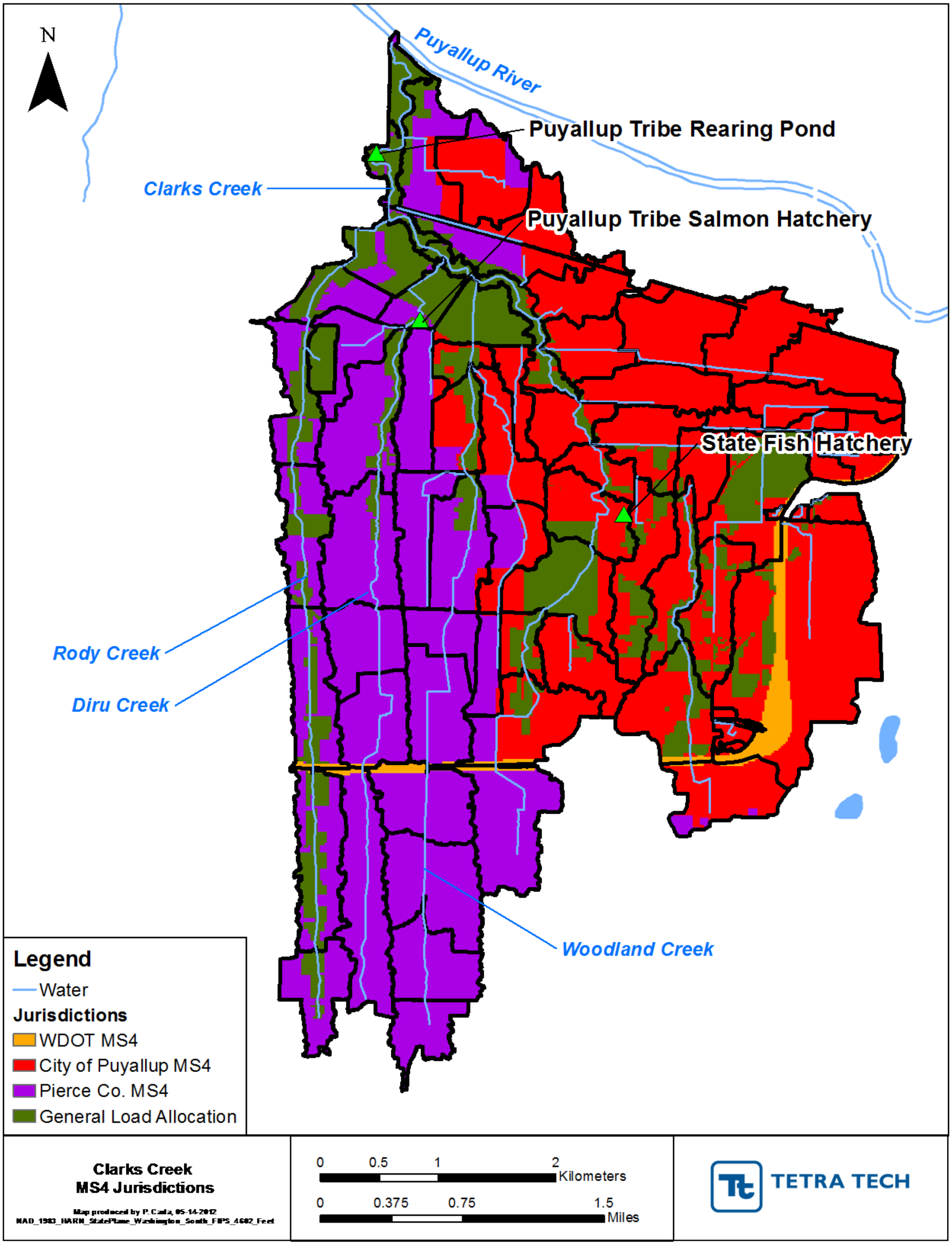

Figure 53. Clarks Creek Allocations by Jurisdiction

Dissolved oxygen deficit (DOD)

Load and WLAs are expressed using DOD to describe the impacts of oxygen-demanding sources in Clarks Creek. Existing discharges from the state hatchery were determined to contribute less than 1% of the DOD loading. Because this appears to be a *de minimis* source of DOD in Clarks Creek, no reductions are required. Instead, the TMDL allocations for this source require maintenance of current loading rates (or better) of Carbonaceous biochemical oxygen demand (CBOD), Nitrogenous biochemical oxygen demand (NBOD), and nutrients that ultimately contribute to DOD.

Responsibility for achieving the overall DOD allocations is assigned to the three MS4 permittees and the state hatchery (WLA), to other stormwater sources and the Tribal hatcheries (LA) based on the relative amount of stormwater runoff contributed by each source. As noted previously, the loading capacity expressed in DOD, and the WLAs and LAs that make up the TMDL, vary as a function of temperature as well as flow. The TMDL allocations, after accounting for the allocations to the hatcheries, are apportioned based on the fraction of annual surface runoff derived from each jurisdictional area. These fractions were determined using the HSPF watershed model (Appendix B, C; Tetra Tech, 2012a), and were used to analyze the distribution of flow during the wet weather event on October 21, 2003, defined as the *critical condition*. The resulting DOD allocation fractions are presented in Table 12. Table 13 presents the resulting allocations for the critical condition event.

Table 12. Fractions of Stormwater Flow by Source During 10/21/2003 Critical Event

Total Flow	WLA: City of Puyallup MS4	WLA: Pierce County MS4	WLA: WSDOT MS4	LA: Properties adjacent to creek
100%	46%	38%	3%	13%

Table 13. Allocations Expressed as DOD (kg/d)

	DOD (kg/d)
TMDL (kg/d) = WLA + LA + MOS	**719**
Total WLA (kg/d) +	**625**
*WLA: State hatchery**	24
WLA: City of Puyallup MS4	318
WLA: Pierce County MS4	263
WLA: WSDOT	21
Total LA (kg/d)	**94**
LA: Properties adjacent to creek	90
LA: Diru Creek Tribal Hatchery	2.4**
LA: Clarks Creek Tribal hatchery	1.6***

	DOD (kg/d)
MOS (kg/d)	*implicit*

+Due to rounding, the WLAs add up to 626 kg/day.
*This translates to a CBOD-5 of 47.7 kg/day.
**This translates to a CBOD-5 of 4.56 kg/day.
***This translates to a CBOD-5 of 3.04 kg/day.

Stormwater implementation targets for DOD

DOD provides a quantitative summary of the TMDL in units of mass per time, as required by the TMDL regulations. DOD does not, however, provide a feasible basis for planning implementation due to the complex pathways that give rise to instream conditions. The conditions that will support designated uses include (1) reduction in SOD, (2) control of elodea density, and (3) maintenance of DO concentrations in tributary inflow. These factors are interrelated with one another, as explained under the data review discussion and simplified conceptual model. Model simulations were used to quantify implementation targets for these conditions that would result in attaining the applicable water quality standards.

The relative importance of various processes affecting DO varies according to flow condition. During baseflow conditions (7/10/2009), the relative influence of internal sources of DOD (SOD and elodea respiration) is greater. During storm events (10/21/2003), the relative influence of reduced DO in storm drainage is greater. The pathways that appear to be of greatest importance lead back to pollutants in urban stormwater (plus lack of riparian cover) as the primary stressor source. Therefore, implementation will need to have a focus on controlling untreated urban runoff, which is best expressed through implementation targets related to stormwater flows. In addition, achieving the desired reductions in SOD and elodea density will likely require reduced flows and associated sedimentation in downstream reaches, and increased riparian shading to limit elodea growth potential. The following sections summarize actions which when implemented together are assumed to meet the DO TMDL, including; 1) reduction in untreated stormwater flow; 2) control of elodea density; and; 3) riparian shading.

Reduction of untreated stormwater flow

Stormwater contributes to impairment in Clarks Creek in several ways. First, stormwater conveyances in the lower watershed have low DO (due to consumption of oxygen within the conveyances), which depresses DO levels in Clarks Creek. Second, stormwater is a source of sediment and nutrient loads that support elodea growth. Finally, stormwater flows contribute to channel instability and sedimentation problems that further enhance elodea growth.

The QUAL2Kw modeling showed that a 50% reduction of stormwater volume or treatment of 50% of untreated stormwater would result in attaining the water quality standard of 9.5 mg/L throughout the watershed. This reduction would support water quality standards directly by reducing the DOD contributed by stormwater inflow, and indirectly by reducing pollutant and sediment loads. Therefore, the implementation target is expressed as a reduction in *untreated* volume. As described in the following paragraph, the modeling identified the event of 10/21/2003 as representing critical conditions for stormwater-induced excursions of the DO criteria. Therefore, a 50% reduction or treatment in the volume of untreated stormwater from the 10/21/2003 event is an appropriate implementation target.

The 50% reduction of stormwater volume or treatment of 50% of untreated stormwater may be achieved either by a direct reduction in storm runoff volume or by converting volume from untreated to treated status. The draft Western Washington Hydrology Manual (Volume 5, Section 3.5) presents a basic treatment menu (BTM) that applies to most projects and presents a variety of best management practices (BMP) facility designs. These designs are derived to be consistent with a performance goal, as the BTM facility choices "are intended to achieve 80% removal of total suspended solids for influent concentrations that are greater than 100 mg/L, but less than 200 mg/L. For influent concentrations greater than 200 mg/L, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/L, the facilities are intended to achieve an effluent goal of 20 mg/L total suspended solids. The performance goal applies to the water quality design storm volume or flow rate, whichever is applicable." The BTM provides a baseline for evaluating whether a stormwater BMP performs well enough to achieve the desired "reduction in the volume of untreated stormwater." Facilities that are designed consistent with the BTM are automatically assumed to meet the TMDL volume reduction or treatment allocation requirement, as is further discussed in the Implementation section.

Selection of critical storm event

The analysis supporting the 50% reduction or treatment of untreated stormwater flow volume relied on model application to two well-monitored storm events: 9/12/2003 and 10/21/2003. Both storm events were evaluated to assess the representativeness of these storm events and to verify that the 10/21/2003 was a critical, but not unusual stormflow event.

The two stormflow events from 2003 were of very different character and provide a reasonable range of likely events. September 12, 2003 was a small event, which produced mostly impervious surface runoff. There was 0.12 inches of rainfall on 9/10 and 0.17 inches on 9/11, and flow at Tacoma Road on 9/12 was 61 cfs, an increase of about 4 cfs over the antecedent dry period. The October 21, 2003 event was rather large with 0.13 inches of rainfall on 10/19, 3.70 inches on 10/20, and 0.51 inches on 10/21; the instream flow measured at Tacoma Road was 138 cfs. In comparison, the maximum observed flow at the gage during its period of operation (3/95 – 11/08) was 272 cfs.

To compare these storm events with other flows, the HSPF model (Tetra Tech, 2012a) was used to simulate storm events over a 50-year period from January 1960 to March 2010. The daily output was used to create a flow-duration curve (Figure 54). From this it will be seen that the 61 cfs flow of 9/12/03 was only slightly above the median, with a flow of this magnitude exceeded 42.9% of the time. The 138 cfs flow of 10/21/03 is predicted to be exceeded on only 0.1396% of days. This yields a recurrence interval of just under 2 years ($1/(0.001396 \cdot 365.25) = 1.96$ years). Thus, the 10/21/03 event (despite the high rainfall total for 10/20) is a high flow event, but not a particularly extreme high flow event. In order to capture the critical condition, the distribution of runoff simulated for the 10/21/2003 storm event was used as a basis to allocate the target of 50% of untreated stormwater flow volume.

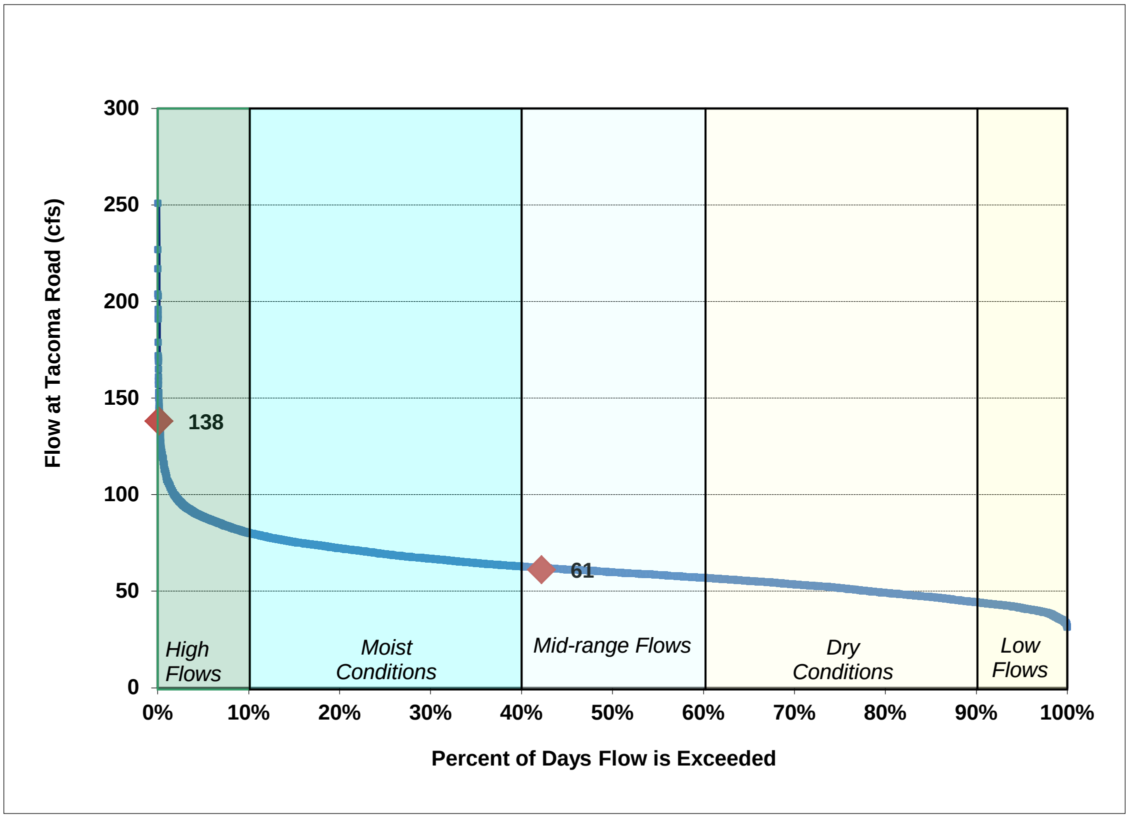

Figure 54. HSPF-Simulated Flow Duration at Tacoma Road, 1960-2010.

Assignment of stormflow reduction targets

The target of 50% reduction or treatment in untreated stormwater flow volume applies to land draining to Meeker Creek, 7th Avenue and Pioneer Way Conveyances, and Rody, Diru, and Woodland Creeks, consistent with the model simulation of compliance with the DO standard. The target is applicable to all sources of storm water, including the three MS4s and the unpermitted stormwater runoff associated with properties adjacent to the creek.

To calculate the amount of stormwater flow volume that needs to be either treated or detained by a jurisdiction in a given drainage area, the WLA (or LA) is set equal to one-half the stormwater flow volume predicted to be generated by the HSPF model for the 10/21/03 event from upland land areas within that jurisdiction and specified conveyance drainage area. Table 14 shows the total stormwater flow volume for the 10/21/03 event originating within each jurisdiction by conveyance. Table 15 presents the targets in terms of untreated stormwater flow volume (50% reduction or treatment of stormwater flow volumes from Table 14) to be reduced. These targets are met if stormwater volume is reduced or if additional stormwater is treated such that, if a storm event identical to the 10/21/03 event were to occur, untreated stormwater flow would not exceed the flow volumes in Table 15.

Table 14. Total Stormwater Flow Volume by Conveyance and Jurisdiction
(million gallons for 10/21/03 event)

Jurisdiction	Whole watershed	Meeker	Pioneer + 7^{th}	Woodland	Diru	Rody
City of Puyallup MS4	82.9	26.9	12.7	6.2	0.1	0.0
Pierce Co. MS4	69.5	0.4	0.0	26.8	20.4	11.9
WSDOT MS4	5.2	1.6	0.2	1.0	0.5	0.6
Properties adjacent to Creek	24.4	9.0	<0.1	1.4	0.9	6.7

Table 15. TMDL Implementation Targets Expressed as Untreated Stormwater Flow Volume Reductions
Needed for Meeker Creek Conveyance, Pioneer Way Plus 7th Avenue Conveyance, Woodland Creek, Diru Creek, And Rody Creek (million gallons for 10/21/03 event, rounded)

Jurisdiction	Meeker	Pioneer + 7^{th}	Woodland	Diru	Rody	Sum
City of Puyallup MS4	13.5	6.4	3.1	<0.1	0.0	23.1
Pierce Co. MS4	0.2	0.0	13.4	10.2	6.0	29.8
WSDOT MS4	0.8	0.1	0.5	0.3	0.3	2.0
Properties adjacent to Creek	4.5	<0.1	0.7	0.4	3.3	8.9

DOD load and wasteload allocations

CBOD-5 allocations for hatcheries

As explained earlier, the WDFW Hatchery and the two tribal hatcheries also receive DO allocations in terms of CBOD. The allocations are based on maintaining estimated current conditions (no reduction), and the WDFW hatchery allocations should be implemented as a requirement to maintain a daily average DO in the discharge of 9.5 mg/L, as equivalent to the DOD allocations.

Reduction in elodea density

Under both baseflow and stormflow conditions, elodea growth is a significant factor in depressed DO and elevated dissolved gas concentrations. Measures to reduce untreated stormwater and associated pollutant loading along with efforts to increase shading will, in the long term, tend to reduce the density of elodea growth. The allocation for Clarks Creek is to reduce elodea coverage to a maximum of 33% of pre-TMDL conditions (67% reduction) between the state hatchery and Tacoma Road and to a maximum of 25% of pre-TMDL conditions (75 percent reduction) between Tacoma Road and the mouth of Clarks Creek. These allocations are based on the instream baseflow analysis using QUAL2Kw, which is introduced in the Analysis for Baseflow Conditions section and described in more detail in Appendix B. The city of Puyallup's

Diver-assisted Suction Harvesting (DASH) project (summer of 2013) has been successful in removing large amounts of elodea from Clarks Creek.

Riparian shading

Increased riparian shading is needed to help achieve the allocation for reduced elodea density in Clarks Creek that will support attainment of the DO standard. Increased riparian shading also provides benefits of reducing thermal input, which in turn increases the carrying capacity for oxygen. Conversion of managed lawns to tree canopy will also reduce direct stormwater flow and associated pollutant inputs from properties adjacent to Clarks Creek, thus helping to meet the allocations for diffuse inputs.

Like all plants, elodea requires light for growth. Sensitivity analyses with the QUAL2Kw model suggest that elodea growth can be reduced by shading, as do qualitative observations of shaded versus unshaded reaches of Clarks Creek. In June 2012, Ecology conducted a study at 21 sites on Clarks Creek to record visual observations of elodea levels and to collect information on current vegetation and shade levels. The goal was to understand the general amount of shade needed to prevent elodea from growing in the Creek. Based on the study, an allocation of 85% effective shade is recommended to reduce elodea density in Clarks Creek (see the Riparian Shading and Elodea Density section and Appendix D).

Seasonal variation for DOD

Excursions of the DO standard occur during both dry and wet seasons in Clarks Creek. As precipitation is reduced during the summer months, lower flow conditions promote further depletion of DO. During stormflow conditions, depleted DO in stormwater discharges is the major factor leading to depressed DO in the stream. Stormflow conditions are also important due to the influence of sediment and nutrient loading in stormwater on subsequent growth of elodea.

Seasonal variation was addressed by establishing allocations that meet standards during stormflow conditions. The critical period for stormflow conditions is believed to be associated with fall storms that flush material from the drainage system while temperatures are still relatively high. Model analysis based on the event of 10/21/03 is believed to be representative of the upper range of DO impacts during the wet season.

Low DO under baseflow conditions occurs July through September, and the baseflow analysis was based on model dates during this period. Low DO occurs more consistently during the summer months due, in part, to higher temperatures reducing the saturation capacity within streams. In addition, a greater availability of light promotes increased algal and plant productivity. While this process initially produces increased DO, the additional production of organic matter in the summer months increases biological oxygen demand in the sediment, tipping the balance towards lower DO over time.

The TMDL analysis found that the most important influences of watershed processes and stormwater loads on the summer DO balance appear to depend on long-term loading of sediment and organic matter. Therefore the loading capacity (LC), based on stormwater flow, is expected to address impairments during both stormflow and baseflow periods. To further address the influence of elodea and temperature during baseflow conditions, the implementation targets for increased riparian shading and reduced elodea density are provided.

Supporting the consideration of summer conditions, the Core Summer Salmonid Habitat designated use, which applies to the entire lengths of Clarks Creek and its tributaries, has a critical period of June 15 - September 15, which corresponds to salmonid spawning, emergence, or adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and sub-adult native char.

Reserve capacity for future growth for DOD

Implementation for the Clarks Creek TMDL will be undertaken in terms of the implementation targets, which provide a practical expression of the WLAs and LA. A reserve capacity for future growth is not needed because the proposed requirements for new development in the Western Washington Phase II Municipal Stormwater Permit will apply the Basic Treatment Menu (BTM) to new projects in 2015. Because the BTM serves as the basis for defining whether stormwater is considered as treated, new projects that meet the BTM will also meet the TMDL implementation target of a 50% reduction or treatment in the volume of untreated stormwater as defined relative to the 10/21/2003 critical event, which has been shown to achieve the DOD TMDL.

While reserve capacity for future growth is not explicitly provided in the loading capacity, stormwater permit requirements are expected to protect the impaired water bodies from further degradation due to future growth. In particular, the following permits, relevant to the Clarks Creek watershed, contain language requiring low impact development (LID) where feasible in new development and re-development:

- Phase I Municipal Stormwater General Permit (WA ECY, 2011a)
- Western Washington Phase II Municipal Stormwater Permit (WA ECY, 2011b)

The LID requirements in the municipal stormwater permits are part of the adaptive process to improve stormwater management and protect surface waters from future degradation. LID stormwater management is a nationally-recognized innovative land use and stormwater management approach that strives to maximize infiltration, filtration, storage, evaporation and transpiration at levels greater than pre-disturbance conditions by emphasizing conservation, use of on-site natural features, site planning, rainwater harvest, rainwater re-use, and distributed stormwater management practices that are integrated into a project design.

Ecology's permits introduce the LID requirements at levels appropriate to the technological capabilities and physical conditions of permittees in each region. Ecology is funding an update to the Western Washington Hydrologic Model to address LID BMPs, as well as a project to develop guidance and training on maintenance of LID BMPs. These statewide requirements will support a fundamental shift to LID stormwater design and management in new and redevelopment areas to help meet the antidegradation requirements of WAC 172-203A-320(6). Requirements for LID include site and subdivision scale requirements, updates of broader development codes, and watershed-scale stormwater planning.

WSDOT is also required to implement LID through its stormwater permit. In its Stormwater Management Program, WSDOT is required to include non-structural preventative actions and source reduction approaches, including LID techniques to minimize the creation of impervious surfaces, and measures to minimize the disturbance of soils and vegetation where feasible (WA ECY, 2012a).

Sediment

Load and wasteload allocations

As presented in the "Elements the Clean Water Act requires in a TMDL" section, a TMDL is the combination of wasteload and load allocations (WLA and LA) given to point and non-point sources, the margin of safety (MOS), and any reserve capacity for future development, if applicable.

The loading capacity of the stream is set at 209 tons/year or .57 tons/day, based on a 64% reduction of the current conditions simulated sediment load (580 tons/year or 1.59 tons/day) at Clark Creek at 66th Avenue (monitoring station CLK-4), estimated by HSPF modeling (Tetra Tech, 2012a).

Because future development is anticipated in the Clarks Creek watershed, the TMDL sets aside the reserve capacity of 10 tons/year of sediment. The remaining allocation, which is a 66% reduction from current sediment loading, consists of 173-tons/year for point sources, 26 tons/year for nonpoint sources, and does not include the reserve capacity. With the reserve capacity set aside the percent reduction needed increases from 64% to 66%.

The construction stormwater WLA is two-tons per year and was calculated using a method applied in the Minnehaha Creek Watershed Lakes TMDL (Zadak et al, 2011). In that TMDL, the acreage of construction sites permitted over six years was determined and compared to the overall watershed size. The percentage of land area for construction sites was applied to the overall loading capacity. In Clarks Creek, a similar approach was used where the WLA was estimated as the median percent of land area under construction over the last 3 years times the sum of the overall LA and WLA (please note, the MOS and Reserve Capacity were not included in the calculation). The acreage from construction sites in the Clarks Creek watershed over three years was 45 acres, which is approximately 1% of the total watershed area of 8320 acres. Therefore, the construction WLA is 1% of the total WLA. A MOS is implicit, as discussed further in the Sediment TMDL MOS section, and a reserve capacity of 5% for future development is discussed in the Reserve Capacity for Future Growth section.

The construction WLA applies to all current and future permittees in the Clarks Creek watershed covered under Ecology's Construction Stormwater General Permit (CGP). In order to be in compliance with this TMDL, permittees must conduct turbidity sampling in accordance with the CGP Special Condition S8. All discharges to 303(d) or TMDL water bodies must comply with the required 25 NTU effluent limit, or stay in compliance with the surface water quality standard for turbidity as defined in S8.C.2. The water quality standard is: no more than 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or no more than a 10% increase in turbidity when the background turbidity is more than 50 NTU.

The sediment WLA for the WDFW Puyallup Hatchery was calculated as 10 tons/year, which equals the average net (hatchery effluent minus hatchery influent), annual sediment load from the facility over the last 5 years. This allocation will be evaluated each calendar year using the hatchery's NPDES permit and equals the sum of monthly sediment wasteload discharged or removed by the facility each year.

The remaining wasteload and load allocations are calculated proportionally based on the percent of contributing stormwater flow (Table 16, 17, and 18).

Table 16. Clarks Creek Sediment Allocations.

	Annual Load (tons/year)	Daily Load (tons/day)*
TMDL (tons/year) = WLA + LA + MOS	**209**	**.57**
Total WLA (tons/year)	**173**	**.47**
WLA: City of Puyallup MS4	85	.23
WLA: Pierce County MS4	70	.19
WLA: WDFW Puyallup Hatchery	10	.027
WLA: WSDOT	6	.016
WLA: Construction Permittees	2	.0055
Total LA (tons/year)	**26**	**.071**
LA: Properties adjacent to creek	26	.071
Reserve Capacity (tons/year)	**10**	**.027**
MOS (tons/year)	*Implicit*	*Implicit*

*While the daily load is provided, it is expected that the allocations will be evaluated using a long-term, 10-year rolling averaging period.

The daily allocations are based on the annual load allocation for sediment, distributed to days within the year based on the proportion of annual stormflow generated on that day. A flow-weighted daily load is appropriate because sediment delivery to streams is variable on a daily basis and sediment loading is based, in part, on related stream flows (EPA, 2007). The WLAs and LAs are based on the product of the measured daily average flow and the annual allocation for the source divided by the modeled average flow, 67 cfs (Tetra Tech, 2012a):

$$\textbf{WLA or LA}_{(tons/day)} = (\textbf{Daily flow}_{(cfs)})\ (\textbf{Annual Allocation}_{(tons/year)}/67_{(cfs)})(1_{year}/365.25_{days})$$

The allocations will be evaluated using a long-term, ten-year rolling averaging period. In addition to the variability of sediment dynamics, daily allocations do not reflect the imprecision of the source analysis available at this time. The point source, wasteload allocations for each jurisdiction or permittee are provided in Table 17. The non-point source, load allocations are provided in Table 18.

Table 17. Clarks Creek Sediment Daily Wasteload Allocations.

		WLA: City of Puyallup MS4	WLA: Pierce County MS4	WLA: WSDOT MS4	WLA: Construction Permittees
Percent of Stormwater Flow		46%	38%	3%	1%
Annual Sediment Allocation (tons/year)		85	70	6	2
Example Daily Allocation (tons/day)	Flow = 40 cfs	0.15	0.12	0.01	0.0033
	Flow = 200 cfs	0.75	0.62	0.05	0.017

Table 18. Clarks Creek Sediment Daily Load Allocations.

		LA: Properties adjacent to creek
Percent of Stormwater Flow		13%
Annual Sediment Allocation (tons/year)		26
Example Daily Allocation (tons/day)	Flow = 40 cfs	0.04
	Flow = 200 cfs	0.21

Seasonal variation for sediment

The TMDL accounted for seasonal variation by simulating storm patterns over 70 years that occur year-round. This included looking at all data throughout the year and picking the critical time when sediment loading occurs, which was during storm events and through in-stream channel erosion. Seasonal variation is captured by the annual basis for the loading allocations. This approach recognizes that sediment loads vary in response to different precipitation patterns.

Reserve capacity for future growth for sediment

The reserve capacity for future growth is 5% of the loading capacity to account for development in the Clarks Creek watershed from construction activities or any new sources. In addition, municipal, construction and industrial stormwater permit requirements are expected to protect the impaired water bodies from further degradation due to future growth. In particular, the following draft permits, relevant to the Clarks Creek watershed, contain language requiring low impact development (LID) where feasible in new development and re-development:

- Phase I Municipal Stormwater General Permit (WA ECY, 2011a)
- Western Washington Phase II Municipal Stormwater Permit (WA ECY, 2011b)

The LID requirements in the municipal stormwater permits are part of the adaptive process to improve stormwater management and protect surface waters from future degradation. LID stormwater management is a nationally-recognized innovative land use and stormwater management approach that strives to mimic pre-disturbance hydrologic processes of infiltration, filtration, storage, evaporation and transpiration by emphasizing conservation, use of on-site natural features, site planning, rainwater harvest, rainwater re-use, and distributed stormwater management practices that are integrated into a project design.

Ecology's permits introduce the LID requirements at levels appropriate to the experience and physical conditions of permittees in each region. Ecology is funding an update to the Western Washington Hydrologic Model to address LID BMPs, as well as a project to develop guidance and training on maintenance of LID BMPs. These statewide requirements will support a fundamental shift to LID stormwater design and management in new and redevelopment that help meet the antidegradation requirements of WAC 172-203A-320(6). Requirements for LID include site and subdivision scale requirements, updates of broader development codes, and watershed-scale stormwater planning.

WSDOT is also required to implement LID through its stormwater permit. In its Stormwater Management Program, WSDOT is required to include non-structural preventative actions and source reduction approaches including LID techniques, to minimize the creation of impervious surfaces, and measures to minimize the disturbance of soils and vegetation where feasible (WA ECY, 2012a).

Margin of Safety

The margin of safety (MOS) is intended to account for the uncertainty in the relationship between pollutant loads and the water quality response. There are two methods for incorporating a MOS in the analysis: 1) by implicitly incorporating a MOS using conservative model assumptions to develop allocations, or 2) by explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations. The MOS for the DO and sediment TMDLs are discussed separately in the following sections.

Dissolved oxygen TMDL MOS

For the Clarks Creek DO TMDL, the allocations are expressed in terms of DOD loads, and implementation targets were derived as actions assumed to achieve the allocations. Conservative assumptions were applied in the modeling runs that were used to derive both the quantitative DOD allocations and the corresponding implementation targets. Specifically, the target decrease of 50% in untreated stormflow volume is based on the analysis of a critical wet weather event on 10/21/2003 that combined high runoff (approximately 2-year recurrence frequency), high water temperature for the season, and assumptions of very low DO (less than 4 mg/L) in stormwater and diffuse discharges. Less stringent reductions would be needed to achieve the DO (and dissolved gases) criteria for events with lower flows or lower temperatures or higher DO in stormwater discharges. The conservative assumptions applied to the 10/21/2003 event constitute an implicit MOS relative to the DOD and CBOD analysis.

While not directly part of the TMDL MOS, the assumption that the implementation targets will achieve the TMDL allocations is conservative. The implementation target for re-establishing potential natural vegetation in the riparian corridor will create a more favorable temperature regime that is not accounted for in the modeling. Finally, the proposed reductions in untreated stormwater flow will also bring improvements in sediment and nutrient loading to Clarks Creek. Over time, these reductions in pollutant load, coupled with increased riparian shading, are expected to reduce the growth of elodea in the stream, which will directly reduce diurnal DO variability and ultimately decrease the SOD while also increasing stream velocity and enhancing reaeration capacity.

Sediment TMDL MOS

For the Clarks Creek Sediment TMDL, the margin of safety is implicit. Conservative assumptions were applied by selecting the critical location at 66th Avenue as opposed to the mouth of Clarks Creek. To ensure protection of designated uses throughout Clarks Creek, this approach targets a location where sediment loads are greater than at the mouth. In addition, the conservative target of percentage of sand and fines to meet reference conditions was chosen. The 64% reduction is greater than the reduction required for other parameters, such as the 36% reduction in percentage of fines and the 10% reduction in suspended solids to meet reference conditions. It is similar to the 66% percent reduction required to meet TSS concentrations in the natural conditions- modeled scenario and is well within the range of the predicted reduction necessary to reduce the impact of suspended sediment on aquatic life.

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Reasonable Assurance

When establishing a TMDL, reductions of a particular pollutant are allocated among the pollutant sources (both point and nonpoint sources) in the water body. For the Clarks Creek DO and sediment TMDL, both point and nonpoint sources exist. TMDL projects (and related implementation plans) must show "reasonable assurance" that these sources will be reduced to their allocated amount. Education, outreach, technical and financial assistance, permit administration, and enforcement will all be used to ensure that the goals of this TMDL project are met.

Ecology believes that the following activities already support this TMDL project and add to the assurance that dissolved oxygen (DO) and sediment in Clarks Creek will meet conditions provided by Washington State water quality standards. This assumes that the following activities are continued and maintained.

The goal of the Clarks Creek TMDL project for dissolved oxygen and sediment is to help the waters of the basin meet the state's water quality standards. Education, outreach, technical and financial assistance, permit administration, and enforcement will all be used to ensure that the goals of this TMDL are met. There is considerable interest and local involvement in resolving the water quality problems in Clarks Creek watershed. Numerous organizations and agencies are already engaged in stream restoration and source correction actions that will help resolve the DO and sediment problems. The following rationale helps provide reasonable assurance that the Clark Creek DO and sediment nonpoint source TMDL goals will be met by 2034.

- **NPS and PS quantified**: The QUAL2K storm event modeling was used to quantify the percent of stormwater flow contributed by land directly draining to the creek, as well as by the MS4 point sources. These percentages characterize the contribution of biochemical oxygen demand (BOD) from both non-point source (NPS) and point source to Clarks Creek during storm events. NPS are not expected to contribute BOD during baseflow conditions, and therefore were not characterized during these conditions.
- **Technically achievable load reductions:** The Stormwater Management Manual for Western Washington provides detailed guidance on the implementation of stormwater best management practices to comply with water quality standards and contribute to the protection of beneficial uses of the receiving waters. As one of the minimum requirements stormwater facilities, for most new and redevelopment sites, are required to match 50% of the 2-year predevelopment peak flow up to the full 50-year peak flow to provide a sufficient level of mitigation for the additional runoff from land development (WA ECY, 2012b). This requirement is consistent with the degree of stormwater management assumed to meet the TMDL allocations. The technical feasibility of achieving this flow using stormwater management in Western Washington is well documented by the 2012 manual.
- **Identified programs to achieve the NPS reductions:** Ecology believes that the following activities already support this TMDL and add to the assurance that DO in Clarks Creek watershed will meet conditions provided by Washington State water quality standards. This assumes that the following activities are continued and maintained:

- **Property owner education on riparian planting:** In the fall of 2006, the city of Puyallup, assisted by Pierce County Water Programs, planted portions of Clarks Creek Park, adjacent to Clarks Creek, with native trees and shrubs. The city will encourage the private property owner(s) to plant the Meeker Creek riparian corridor of their property with native vegetation.
- **Implementation of the Clarks/Clear Creek Basin Plan:** The Clarks/Clear Creek basin plan, developed by Pierce County, contains programs and action items that will involve water quality improvement targeted towards NPS and funded through the County's stormwater utility. These programs include floodplain/riparian corridor land management, invasive species management, and education programs. Specific actions in the plan include lawn care and pet waste education, as well as riparian buffer restoration (Pierce County, 2006).
- **Pierce County Stream Team planting events and plant replacement:** The Stream Team completed five planting events on Clarks Creek and continues to plan future events. The Stream Team is very helpful in determining native species that will thrive in the basin conditions. They can help with plant replacement after invasive plant removal.
- **Washington Department of Fish and Wildlife (WDFW) ditch maintenance:** WDFW periodically hires a construction crew to open up the drainage ditch from the state hatchery. They remove material from the intake pond that is currently contributing sediments downstream. The most recent maintenance removed ten cubic yards of sediment.
- **City of Puyallup Stormwater Management Program:** In addition to projects within the MS4 jurisdiction, the city of Puyallup has been implementing restoration and related-projects that help reduce the water-quality impact of lands along and near the creek banks. Planned projects include restoration of the most downstream 1000 feet of Meeker Creek to a natural, meandering stream channel with riparian vegetation. Completed projects include conversion of maintenance road to porous pavement and restoration of the riparian buffer in Clarks Creek Park, and restoration of riparian areas along Silver and Meeker Creeks.
- **City of Puyallup Rain Garden Program:** Dozens of demonstration sites around Puyallup have been established since 2009. These demo sites educate businesses and residents of Puyallup about rain gardens, permeable pavements, and rainwater harvesting and will help promote implementation of these practices on land throughout the watershed.
- **Pierce County LID Grant:** Through a 2011 Ecology stormwater retrofit grant Pierce County, in cooperation with the city of Puyallup, is planning to retrofit residential and road system impervious areas using Low Impact Development (LID) treatment methods such as bio-filtration, bioretention, infiltration, filtration, hydrodynamic separation, and rain gardens.

- **Technically achievable load reductions:** The Sediment Reduction Plan, funded by the Tribe, provides a detailed analysis of the probable causes of sediment loading in the system and several projects from the city of Puyallup and Pierce County that would meet a 50%

overall load reduction. These include primarily channel stabilization projects, green infrastructure, and detention systems.

- **Identified programs to achieve NPS reductions:** (See previous descriptions.)
    - Property Owner Education on Riparian Planting
    - Implementation of Clarks/Clear Creek Basin Plan
    - Pierce County Stream Team Planting Events and Plant Replacement
    - WDFW ditch maintenance
    - City of Puyallup Stormwater Management Program
    - City of Puyallup Rain Garden Program
- **Schedule and milestones to achieve LA**: The implementation section includes a description of Ecology's adaptive management approach, a schedule of actions for reductions from the NPS sources, including interim targets and dates in which to review monitoring data, BMP effectiveness, and progress towards meeting WQS.
- **Monitoring and tracking approach to evaluate progress**: The implementation section includes a description of how monitoring will be used to evaluate progress and make adjustments. As noted in the Study Results and Discussion Section, six different agencies/interest groups collect water quality data including the USGS, Ecology, Pierce County, the city of Puyallup, Puyallup Tribe of Indians (PTI), and the Western Washington Fair (WWF).
- **Follow-up actions:** Ecology has the legal authorities that would allow the possibility of requiring more stringent permit limits or more effective NPS controls if there is insufficient progress in the expected NPS control implementation. Ecology will consider and issue notices of noncompliance in accordance with the Regulatory Reform Act in situations where the cause or contribution to noncompliance with load allocations can be established.
- **Linkage of WLA to LA:** The determination of the WLA is directly linked to the LA, as both are calculated based on the percent of stormwater flow generated by the respective jurisdictions.

To provide additional assurance beyond existing programs and planned activities, the actions described in the Implementation Plan section are provided to help the permittees and property owners better understand how to implement the WLAs and LA in the TMDL report. The implementation section of this water quality improvement report (WQIR) describes the BMPs that can be used to achieve these actions and describes a corresponding BMP tool that will help the permittees and property owners estimate load reductions of various BMPs and select the best mix to meet their allocations.

While Ecology is authorized under Chapter 90.48 RCW to impose strict requirements or issue enforcement actions to achieve compliance with state water quality standards, it is the goal of all participants in the Clarks Creek TMDL process to achieve clean water through cooperative efforts.

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Implementation Plan

Introduction

This *implementation plan* was developed jointly by Ecology and interested and responsible parties. It describes what will be done to improve water quality. It explains the roles and authorities of cleanup partners (those organizations with jurisdiction, authority, or direct responsibility for cleanup), along with the programs or other means through which they will address these water quality issues. It prioritizes specific actions planned to improve water quality and achieve water quality standards. It expands on the recommendations made in Part 1 of this report.

Typically, Ecology produces an implementation strategy, which is submitted with the technical analysis to the U.S. Environmental Protection Agency (EPA) for TMDL approval as part of the water quality improvement report (WQIR). Then, following EPA's approval, Ecology and interested and responsible parties develop a water quality implementation plan. However, this section of this water quality improvement report will serve as both the implementation *strategy* and the implementation *plan*.

This implementation plan describes how dissolved oxygen and sediment pollutant levels will be reduced to meet water quality standards. The annual load for sediment is 209 tons per year; the daily load for dissolved oxygen deficit is 719 kilograms per day. TMDL reductions should be achieved by 2034 in the Clarks Creek watershed.

Who needs to participate in implementation

Because nonpoint pollution comes from diffuse sources, all upstream watershed areas have the potential to affect downstream water quality. Therefore, all potential nonpoint sources in the watershed must use the appropriate best management practices (BMPs) to reduce impacts to water quality. Similarly, all point source dischargers in the watershed must also comply with the TMDL.

The Clarks Creek Study Team met monthly since May 2010. The original team consisted of the city of Puyallup, Pierce County, and WSU Puyallup; WSDOT joined in January 2011. We included the partners early to keep the process very open and get input along the way. In May 2011, EPA selected the Clarks Creek Watershed as its Green Infrastructure partner for the states of WA, ID, OR, and AK.

The area subject to the TMDL is shown in Figure 2. The subject area represents a number of responsible parties and stakeholders, including the city of Puyallup, Pierce County, PTI, and a number of private organizations. Following are descriptions of the larger organizations affected by the TMDL.

City of Puyallup

The Engineering and Collection Division of the city's Public Works Department is responsible for stormwater infrastructure, drainage and flood protection, improving surface water quality, incorporating current development standards, and stormwater management. The city recently received coverage under the Phase II NPDES Municipal Stormwater Permit and is currently in the process of assessing and enhancing the city's stormwater program.

The city's current stormwater program is governed by the requirements of Chapter 21.10 of the Puyallup Municipal Code (PMC). New development within the city jurisdiction must meet criteria in the specified King County Manual and current city standards. PMC Chapter 21.10 also states that it is unlawful to discharge pollutants into the public storm drainage system directly or indirectly, and prohibits any cross-connection between the storm drainage system and any sanitary sewer system.

The city of Puyallup Planning Division is responsible for decision making regarding land use actions within the city. This is accomplished through evaluating land- use proposals for compliance with existing city regulations, and through compliance with the Critical Areas Ordinance contained in Chapter 21.06 of the PMC and developed in accordance with the state of Washington's Growth Management Act.

The city should consider TMDLs during State Environmental Policy Act (SEPA) and other local land use planning reviews. If the land use action under review is known to potentially impact temperature and dissolved oxygen as addressed by this TMDL project, then the project may have a significant adverse environmental impact. SEPA lead agencies and reviewers are required to look at potentially significant environmental impacts and alternatives and to document that the necessary environmental analyses have been made. Land use planners and project managers should consider findings and actions in this TMDL project to help prevent new land uses from violating water quality standards. Ecology recently published a focus sheet on how TMDLs play a role in SEPA impact analysis, threshold determinations, and mitigation (https://fortress.wa.gov/ecy/publications/SummaryPages/0806008.html). Additionally, the TMDL should be considered in the issuance of land use permits by local authorities.

The Planning Division has enforcement authority for improper land use actions. Planning decisions will have a large impact upon future loadings.

Puyallup Tribe of Indians (PTI)

PTI has worked with local governments and homeowners to protect and restore the Clarks Creek watershed for the past two decades. They conduct water-quality monitoring and spawning surveys, mitigation and restoration projects, as well as operate two hatcheries in the Clarks Creek watershed. The fisheries crew augments salmonid stocks in the Clarks Creek basin as well.

Most recently, PTI worked in cooperation with Tetra Tech to conduct monitoring of stormwater conveyances and the creek in 2011 and 2012. In addition to storm water conveyance monitoring, PTI was awarded an EPA grant to develop the Clarks Creek Sediment Reduction Action Plan, which included monitoring, modeling, and the development of general planning-level concepts for 23 projects that are estimated to reduce sediment loads by 390 tons/year (Brown and Caldwell, 2013). PTI began collecting water quality data in Clarks Creek beginning in 1998.

Clarks Creek flows through the exterior boundaries of the 1873 Survey Area of the Puyallup Reservation, discharging into the Puyallup River at River Mile 5.8. Within the exterior boundary of the 1873 Survey Area of the Puyallup Reservation, PTI and EPA have exclusive jurisdiction for administration and implementation of environmental laws on trust and restricted lands. EPA granted PTI treatment as a state, under Section 518(e) of the Clean Water Act, to carry out the water quality standards program under Section 303 of the Clean Water Act on trust and restricted lands within the Reservation which included, but was not limited to the Reservation reach of the Puyallup River. In October 1994 EPA approved PTI's water quality standards.

Friends of Clarks Creek

The Friends of Clarks Creek is a group of citizens who live on or nearby Clarks Creek. They have been very effective in persuading local landowners to plant native riparian vegetation. They also organize creek cleanups. They are the driving force between local governments and the citizens of this watershed.

Pierce County Public Works and Utilities, Water Programs Division

In addition to other responsibilities, the Water Programs Division of Pierce County's Public Works and Utilities Department is responsible for managing water quality and flooding through basin-specific planning efforts, ensuring compliance with the stormwater quality management requirements of the Clean Water Act. It is also responsible for gathering existing water quality data, performing physical surveys, water quality monitoring, and coordinating public input for the Water Programs Division.

Under federal regulation CFR Title 40 122.26, Pierce County manages a stormwater system. The unincorporated areas of the county are covered under a Phase I municipal stormwater NPDES permit. The county has oversight of the permit requirements and developed both a stormwater manual and a BMP manual for potential dischargers to this system.

Chapter 11.05 of the Pierce County Code, Illicit Stormwater Discharges (Ordinance Number 96-47), makes it unlawful for any person to discharge any pollutants into municipal drainage facilities. The county usually uses education and technical assistance to address nonpoint source pollution entering drainage ditches, but can require immediate cessation of discharges and implementation of BMPs.

Pierce Stream Team

Pierce County Water Programs and the cities of Tacoma, Bonney Lake, Fife, and Sumner, as well as monies collected from the Conservation Assessment Fee (from unincorporated Pierce County and the cities of Tacoma, Lakewood, Puyallup, Sumner, University Place, Fircrest, Steilacoom, and Milton) support the Pierce Stream Team. The Stream Team is a coalition of volunteers whose goal is to improve the quality of streams in Pierce County for the benefit of fish, wildlife, and people through public education and action projects. Stream Team offers opportunities for volunteers to participate in water quality monitoring, streamside re-vegetation with native plants, storm drain stenciling, and stream clean-up projects. Stream Team members educate the public through participation in educational displays about streams and related issues at a variety of events, including the Puyallup Fair. In addition, the Stream Team program offers workshops and tours dealing with stream improvement and habitat enhancement for salmon and other wildlife living in and along streams.

Pierce Conservation District

Pierce Conservation District, under authority of Ch. 89.08 RCW, Conservation Districts, provides education and technical assistance to residents, develops conservation plans for farms, and assists with design and installation of BMPss. When developing conservation plans, the district uses guidance and specifications from the U.S. Natural Resources Conservation Service. Farmers who receive a Notice of Correction from Ecology are normally referred to Pierce Conservation District for assistance.

In 2002, the district requested, and was granted, fee funding from the Pierce County Council, in accordance with Chapter 89.08.400 RCW. This provided a stable source of funding and allowed an increase in services.

Tacoma Pierce County Health Department (TPCHD)

TPCHD regulates on-site septic systems in Pierce County in accordance with Ch. 246-272 WAC, and the Tacoma Pierce County Board of Health Resolution 2001-3411 has an on-site operations and maintenance program. Both business and residential high-volume and complex systems are required to perform yearly inspections. Moderate-volume business systems and systems using enhanced treatment technology are required to perform inspections every three years. Other residential systems must be inspected at time of sale. Sanitary surveys or other investigative work are usually complaint or problem-driven and usually must be grant funded. Education and outreach is accomplished through a variety of tasks, including providing educational DVDs, presentations, and “as-built” information to property owners; giving presentations to community groups and organizations; and mailings of educational materials to targeted audiences.

Washington State Department of Ecology

Ecology is responsible, under the federal Clean Water Act, for establishing water quality standards, issuing NPDES discharge permits, coordinating water cleanup projects (e.g., TMDLs), and enforcing water quality regulations under the Water Pollution Control Act (Chapter 90.48 RCW). In addition to this regulatory role, Ecology gives grants and loans to local governments, tribes, conservation districts, and citizen groups for water quality projects. Projects that carry out water cleanup plans for TMDLs are given a high priority for funding. If necessary, Ecology can require specific actions under Ch. 90.48 RCW to correct problems.

Washington State Department of Fish and Wildlife (WDFW)

The mission of the Washington State Department of Fish and Wildlife (WDFW) is to provide sound stewardship of fish and wildlife. The health and well-being of fish and wildlife is important, not only to the species themselves but to humans as well. Often, when fish and wildlife populations are threatened, their decline can predict environmental hazards or patterns that also may have a negative impact on people.

The WDFW is an important partner in managing the Clarks Creek watershed. The agency provides technical assistance about the design of restoration projects, reviews hydraulic permit approvals, and participates in the Clarks Creek Technical Advisory Committee activities to help create and implement sound watershed management policies. The state hatchery operates under a NPDES individual permit issued by Ecology. Their discharges to Clarks Creek are regulated by their NPDES individual hatchery permit. The WDFW is working to remove sediment from the intake pond that contributes to the sediments reaching Clarks Creek.

Washington State University (WSU Puyallup)

WSU Puyallup started the Clarks Creek Initiative, a group of stakeholders working to monitor and improve the quality of Clarks Creek. WSU Puyallup also conducts water quality sampling, restoration projects, and education outreach in the watershed. They also operate the Low Impact Development (LID) Stormwater Research Program. This program is in collaborative partnership with the University of Washington, Tacoma Center for Urban Waters, which serves as a clearinghouse for stormwater technology information and permittee assistance.

Washington State Department of Transportation (WSDOT)

Ecology did not directly measure WSDOT stormwater outfalls during the TMDL study. But it is reasonable to assume that WSDOT stormwater is a source or a conveyance. While WSDOT stormwater outfalls can be the source of sediment in some locations, there is greater likelihood that the pollutants at a WSDOT outfall (if measured) come from adjacent private property via an illicit discharge or illegal connection.

Compliance with the following specific actions constitutes compliance with the assigned Wasteload allocations.

WSDOT will implement the following, which includes some pollution-prevention measures that address sediment delivery, for state road and highway runoff according to its Stormwater Management Program Plan (SWMPP) and Municipal Stormwater NPDES General Permit in all applicable Phase I and II coverage areas:

- Discharge inventory/IDDE (source identification and control). Construction stormwater pollution prevention.
- Implementation of Highway Runoff Manual (stormwater BMP design manual equivalent to Ecology's Stormwater Management Manual.)
- Stormwater BMP retrofit program.
- Highway maintenance program.

WSDOT will inventory its stormwater-related facilities to document their location and aid in setting levels of maintenance service, identify deficiencies and illicit discharges, and address deficiencies by prioritizing retrofits. All known outfalls, discharge points, and stormwater treatment/ control facilities (including underground injection control [UIC] facilities) owned or operated by WSDOT will be mapped. WSDOT must maintain and update the inventory to reflect new construction and system modifications as they occur.

Washington State Fair Association

The Washington State Fair Association has the authority to plant riparian vegetation along streams located on their property. They are required by the state Water Pollution Control Act (Chapter 90.48 RCW) to ensure that no pollution from their site reaches waters of the state.

Pollution sources and organizational actions, goals, and schedules

Activities to address pollution sources

The following stakeholders shall implement the actions below to achieve water quality standards.

Table 19. Clarks Creek Stakeholders

Entity	Action	Date
Pierce County	• Develop a Stormwater Retrofit Plan (including a scope of work and schedule) to identify and prioritize structural stormwater BMPs for construction within the Clarks Creek watershed to address stormwater flows and sediment transport from the MS4. The plan must be submitted to Ecology by January 31, 2016, for review and approval. Ecology reserves the right to require changes to the plan. The approved plan must be finalized by April 15, 2016, provided that this deadline shall be extended by the number of days by which Ecology exceeds 90 days for plan review. The plan must include: o The Plan must demonstrate how the County will achieve the DOD wasteload allocation *or* the 50% reduction in stormwater flow volume or untreated stormflow and the 66% sediment reduction. o Proposed BMPs designed to provide treatment or reduction of the total stormwater flow volume discharged from portions of the MS4 located within the zones identified in the TMDL as subject to the volume reduction WLA to Clarks Creek and tributaries by 50% relative to the 10/21/2003 storm event. o Proposed BMPs designed to reduce sediment to levels required by the WLA of 66% sediment reduction. o Proposed BMPs designed to reduce sediment transport from washoff and erosion and provide for long-term channel stability. BMPs may be selected from the prioritized lists identified in the PTI Sediment Reduction Study (2012) as providing for long-term channel stability. It is important to note that if projects from the PTI Sediment Reduction Study are used, it would result in a 50% reduction in sediment, and many of these projects would also be able to count towards achievement of the 50% reduction/treatment target in stormwater. Thus, many of these projects have dual benefits. o An implementation section that identifies a schedule of actions, construction timelines, responsible parties, estimated costs, and funding strategies.	Draft Submittal: 01/31/2016 Approved Plan: 04/15/2016
Pierce Conservation District	Assists stakeholders with tree planting along the shores of Clarks Creek and its tributaries.	Ongoing

Entity	Action	Date
City of Puyallup	• Develop a Stormwater Retrofit Plan (including a scope of work and schedule) to identify and prioritize structural stormwater BMPs for construction within the Clarks Creek watershed to address stormwater flows and sediment transport from the MS4. The plan must be submitted to Ecology by January 31, 2016, for review and approval. Ecology reserves the right to require changes to the plan. The approved plan must be finalized by April 15, 2016, provided that this deadline shall be extended by the number of days by which Ecology exceeds 90 days for plan review. The plan must include: o The Plan must demonstrate how the City will achieve the DOD wasteload allocation *or* the 50% reduction in stormwater flow volume or untreated stormflow and the 66% sediment reduction. o Proposed BMPs designed to provide treatment or reduction of the total stormwater flow volume discharged from portions of the MS4 located within the zones identified in the TMDL as subject to the volume reduction WLA to Clarks Creek and tributaries by 50% relative to the 10/21/2003 storm event. o Proposed BMPs designed to reduce sediment to levels required by the WLA of 66% sediment reduction. o Proposed BMPs designed to reduce sediment transport from washoff and erosion and provide for long-term channel stability. BMPs may be selected from the prioritized lists identified in the PTI Sediment Reduction Study (2012) as providing for long-term channel stability. It is important to note that if projects from the PTI Sediment Reduction Study are used, it would result in a 50% reduction in sediment, and that many of these projects would also be able to count towards achievement of the 50% reduction/treatment target in stormwater. Thus, many of these projects have dual benefits. o An implementation section that identifies a schedule of actions, construction timelines, responsible parties, estimated costs, and funding strategies. • Work towards getting homeowners still on septic tanks converted to sewer.	Draft submittal: 01/31/2016 Approved Plan: 04/15/2016
Tacoma Pierce Health Department	Investigate referrals from citizen/local governments where there is evidence of suspected on-site sewage failures.	Continuously
Clarks Creek Elodea Task Force	Work with local citizens, regulatory representatives, and other affected organizations to study the effects of the excessive elodea growth. Find possible solutions and ways to achieve them with a sustainable long-term plan for elodea management. Implement actions identified and monitor Elodea growth to gage effectiveness and long term success.	Ongoing
Streamside Private Property Owners	Restore Trees and Native Vegetation in riparian corridor along Clarks Creek.	Ongoing
Washington State Department of Fish and Wildlife	Receiving water monitoring for DO both upstream and downstream (NPDES permit expected to be re-issued in 2015). Coordinate efforts to remove sediment from intake structure at Puyallup trout hatchery.	2015

Entity	Action	Date
Washington State Department of Transportation	WSDOT will inventory highway stormwater discharge locations within its right-of-way inside of the Clarks Creek DO and Sediment TMDL boundary.	By next permit cycle (April 5, 2019)
Washington State University Puyallup Research and Extension Center	Conduct Low Impact Development Research Program: • Education and outreach throughout watershed • Water quality sampling and analysis • Restoration projects • Reduce the impacts of stormwater on streams, lakes, wetlands, and coastal areas through effective, research-based application of LID management principles and practices.	Ongoing
Puyallup Tribe of Indians	Conduct monitoring for nutrients, solids, and flow from their Clarks Creek Chinook and Diru Creek hatcheries when fish are on-station and/during periods of continuous discharge. Best Management Practices will be implemented at the hatcheries to reduce solids and nutrients discharged into the creeks. A record of drugs used by the hatchery manager will be kept in a log. An annual report of monitoring results, BMPs implemented, and drugs used will be submitted to Ecology at the end of each calendar year. Monitoring results will be reported to Ecology earlier if spikes in the solids or nutrients are observed.	12/31/2014 and each year after
Western Washington Fair	Monitor any discharges from the fairgrounds to Meeker Creek.	Ongoing
Clark Creek Intiative Stakeholder Goup	Engage all stakeholders quarterly to discuss implementation actions. Identify and prioritize implementation efforts to create a list of projects. Use ongoing list to collaborate resources, compete for grants, and track implementation efforts.	Ongoing

Measuring Progress toward Goals

What is the schedule for achieving water quality standards

TMDL reductions should be achieved by 2034. These targets will be described in terms of wasteload allocations or load allocations as well as in terms of implemented cleanup actions. Partners will work together to monitor progress toward these goals, evaluate successes, obstacles, and changing needs, and make adjustments to the cleanup strategy as needed. When enough implementation is completed, Ecology will perform effectiveness monitoring to determine if water quality standards are being met.

Performance measures and targets

Evaluating projects relative to the stormwater allocations

The stormwater allocations are specified as a reduction in the volume of untreated stormwater. This can be achieved by either reducing the volume directly or converting untreated stormwater to treated stormwater. The tracking and accountability memo demonstrated projects at the time of the writing of the TMDL that, if implemented, would significantly reach the allocations listed. The stakeholders will have the option of using the memo, or coming up with alternative projects to meet the same goal. The memo can be used to evaluate projects done prior to the TMDL issuance but after October 2003 (Tetra Tech – Tracking and accountability memo dated May 11, 2012, Appendix H).

Evaluating projects relative to sediment reduction allocations

The sediment reduction allocations are specified as a 66% reduction in sediment load. This can be achieved by either implementing proposed projects in the PTI's Sediment Reduction Plan or by coming up with alternative projects to meet the same goal. The Sediment Reduction Plan demonstrated projects at the time of the writing of the TMDL that, if implemented, would significantly reach the allocations listed. The stakeholders will have the option of using the plan or coming up with alternative projects to meet the same goal (PTI – Sediment Reduction Plan Project sheets, Appendix I).

Effectiveness monitoring plan

Effectiveness monitoring determines if the interim targets and water quality standards have been met after the measures described in the water quality implementation plan are functioning (i.e. the in-stream water quality monitoring). Effectiveness monitoring of TMDL projects is usually conducted by the Environmental Assessment (EA) Program. This plan includes monitoring that will be done by other entities if there is any planned.

Monitoring to determine the quality of water after implementation has occurred will be needed when water quality standards are believed to be achieved.

Entities with enforcement authority will be responsible for following up on any enforcement actions. Stormwater permittees will be responsible for meeting the requirements of their permits. Those conducting restoration projects or installing BMPs will be responsible for monitoring plant survival rates and maintenance of improvements, structures, and fencing.

Monitoring progress

A monitoring program for evaluating progress is an important component of any implementation plan. Monitoring is needed to keep track of what activities have or have not been done, measure the success or failure of target pursuit actions, and evaluate improvements in water quality. Attainment monitoring should occur after a significant amount of implementation has occurred. This monitoring should begin after the first implementation activities occur (2020). Monitoring should also be done after water quality standards are achieved (compliance monitoring) to ensure that standards continue to be met.

Monitoring implementation actions and how they will be maintained

The allocations for sediment should be achieved within 20 years, and, as a way to measure progress, an interim loading milestone of 99.5 tons/year, halfway between the current load and the allocation, should be achieved within ten years. Allocations for dissolved oxygen can be achieved through the dissolved oxygen deficit allocations *or* stormwater flow implementation targets. If the municipality opts to develop a plan to meet the DOD allocations, the plan must include an interim loading milestone which will be achieved by 2024 and ensure progress toward the final allocation. If the municipality opts to implement the stormwater flow reduction or treatment targets, then by 2024 25% of the stormwater volume, based on the 10/21/2003 storm event, should be reduced or 25% of the untreated stormwater should be treated. If the interim loading milestone is not achieved, NPDES-permitted entities shall demonstrate reasonable and measurable progress toward achieving the 10-year loading milestone.

Compliance monitoring will be needed when water quality standards are believed to be achieved. We are expecting that we will see some BMP implementation completed by 2020. Therefore, Ecology will monitor actual reduction numbers in 2020. Adaptive management will be used to determine if adjustment in implementation activities are needed.

Entities with enforcement authority are responsible for following up on any enforcement actions. Stormwater permittees and point-source permittees are responsible for meeting the requirements of their permits. Those conducting restoration projects or installing BMPs are responsible for monitoring plant survival rates and maintenance of improvements, structures, and fencing.

Adaptive management

Natural systems are complex and dynamic. The way a system will respond to human management activities is often unknown and can only be described as probabilities or possibilities. Adaptive management involves testing, monitoring, evaluating applied strategies, and incorporating new knowledge into management approaches that are based on scientific findings. In the case of TMDL projects, Ecology uses adaptive management to assess whether the actions identified as necessary to solve the identified pollution problems are the correct ones and whether they are working. As we implement these actions, the system will respond, and it will also change. Adaptive management allows us to fine-tune our actions to make them more effective, and to try new strategies if we have evidence that a new approach could help us to achieve compliance.

TMDL reductions should be achieved by 2034. Several implementation actions are currently underway in Clarks Creek and the stakeholders expect to have several others completed by 2020. As stated previously attainment monitoring will be conducted in 2020. These targets will be described in terms of percent reductions, concentrations, and implementation activities. Partners will work together to monitor progress towards these goals, evaluate successes, obstacles, and changing needs, and make adjustments to the implementation strategy as needed.

Ecology will use adaptive management when water monitoring data show that the TMDL project targets are not being met or implementation activities are not producing the desired result. A feedback loop (Figure 55) consisting of the following steps will be implemented:

Step 1. The activities in the water quality implementation plan are put into practice.

Step 2. Programs and best management practices (BMPs) are evaluated for technical adequacy of design and installation.

Step 3. The effectiveness of the activities is evaluated by assessing new monitoring data and comparing it to the data used to set the TMDL project targets.

- Step 3a. If the goals and objectives are achieved, the implementation efforts are adequate as designed, installed, and maintained. Project success and accomplishments should be publicized and reported to continue project implementation and increase public support.
- Step 3b. If not, then BMPs and the implementation plan will be modified or new actions identified. The new or modified activities are then applied as in Step 1.

Additional monitoring may be necessary to better isolate the sources of DOD and sediment so that new BMPs can be designed and implemented to address all sources of pollutants to the streams.

It is ultimately Ecology’s responsibility to assure that implementation is being actively pursued and water standards are achieved.

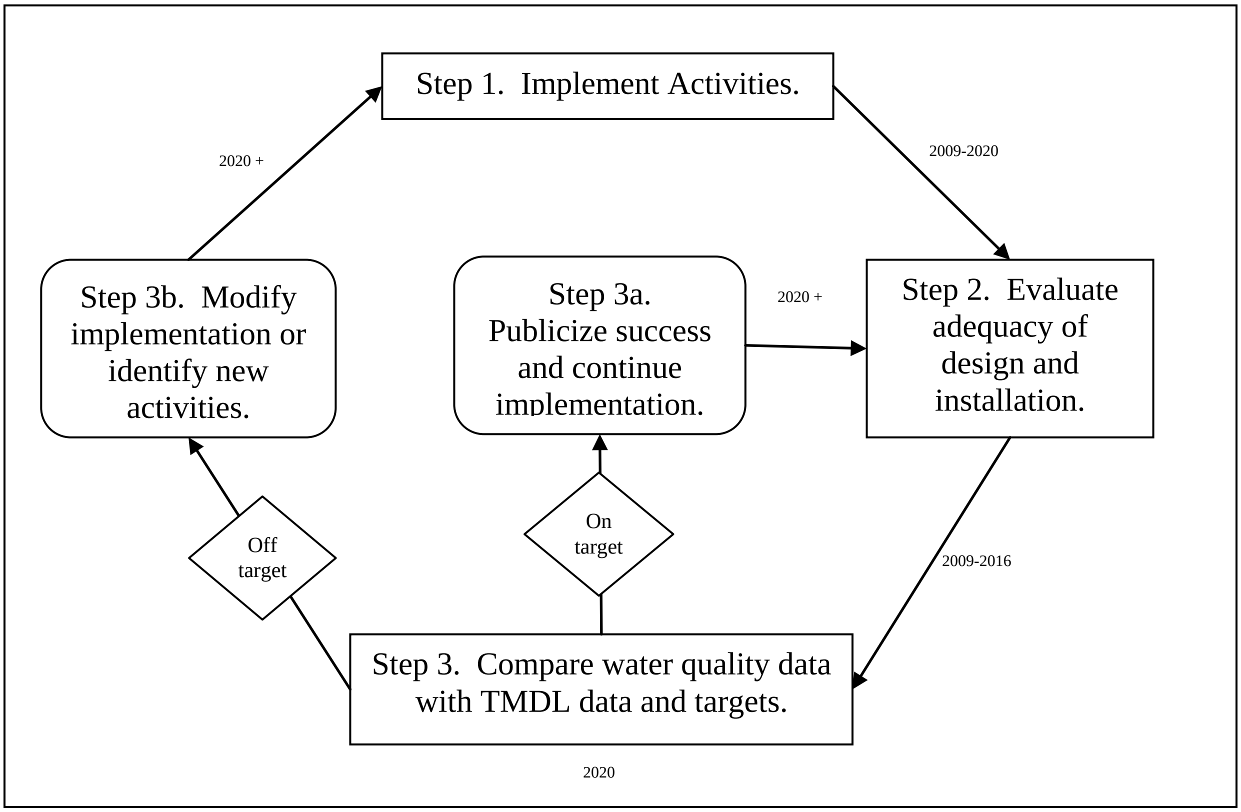

Figure 55. Feedback loop for determining need for adaptive management.

Dates are estimates and may change depending on resources and implementation status.

Funding Opportunities

Table 20: Potential funding sources

Sponsoring Entity	Funding Source	Uses to be Made of Funds
Department of Ecology	Centennial Clean Water Fund, Section 319, and State Revolving Fund www.ecy.wa.gov/programs/wq/funding/funding.html	Facilities and water pollution control-related activities. Implementation, design, acquisition, construction, and improvement of water pollution control. Priorities include: implementing water cleanup plans, keeping pollution out of streams and aquifers, modernizing aging wastewater treatment facilities, and reclaiming and reusing waste water.
Puget Sound Partnership	www.psp.wa.gov/funding.php	The Partnership works collaboratively with all levels of government, tribes, businesses and citizen groups in its charge to lead and coordinate efforts to protect and restore Puget Sound. The Puget Sound Partnership funds partner organizations through contracts and grants.
County Conservation District	Federal Conservation Reserve Enhancement Program http://snohomishcd.org/links-and-resources/crep-program/CREP_Fact%20Sheet_05.pdf	Conservation easements and cost-share for implementing agricultural/riparian BMPs.
Natural Resources Conservation Service	Environmental Quality Incentive Program www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/	Voluntary conservation program for farmers and ranchers that promotes agricultural production and environmental quality as compatible national goals (includes cost-share funds for farm BMPs).
Office of Interagency Committee, Salmon Recovery Board	Salmon Recovery Funding Board www.rco.wa.gov/boards/srfb.shtml	Provides grants for habitat restoration, land acquisition and habitat assessment.
Natural Resources Conservation Service	Emergency Watershed Protection www.nrcs.usda.gov/programs/ewp/index.html	NRCS purchases land vulnerable to flooding to ease flooding impacts.
Natural Resources Conservation Service	Wetland Reserve Program www.wa.nrcs.usda.gov/programs/wrp/wrp.html	Landowners may receive incentives to enhance wetlands in exchange for retiring marginal agricultural land.
The Russell Family Foundation, Puyallup Watershed Imitative.	www.trff.org/call-for-ideas-puyallup-watershed/	The Russell Family Foundation has invested in the waters of Puget Sound since the foundation began in 1999. We believe that the people and places around our region play a critical role in the quality and health of Puget Sound. We know that the health of the Sound is directly tied to the health of the surrounding watersheds. To assist us in this initiative, we have partnered with Bonneville Environmental Foundation (BEF). BEF is serving as a near-term partner for The Russell Family Foundation, extending our presence and reach into the watershed. BEF will provide direct support, proposal development and thought-partnership to communities within the watershed interested in applying for funds from The Russell Family Foundation.

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Summary of Public Involvement Methods

In 2009, the Clarks Creek Initiative group was formed to address pollution sources not addressed by the 2009 Fecal Coliform Bacteria TMDL published by Ecology.

Ecology, Puyallup Tribe of Indians, U.S. Environmental Protection Agency, Pierce County and the city of Puyallup reached out to several local citizen groups to educate and get their input on what needed to be done in Clarks Creek. From 2009-2013 several educational and outreach opportunities were organized by the stakeholders. The TMDL was presented several times to the Puyallup Watershed Council and at Puyallup City Council meetings.

The Friends of Clarks Creek (a group of local citizens that live along the creek) was a key stakeholder throughout this process.

Through this effort the Clarks Creek Elodea Task Force was formed. The Task Force is made up of City staff, local citizens, regulatory representatives, and other affected organizations. They met October-December 2012 and focused various workshops on discussions of the problem(s), the effects of the excessive elodea growth, possible solutions, and ways to achieve them with a sustainable long term plan for elodea management.

All Task Force members - as well as the public - were invited to attend the October-December 2012 meetings held at City Hall.

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Appendices

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Appendix A. Glossary, acronyms, and abbreviations

303(d) List: Section 303(d) of the federal Clean Water Act requires Washington State periodically to prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited water bodies (ocean waters, estuaries, lakes, and streams) that fall short of state surface water quality standards and are not expected to improve within the next two years.

Analyte: Water quality constituent being measured (parameter).

Best management practices (BMPs): Physical, structural, or operational practices that, when used singularly or in combination, prevent or reduce pollutant discharges.

Char: Char (genus *Salvelinus*) are distinguished from trout and salmon by the absence of teeth in the roof of the mouth, presence of light colored spots on a dark background, absence of spots on the dorsal fin, small scales, and differences in the structure of their skeleton. (Trout and salmon have dark spots on a lighter background.)

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Designated uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each water body or segment, regardless of whether or not the uses are currently attained.

Enterococci: A subgroup of the fecal streptococci that includes *S. faecalis*, *S. faecium*, *S. gallinarum,* and *S. avium*. The enterococci are differentiated from other streptococci by their ability to grow in 6.5 percent sodium chloride, at pH 9.6, and at 10 degrees C and 45 degrees C.

Exceeded criteria: Did not meet criteria.

Existing uses: Those uses actually attained in fresh and marine waters on or after November 28, 1975, whether or not they are designated uses. Introduced species that are not native to Washington, and put-and-take fisheries comprised of non-self-replicating introduced native species, do not need to receive full support as an existing use.

Extraordinary primary contact: Waters providing extraordinary protection against waterborne disease or that serve as tributaries to extraordinary quality shellfish harvesting areas.

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform bacteria are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100mL).

Geometric mean: A mathematical expression of the central tendency (average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either:

1. Taking the nth root of a product of n factors, or
2. Taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

Load allocation: The portion of a receiving water's loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading capacity: The greatest amount of a substance that a water body can receive and still meet water quality standards.

Margin of safety: Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving water body.

Municipal separate storm sewer systems (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains): (1) owned or operated by a state, city, town, borough, county, parish, district, association, or other public body having jurisdiction over disposal of wastes, stormwater, or other wastes and (2) designed or used for collecting or conveying stormwater; (3) which is not a combined sewer; and (4) which is not part of a Publicly Owned Treatment Works (POTW) as defined in the Code of Federal Regulations at 40 CFR 122.2.

National Pollutant Discharge Elimination System (NPDES): National program for issuing and revising permits, as well as imposing and enforcing pretreatment requirements, under the Clean Water Act. The NPDES permit program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to, atmospheric deposition; surface water runoff from agricultural lands; urban areas; or forest lands; subsurface or underground sources; or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System Program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Phase I stormwater permit: The first phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to medium and large municipal separate storm sewer systems (MS4s) and construction sites of five or more acres.

Phase II stormwater permit: The second phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to smaller municipal separate storm sewer systems (MS4s) and construction sites over one acre.

Plume: Describes the three-dimensional concentration of particles in the water column (example, a cloud of sediment).

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than five acres of land.

Pollution: Such contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Primary contact recreation: Activities where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and water skiing.

Reach: A specific portion or segment of a stream.

Salmonid: Any fish that belong to the family *Salmonidae*. Basically, any species of salmon, trout, or char. www.fws.gov/le/ImpExp/FactSheetSalmonids.htm

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt.

Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Surrogate measures: To provide more meaningful and measurable pollutant loading targets, EPA regulations [40 CFR 130.2(i)] allow other appropriate measures, or surrogate measures in a TMDL. The Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program (EPA, 1998) includes the following guidance on the use of surrogate measures for TMDL development:

> *When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional "pollutant," the state should try to identify another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not.*

Total maximum daily load (TMDL): A distribution of a substance in a water body designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Total suspended solids (TSS): The suspended particulate matter in a water sample as retained by a filter.

Turbidity: A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

Wasteload allocation: The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality-based effluent limitation.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Angular canopy density (ACD): The percentage of time that a given point on a stream will be shaded from direct beam solar radiation between 10 a.m. to 2 p.m. local solar time. For example, if a point on a stream is always shaded from 10 a.m. to 2 p.m. in August, then August ACD at that point is 100 percent. If that point is never shaded between 10 a.m. to 2 p.m., then ACD at that point is zero. Average ACD of a stream reach is estimated by sampling it over the width and length of the reach. Typical values of the ACD for old-growth stands in western Oregon have been reported to range from 80 to 90 percent.

Bankfull stage: Formally defined as the stream level that “corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels” (Dunne and Leopold, 1978).

Chronic critical effluent concentration: The maximum concentration of effluent during critical conditions at the boundary of the mixing zone assigned in accordance with WAC 173-201A-100. The boundary may be based on distance or a percentage of flow. Where no mixing zone is allowed, the chronic critical effluent concentration shall be 100 percent effluent.

Critical condition: When the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or designated water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 (see definition) flow event unless determined otherwise by the department.

Diel: Of, or pertaining to, a 24-hour period.

Dilution factor: The relative proportion of effluent to stream (receiving water) flows occurring at the edge of a mixing zone during critical discharge conditions as authorized in accordance with the state’s mixing zone regulations at WAC 173-201A-100.

http://app.leg.wa.gov/WAC/default.aspx?cite=173-201A-020

Diurnal: Of, or pertaining to, a day or each day; daily. (1) Occurring during the daytime only, as different from nocturnal or crepuscular, or (2) Daily; related to actions which are completed in the course of a calendar day, and which typically recur every calendar day (for example, diurnal temperature rises during the day and falls during the night.)

Effective shade: The fraction of incoming solar shortwave radiation that is blocked from reaching the surface of a stream or other defined area.

Hyporheic: The area beneath and adjacent to a stream where surface water and groundwater intermix.

Near-stream disturbance zone (NSDZ): The active channel area without riparian vegetation that includes features such as gravel bars.

Riparian: Relating to the banks along a natural course of water.

System potential: The design condition used for TMDL analysis.

System-potential channel morphology: The more stable configuration that would occur with less human disturbance.

S**ystem-potential mature riparian vegetation:** Vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

System-potential riparian microclimate: The best estimate of air temperature reductions that are expected under mature riparian vegetation. System potential riparian microclimate can also include expected changes to wind speed and relative humidity.

System-potential temperature: An approximation of the temperatures that would occur under natural conditions. System potential is our best understanding of natural conditions that can be supported by available analytical methods. The simulation of the system-potential condition uses best estimates of *mature riparian vegetation, system potential channel morphology, and system-potential riparian microclimate* that would occur absent any human alteration.

1-DMax or 1-day maximum temperature: The highest water temperature reached on any given day. This measure can be obtained using calibrated maximum and minimum thermometers or continuous monitoring probes having sampling intervals of 30 minutes or less.

7-DADMax or 7-day average of the daily maximum temperatures: The arithmetic average of seven consecutive measures of daily maximum temperatures. The 7-DADMax for any individual day is calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the three days prior and the three days after that date.

7Q2 flow: A typical low-flow condition. The 7Q2 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every other year on average. The 7Q2 flow is commonly used to represent the average low-flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q2 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every 10 years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10 percent of the data exists and below which 90 percent of the data exists.

Acronyms and abbreviations

Following are acronyms and abbreviations used frequently in this report.

B-IBI	benthic index of biologic integrity
BMP	best management practice
BOD	Biochemical Oxygen Demand
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
NAF	new approximation flow
NPDES	National Pollutant Discharge Elimination System
NSDZ	near-stream disturbance zone
RM	river mile
TIR	thermal infrared radiation
TMDL	total maximum daily load (water cleanup plan)
TOC	total organic carbon
USFS	United States Forest Service
USGS	United States Geological Survey
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resources Inventory Area
WWTP	wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cms	cubic meters per second, a unit of flow
dw	dry weight
ft	feet
g	gram, a unit of mass
kcfs	1000 cubic feet per second
kg	kilograms, a unit of mass equal to 1,000 grams
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters
l/s	liters per second (0.03531 cubic foot per second)
m	meter
mg	million gallons
mgd	million gallons per day
mg/d	milligrams per day
mg/Kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mg/L/hr	milligrams per liter per hour
mL	milliliters
mmol	millimole or one-thousandth of a mole. A mole is an S1 unit of matter.

ng/g	nanograms per gram (parts per billion)
ng/Kg	nanograms per kilogram (parts per trillion)
ng/L	nanograms per liter (parts per trillion)
pg/g	picograms per gram (parts per trillion)
pg/L	picograms per liter (parts per quadrillion)
psu	practical salinity units
s.u.	standard units
ug/g	micrograms per gram (parts per million)
ug/Kg	micrograms per kilogram (parts per billion)
ug/L	micrograms per liter (parts per billion)
um	micrometer
uM	micromolar (a chemistry unit)
umhos/cm	micromhos per centimeter
us	microsiemens per centimeter
uS/cm	microsiemens per centimeter, a unit of conductivity
ww	wet weight

Appendix B. Model development summary

This appendix provides a summary of the model selection, quality assurance, calibration, validation, sensitivity, and error approaches for the QUAL2Kw and HSPF model applications in this TMDL. More details can be found in the QUAL2Kw and HSPF model reports, Tetra Tech (2011a) and Tetra Tech (2012a) respectively; see also Appendix C for a link to download the HSPF model report (Tetra Tech, 2012a).

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HSPF model documentation

A watershed model focusing on flow and sediment loads was completed through an EPA-funded grant awarded to PTI entitled, “Reducing Effective Impervious Surfaces in a Small Urban Catchment Using LID Practices.” The watershed model was created as a tool to assist in evaluating the relationship between sediment sources, urban stormwater, and conditions within Clarks Creek (Tetra Tech, 2012a).

Model selection

A modeling framework was needed that could provide a dynamic simulation of flow, upland sediment loading, and instream sediment transport processes in Clarks Creek. The Hydrologic Simulation Program – FORTRAN (HSPF) model (Bicknell et al., 2005) was selected for this purpose for several reasons:

1. HSPF provides dynamic simulation of water and sediment, including both upland and instream sediment processes at a user-specified level of detail and complexity, and is thus suitable for addressing the principle study questions.
2. HSPF models have previously been developed to address storm flows in Clarks Creek (Mastin, 1995, CH2MHill, 2003, Pierce Co., 2009). While these models are not fully calibrated for hydrology and have not yet been developed for water quality simulation, they provide a basis for additional development of the current HSPF model.
3. HSPF is supported by EPA with open source code and has a long history of well-documented applications for addressing hydrology and sediment management applications. It also provides a platform for full simulation of nutrients, bacteria, and other endpoints of potential interest.

Modeling QAPP

A modeling Quality Assurance Project Plan (QAPP) was developed in 2011 (Tetra Tech, 2011b), which provided a general description of the modeling and associated analytical work used for the Clarks Creek Sediment Study, including data quality objectives (DQOs) and quality control (QC) procedures to ensure that the final product satisfies user requirements. The QAPP also provided acceptance criteria and performance targets for model calibration and validation. The QAPP addresses the use of secondary data (data collected for another purpose or collected by an organization or organizations not under the scope of the QAPP) to support TMDL development. The QAPP and subsequent model report identified the following primary study questions to be addressed by the model:

1. What are the principal sources of sediment load in the Clarks Creek watershed?
2. How are sediment loads in the watershed transported to Clarks Creek?
3. What is the significance of sources of instream generation of sediment load due to scour and bank failure and what factors control these loads?
4. What is the optimal selection of management measures to reduce both the anthropogenic sediment load and excess flows that promote instream generation of sediment load via channel degradation?

Model calibration

Hydrologic calibration and validation

The hydrology model is calibrated to observed flow gaging data. The primary source of flow data for calibration is the USGS gage on Clarks Creek at Tacoma Road (Station 12102075). To provide for model validation, flow calibration was undertaken on the gage data for 2000 – 2008, while the data for 1995 – 1999 were used for a validation test. The overall model fit for the calibration time period was rated as good.

As shown in Table B-1, all of the annual and seasonal relative mean error statistics are in the "very good" range. The uncertainties introduced by the spring simulation, which has some difficulties in representing the short-term variations in baseflow discharge, are, however, evident in the relatively low daily *E* value of 0.54. The coefficient of determination (R^2) for daily discharges is 0.70, which is in the good range. The coefficient of determination for monthly discharges is, however, poor. This is largely due to two periods in which the model under-predicts observed flow (Nov.-Dec. 2002 and Nov.-Dec. 2006). Despite this, the monthly *E* (0.95) is very high. Therefore, the model calibration is deemed acceptable. The hydrology validation was conducted for 1995-1999 and confirms the performance of the calibrated model.

Table B-1. Summary statistics: model vs. USGS 12102075 Clarks Creek at Tacoma Road near Puyallup, WA, calibration period

HSPF Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM DSN 103 8.92-Year Analysis Period: 1/1/2000 - 11/30/2008 Flow volumes are (inches/year) for upstream drainage area This version has fix to hydrograph separation		USGS 12102075 CLARKS CREEK AT TACOMA ROAD NEAR PUYALLUP, WA Hydrologic Unit Code: 17110014 Latitude: 47.19760016 Longitude: -122.337343 Drainage Area (sq-mi): 13		
Total Simulated In-stream Flow:	**55.72**	Total Observed In-stream Flow:		**56.07**
Total of simulated highest 10% flows:	**8.30**	Total of Observed highest 10% flows:		**8.64**
Total of Simulated lowest 50% flows:	**23.64**	Total of Observed Lowest 50% flows:		**23.61**
Simulated Summer Flow Volume (months 7-9):	**12.40**	Observed Summer Flow Volume (7-9):		**12.76**
Simulated Fall Flow Volume (months 10-12):	**14.14**	Observed Fall Flow Volume (10-12):		**15.16**
Simulated Winter Flow Volume (months 1-3):	**15.45**	Observed Winter Flow Volume (1-3):		**14.97**
Simulated Spring Flow Volume (months 4-6):	**13.74**	Observed Spring Flow Volume (4-6):		**13.18**
Total Simulated Storm Volume:	**2.60**	Total Observed Storm Volume:		**2.38**
Simulated Summer Storm Volume (7-9):	**0.21**	Observed Summer Storm Volume (7-9):		**0.23**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*Run (n-1)*	*Prev Cal*
Error in total volume:	-0.62	10	-0.75	-0.41
Error in 50% lowest flows:	0.14	10	0.11	0.41
Error in 10% highest flows:	-3.94	15	-4.39	-3.93
Seasonal volume error - Summer:	-2.82	30	-2.78	-2.58
Seasonal volume error - Fall:	-6.72	30	-6.75	-6.67
Seasonal volume error - Winter:	3.20	30	2.79	3.43
Seasonal volume error - Spring:	4.19	30	4.10	4.54
Error in storm volumes:	9.10	20	8.47	8.80
Error in summer storm volumes:	-8.83	50	-8.79	-8.83
Nash-Sutcliffe Coefficient of Efficiency, E:	0.539	Model accuracy increases	0.540	0.538
Monthly NSE	0.950	as E approaches 1.0	0.950	0.950

Water quality calibration and validation

Calibration of watershed sediment models is complex because instream observations of TSS are the net result of a variety of complex processes, including sediment detachment on the uplands, transport of detached sediment from the land surface to streams, and bank erosion, scour, and deposition within the streams. In addition, data for calibration are often limited. As a result, there is often not a unique solution to model calibration, as, for example, high concentrations observed in stream could result from elevated upland loads and/or sediment scour within the channel. These two sources are not readily distinguished through observations unless auxiliary information (such as radionuclide data) is collected to identify the fraction of stream sediment that has been in recent contact with the atmosphere.

An additional challenge for sediment calibration is that sediment concentrations often vary rapidly over short time intervals. For instance, the first flush phenomenon can result in TSS concentrations that spike up in the rising limb of the storm hydrograph, then decline. Instantaneous grab samples may provide little information on the daily average sediment concentration, while sub-daily model predictions and observations for the same time interval may show large discrepancies if there are small differences in the timing of predicted and observed flows. Flow-weighted composites over the storm hydrograph are most informative. For Clarks

Creek, most available TSS samples are grab samples, and the time of collection is not available for most of the samples. To address these issues, Tetra Tech compared these point-in-time samples to daily average concentrations produced by the model and obtained a representation that is unbiased over the long term, recognizing that there will be discrepancies between some individual observations and model predictions.

The approach undertaken for sediment calibration follows the guidance of EPA (2006) and Donigian and Love (2003) and consists of the following steps:

- Specify initial upland parameter values for soil erodibility (detachment rates) on pervious land and soil accumulation rates on impervious surfaces based on external information (e.g., soils data, literature).
- Adjust upland sediment transport rates from individual land uses to achieve general consistency with annual sediment loading rates reported in the literature (preferably from local studies).
- Analyze the instream sediment mass balance on a reach by reach basis to ensure reasonable representation of areas of scour and deposition.
- Adjust instream/channel parameters to match observed TSS concentrations and loads.

The full sediment model is calibrated through comparison to observed total suspended solids concentrations by adjusting the parameters that control the scour and deposition of sand, silt, and clay (as well as by adjusting the upland transport simulation). Suspended solids observations are available at multiple stations, but the number of samples at individual stations is limited. The calibration period was selected as the more data rich period of 2002 – 2010, while earlier data were used for validation. Unfortunately, the desired minimum sample size of 20 observations is attained at only a few of the stations. Accordingly, a weight of evidence approach was used, for which model fit statistics are supplemented with a variety of graphical comparisons.

Calibration statistics for TSS are presented in Table B-2. Most of the stations either do not meet the minimum data requirement for quantitative analysis of 20 samples, or exceed it by only a small amount. This leaves the results open to undue influence by outliers. This can be mitigated by examining median rather than average relative errors. Good or very good results are obtained for most stations and high average relative errors are mostly attributable to outliers. Results for Clarks Creek above the State Hatchery should be viewed in light of the observation that flow is often under-predicted at this site due to uncertainty as to where the spring-fed baseflow enters the stream. Therefore, the over-estimation, on average, of TSS at this location is not unexpected.

The limited sampling at the mouths of Meeker, Rody, and Diru Creeks and upstream on Meeker Creek is also affected by occasional outliers and mistiming of event peaks, although the overall results appear consistent with the observations. Further, the simulated concentrations in Meeker, Rody, and Diru are consistent with the observed concentrations just downstream in Clarks Creek at 66th Street.

Table B-2. Calibration statistics for total suspended sediment, 2002 – 2010

Station	Observation Count	Mean Observed (mg/L)	Average Relative Error	Median Relative Error
Clarks Creek at 66th Street	25	15.03	-21.7%	-8.6%
Clarks Creek above 7th Street	12	9.00	6.9%	-7.6%
Clarks Creek at 12th Street	32	4.48	70.4%	-7.2%
Clarks Creek below State Hatchery	12	8.17	17.4%	-0.8%
Clarks Creek above State Hatchery	18	4.26	152.3%	3.7%
Meeker Creek mouth	12	28.61	1.7%	-6.8%
Meeker at Reach 123	11	43.98	-27.0%	5.6%
Rody Creek mouth	11	30.67	-6.1%	-2.1%
Diru Creek mouth	11	14.02	51.3%	4.0%

Note: Relative errors are calculated as simulated minus observed normalized to the observed mean.

In sum, data for model calibration to TSS are limited; however, the model appears to perform adequately in predicting the available data. Sample sizes are small and easily influenced by a few outliers. The model represents both the temporal and spatial trends in observed TSS.

Model Results

The model was used to provide an overall sediment balance for a 51-year simulation period. The model identified runoff from upland impervious areas as the primary contributor to sediment loading, followed by channel erosion in the steeper stream segments. In addition, Tetra Tech modified the existing conditions model to develop two additional scenarios: natural conditions (i.e., fully forested) and future/buildout conditions. The buildout scenario assumes that all parcels have been converted to their zoned land use except where protected from development. This change results in a relatively small increase in total imperviousness as the watershed is already approaching full buildout. However, the buildout scenario also mitigates for this increased imperviousness based on current stormwater requirements for new development/redevelopment. In other words, impervious surfaces from redeveloped areas were routed through a hypothetical stormwater facility to adjust for current flow control requirements.

In sum, the watershed model scenarios suggest that existing development has substantially altered the natural hydrology and sediment dynamics of Clarks Creek, leading to increased peak flows, increased sediment load, degradation of upland stream reaches, and aggradation of reaches in the alluvial plain. However, risks from future development appear relatively small – mostly because most of the available land has already been developed. Mitigation of sediment problems in Clarks Creek would thus require addressing flow and sediment loads from existing development.

QUAL2Kw model documentation

Model selection

Based on analysis of observed data as discussed in Section 7 the most important influences of watershed processes and stormwater loads on the summer DO balance appear to depend on long term loading of sediment and organic matter. As a result, the QUAL2Kw stream water quality model (Pelletier and Chapra, 2008; an extension of the older QUAL2E model [Brown and Barnwell, 1987]) was selected. QUAL2Kw is a quasi-steady state water quality model. In the Clarks Creek TMDL, the model was used to determine the DO mass balance assuming constant external forcing of certain variables (such as tributary concentrations) during critical periods and diurnal cycles of DO kinetics, light, and temperature.

Model QAPP

The Modeling Quality Assurance Project Plan (QAPP) provides a general description of the modeling and associated analytical work used for the Clarks Creek TMDL study, including data quality objectives (DQOs) and quality control (QC) procedures to ensure that the final product satisfies user requirements. The QAPP also addresses the use of secondary data (data collected for another purpose or collected by an organization or organizations not under the scope of the QAPP) to support TMDL development. The modeling QAPP was the guiding document for modeling applications in this study (Tetra Tech, 2010b).

Model calibration

The QUAL2Kw model was first calibrated for three monitored dates with representative summer dry weather conditions (July 10, 2009; July 20, 2009; and August 6, 2009). Initial calibration was conducted for conditions of July 10, 2009, a period of diurnal monitoring during what appears to be typical summer baseflow conditions (although no flow gaging is available). The calibration proceeded in stepwise fashion for flow, water temperature, nutrients, and DO. This model provides a close approximation to the estimated HEC-RAS estimates of travel time through the system. For the DO balance, the significant unknown factor is sediment oxygen demand (SOD), which has not been measured. An SOD rate of 8 g-O2/m^2/d results in a close fit to the observed DO daily range and longitudinal profile. The match to the diurnal cycle is also reasonable, although there is a shift in the time of peak DO at Tacoma Road that likely reflects uncertainty in the daily cycle of shading.

The July 20, 2009 model provides a good fit to observed temperature and DO, including the reduced diurnal range at the tribal hatchery. This suggests the calibration is robust for summer baseflow conditions.

Model application for August 6 produces a close match to the observed DO profile, including the increased daily minimum DO at Tacoma Road and other locations. No adjustment to the assumed SOD was needed – suggesting that this demand is most likely primarily associated with the sediment rather than the algal mats.

To further evaluate the performance of the QUAL2Kw model, application was made to conditions from the 2002-2003 monitoring effort. Performance of the summer baseflow simulation was checked through application to conditions of 8/20/2002 (dry weather) and 9/12/2003 (minor stormflow). The model was then extended to a fall period of higher flows on 10/21/2003. These multiple individual runs demonstrated that observed DO can be well predicted under baseflow conditions with unified assumptions of (1) ubiquitous elodea growth (except following cutting), (2) impacts of elodea growth on water depth and velocity, and (3) a constant SOD (or apparent SOD) rate of 8 $mg/m^2/d$. During higher flow conditions, simulated temperature matched observations well. Assigning measured concentrations to diffuse surface inflows provided a reasonable fit to the DO concentrations observed in the mainstem under high flow conditions. The above evaluation was considered corroboration rather than a full model calibration. More detailed explanation of these corroboration exercises are provided in the model report (Tetra Tech, 2011a).

Model validation, sensitivity and error analysis

Following model corroboration as outlined above, further analysis was conducted to assess model sensitivity and explore control options. Changes in nitrate, riparian shading, SOD, and flow withdrawals were tested, and Table B-3 summarizes the results. Decreases in nitrate concentration or flow withdrawals did not predict fewer DO excursions. Increased riparian shading indicated a partial but inconclusive effect on DO as the exact light requirements of elodea (e.g., *Elodea nuttalli)* are not well established. A decrease in SOD did result in a strong increase in DO concentrations, supporting the control of SOD as a promising management measure.

No additional validation or error analysis was conducted. The model was used as a tool for exploratory analysis of potential cause and effect relationships or risk hypotheses in the system, with consideration of model uncertainty.

Table B-3. Sensitivity analysis results

Parameter	Hypothesis	Result
Nitrate	Decreased nitrate loads in Maplewood Springs and other groundwater sources would lead to reduced elodea growth and fewer excursions of the DO criterion.	**Not supported**: A marginal reduction in elodea growth was observed, but this did not yield predicted increases in daily minimum DO concentrations under baseflow conditions (using the July 10, 2009 models).
Riparian shading	Greater shading of Clarks Creek would decrease the diurnal range of DO variability and the daily average stream DO (due to decreased stream temperature and decreased photosynthetic DO production, respectively).	**Partially supported**: Increased shading reduced daily DO maxima but almost no change was observed in the daily DO minima under baseflow conditions (using the July 10 and July 20, 2009 models).
SOD	Reducing SOD would result in an increase in diurnal minimum DO.	**Supported:** Decreased SOD results in a strong increase in daily minimum DO under baseflow conditions (using July 10, 2009 model).

Parameter	Hypothesis	Result
Flow Withdrawals	Increased flow would increase re-aeration rates and increase water depth.	**Not Supported:** Increased flow did not produce a significant effect on daily minimum DO under baseflow conditions (using the July 20, 2009 model).

Baseflow analysis, elodea reduction

To determine the necessary reduction in Elodea growth to meet the DO and dissolved gases criteria, the model was first adjusted to achieve the DO criterion without active elodea growth and respiration. A second application was then used to determine the level of elodea density reduction needed to meet both the DO and dissolved gasses criteria during baseflow conditions. The conditions that achieve the DO criteria *without* active elodea growth and respiration are as follows:

- SOD upstream of Tacoma Road is reduced from 8 to 2.5 mg/m^2/d. SOD downstream of Tacoma Road is reduced from 8 to 4 mg/m^2/d.
- Tributary and diffuse inflows to Clarks Creek upstream of Tacoma Road are assumed to meet the following minimum conditions:
    - Inflow at the headwaters (including Maplewood Springs) maintains a daily average of 9.5 mg/L DO (with diurnal variability of ± 1 mg/L).
    - Discharges from the state hatchery achieve a daily average of 9.5 mg/L DO (with diurnal variability of ± 1 mg/L).
    - Discharges from the mouth of Meeker Creek achieve a daily average of 9.0 mg/L DO (with diurnal variability of ± 2 mg/L). The mean is about 1 mg/L below saturation at typical summer water temperatures.
    - Discharges at Pioneer Way achieve a daily average of 9.0 mg/L DO (with diurnal variability of ± 2 mg/L).
    - Diffuse discharges to the stream (predominantly groundwater) upstream of Tacoma Road maintain a concentration of 9.0 mg/L.
- No changes are applied to tributary and diffuse inflows downstream of Tacoma Road, which have generally been observed to be near saturation for DO during dry season monitoring.

No changes are made to external loads of carbonaceous BOD or ammonia as these do not provide a significant direct contribution to the total DOD. With these assumptions in the model, the model scenario was run to determine the level of reduction in elodea density needed to meet water quality standards for DO and total dissolved gases throughout the diurnal cycle for all four dates. Under this scenario, the following load allocation for elodea was determined. The results indicated that DO and total dissolved gases criteria would be met if elodea coverage were reduced to a maximum of 33% of pre-TMDL conditions between the state hatchery and Tacoma Road and to a maximum of 25% of pre-TMDL conditions between Tacoma Road and the mouth of Clarks Creek.

Stormflow analysis

During the monitored storm event of September 12, 2003, flow at the Tacoma Rd. gage was 61 cfs, about 20% above dry weather base flow, and significant flows entered through the storm drains at Pioneer Way as well as between Meeker and DeCoursey. DO observations near Tacoma Road declined to about 6 mg/L. Applying the reductions determined for baseflow conditions to this date does not achieve the DO standards, resulting in a predicted DO of 8.97 mg/L at Tacoma Road. The primary remaining source of DOD is the tributary inflows, which become increasingly important as stormflow increases.

The second monitored storm event occurred on October 21, 2003. During this large storm event, a flow of 138 cfs was observed at Tacoma Road and significant DO depression occurred. This was approximately a 2-year runoff event. Observed low DO (< 5 mg/L) was primarily due to reduced DO in storm drain and tributary inflows. As the event occurred near the beginning of the wet season, it is likely that the storm drain system had high levels of stored organic material. The date was also characterized by abnormally high temperatures for the season, with water temperature of 16 °C below the tribal hatchery, which reduced DO saturation concentrations and exacerbated oxygen-consuming biological processes. The combination of high flows and high temperatures at the start of the wet season is believed to represent a critical condition for storm event-associated DO depletion in Clarks Creek.

When the calibrated model is applied to stormflow conditions without additional changes, observed data were much lower than simulated DO, especially for the large event of October 21, 2003 (Figure B-1). This indicates that the October 21, 2003 event has additional sources of DOD.

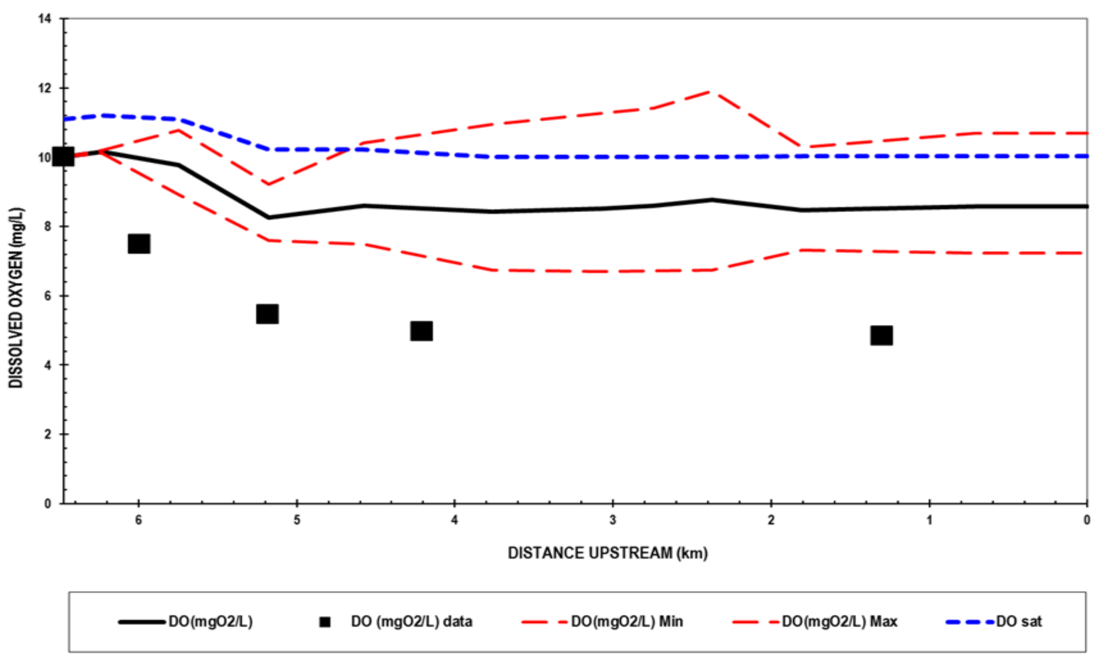

Figure B-1. Model simulation for 10/21/2003 storm event without accounting for additional DOD in stormwater and diffuse inflows.

Most notably, the baseflow model was fit with a DO concentration of 8 mg/L in diffuse inflows to the Clarks Creek mainstem. However, during storm events, the diffuse inflows are a larger proportion of the total flow and include piped stormwater discharges. During the 10/21/2003 storm event, monitoring of the 7th Avenue storm drain showed DO concentration of 3.57 mg/L, far below the DO water quality standard and below the DO concentrations under baseflow conditions. When the model reduced DO in diffuse inflows (which includes stormwater conveyances) from 8.0 mg/L to 3.57 mg/L, the fit to observed data is much improved (Figure B-2).

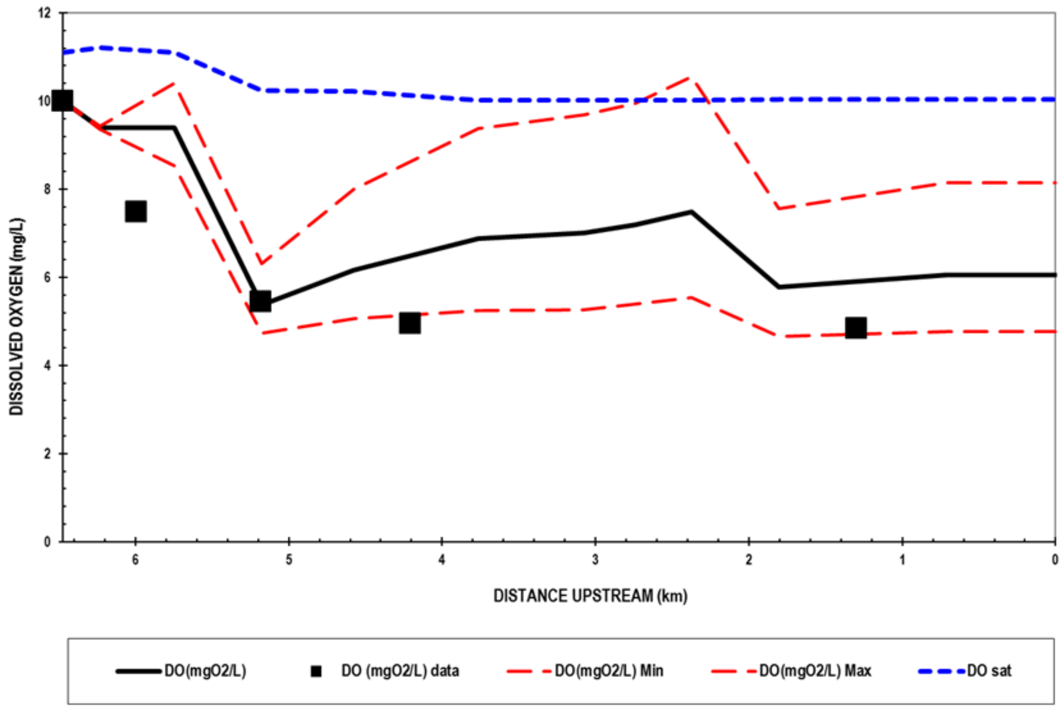

Figure B-2. Model simulation for 10/21/2003 storm event with reduced DO in stormwater and diffuse inflows.

The DO concentration in piped stormwater of 3.57 mg/L is based on a single observation and is not intended to represent all inflows and events. Rather, the exercise demonstrates that the observed DO profile can be explained by low DO concentration in the diffuse inflows. Thus, the DO excursions observed on this date are likely due to mixing of low DO stormwater and urban groundwater into the creek.

Appendix C. HSPF model report

Clarks Creek Sediment Study Watershed Model Report, Final (Tetra Tech, 2012):

www.ecy.wa.gov/programs/wq/tmdl/ClarksCreek/ClarksCrSedStudyWtrshedModelRpt.pdf

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Appendix D. Clarks Creek effective shade and elodea study.

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DEPARTMENT OF ECOLOGY
ENVIRONMENTAL ASSESSMENT PROGRAM

September 10, 2012

TO: Jenny Wu, U.S. Environmental Protection Agency
Cindy James, Washington State Department of Ecology, WQ-SWRO
Char Naylor, Puyallup Indian Tribe

FROM: Stephanie Brock, Washington State Department of Ecology, EAP-WOS

SUBJECT: **CLARKS CREEK EFFECTIVE SHADE AND ELODEA**
Project Code: 13-013

The purpose of this project is to determine the percent effective shade needed to "shade out" elodea along Clarks Creek.

Background

EPA, Ecology, and the Puyallup Indian Tribe began development of the Clarks Creek dissolved oxygen (DO) TMDL with contractor, TetraTech, in August, 2010. The study found the DO impairments in Clarks Creek are a result of complex biological interactions driven by a variety of external factors, including:

- Urban runoff associated with impervious areas, which carry sediment and organic solid loads that increase sediment oxygen demand (SOD) and reduce DO in storm drainage, reducing the average DO. Urban runoff also causes increased channel erosion in the headwaters, further exacerbating sedimentation downstream.
- Nutrient (phosphorus) loads in urban runoff, which promotes elodea nuisance growth, in turn enhancing siltation, contributing to SOD and reducing re-aeration. Sediment loads also promote elodea biomass accumulation, because they provide a favorable substrate for elodea growth. Excess elodea growth results in diurnal DO depression.
- Lack of riparian cover increases solar radiation that promotes elodea growth and also elevates water temperature, resulting in decreased DO saturation concentrations and reduced DO.

TetraTech developed a QUAL2Kw model to evaluate these complex biological interactions and estimate the pollutant reductions needed in Clarks Creek to achieve water quality standards for DO and dissolved gases. Through modeling load allocations were established in the TMDL including control of elodea density.

TetraTech could not establish riparian shading targets with the model. Therefore, the purpose of this project is to develop a relationship specific to Clarks Creek between elodea density and percent effective shade to determine the required effective shade to "limit" elodea growth.

Methods

The relationship between elodea density and effective shade was established through field measurements. Ecology took hemispherical photographs and measured channel geometry and elodea mat data at twenty-one locations along Clarks Creek between the Washington Department of Fish and Wildlife (WDFW) trout hatchery and the 56th Street bridge (Table D-1 and Figure D-1). It was important to complete the surveys prior to elodea cutting which was scheduled to begin on July 15, 2012. The surveys were completed using kayaks provided by the Puyallup Indian Tribe on June 11, 12 and 26, 2012 by Ecology and Puyallup Indian Tribe staff.

Table D-1. Clarks Creek sampling locations

Site Name	Site Description	Latitude	Longitude
CC1	Clarks Creek below the foot bridge at the WDFW trout hatchery	47.18	-122.32
CC2	Clarks Creek upstream of the 12th Ave bridge at Clarks Creek Park	47.18	-122.32
CC3	Clarks Creek downstream of the 12th Ave bridge at Clarks Creek Park	47.18	-122.32
CC4	Clarks Creek below 12th Ave, above the 1st bend after bridge	47.18	-122.32
CC5	Clarks Creek upstream of the Reese household	47.18	-122.32
CC6	Clarks Creek at the baseball fields and public access	47.19	-122.32
CC7	Clarks Creek upstream of the 7th Ave bridge	47.19	-122.32
CC8	Clarks Creek downstream of the 7th Ave bridge	47.19	-122.32
CC9	Clarks Creek downstream of DeCoursey Park outlet	47.19	-122.32
CC10	Clarks Creek ~675 ft downstream from CC9 (above Pioneer bridge)	47.19	-122.32
CC11	Clarks Creek upstream of the Pioneer Ave bridge	47.19	-122.32
CC12	Clarks Creek downstream of the Pioneer Ave bridge	47.19	-122.32
CC13	Clarks Creek at obstruction #21	47.19	-122.33
CC14	Clarks Creek at open area at WSU plot	47.2	-122.33
CC15	Clarks Creek at corner between obstruction #23 and #24	47.2	-122.33
CC16	Clarks Creek at Tacoma Rd bridge	47.2	-122.34
CC17	Clarks Creek upstream of Stewart Ave	47.2	-122.34
CC18	Clarks Creek 500 feet below 66th crossing	47.2	-122.34
CC19	Clarks Creek at/above second 66th crossing	47.2	-122.34
CC20	Clarks Creek upstream of the hatchery	47.2	-122.34
CC21	Clarks Creek at the 56th St. bridge	47.21	-122.34

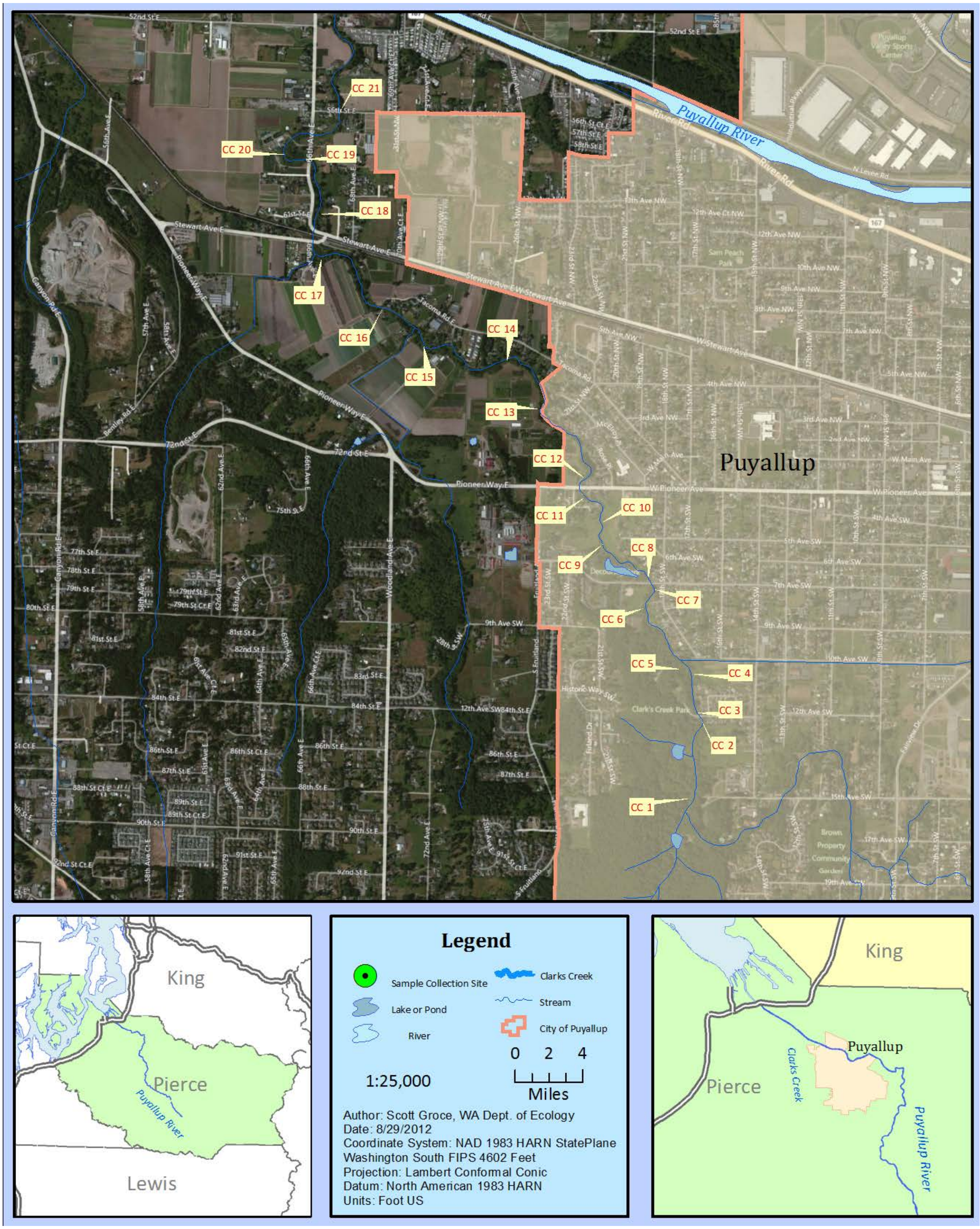

Figure D-1. Clarks Creek Elodea and Hemispherical Photo Sampling Sites.

Hemispherical photographs were collected from the stream center (where possible) using protocols specified in Standard Operating Procedures for hemispherical digital photography field surveys conducted as part of a temperature Total Maximum Daily Load (TMDL) or Forests and Fish Unit technical study (EAP045 – Stohr and Bilhimer, 2008). If the channel was too deep to wade, the photographs were taken from as close to the center of the stream as possible. Figure D-2 shows an example of a hemispherical photograph taken on Clarks Creek at the foot bridge at the state trout hatchery (site CC1).

Figure D-2. Hemispherical photograph taken at site CC1.

At each site cross section, the following measurements were taken:

- Latitude/Longitude
- Stream wetted width and depth (ft)
- Elodea density (percentage)
- Substrate coverage by elodea (percentage)
- Mat width (ft)
- Mat depth (ft)

Elodea density is defined as the density of the mat of elodea. In most cases, if an elodea mat was growing, it was 100% dense. Substrate coverage refers to what percentage of the substrate at a given cross section is covered by elodea.

The hemispherical photographs were analyzed in the office using HemiView Software © to calculate the effective shade at each site. Ecology's protocol for processing the pictures and using the software is outlined in the Standard Operating Procedures for the computer analysis of hemispherical digital images collected as part of a temperature Total Maximum Daily Load (TMDL) or Forests and Fish Unit technical study (EAP046 - Stohr, 2008).

Results

Table D-2 presents the field measurements collected at each site during the surveys. Please note, sites between the outlet of DeCoursey Park and the Pioneer Bridge and down to the 56th Street bridge have high levels of elodea growth as well as other unidentified aquatic plants. These sites also have high levels of reed canary grass which impede the active channel (in some cases, restricting a 70-foot wide wetted channel down to a 20-foot wide active flowing channel). Hard copies of the field sheets are available from Ecology upon request. Copies of the hemispherical photographs are included in this appendix.

Table D-2. Field data collected at each site during the surveys.

SiteCode	Latitude	Longitude	Wetted Width	Ave Wetted Depth	Elodea Density	Substrate Coverage	Mat Width	Mat Depth
			feet		Percent		feet	
CC1	47.18	-122.32	30	0.4	0.0	0.0	n/a	n/a
CC2	47.18	-122.32	45	2.4	100.0	44.4	20	3.0
CC3	47.18	-122.32	45	2.6	100.0	55.0	25	3.5
CC4	47.18	-122.32	*55/24	2.8	100.0	100.0	24	3.7
CC5	47.18	-122.32	53	2.8	100.0	37.7	20	4.0
CC6	47.19	-122.32	45	2.6	100.0	75.0	not measured	
CC7	47.19	-122.32	47	2.6	100.0	10.0	2	3.6
CC8	47.19	-122.32	40	2.9	100.0	50.0	20	4.0
CC9	47.19	-122.32	*75/50	2.3	100.0	75.0	38	4.2
CC10	47.19	-122.32	*70/30	2.6	100.0	100.0	30	4.5
CC11	47.19	-122.32	38	2.9	100.0	78.3	30	4.2
CC12	47.19	-122.32	49	2.9	100.0	84.5	41	
CC13	47.19	-122.33	51	3.4	100.0	60.8	31	4.5
CC14	47.2	-122.33	*61/37	3.0	100.0	100.0	37	
CC15	47.2	-122.33	*72/20	2.2	100.0	100.0	20	4.5
CC16	47.2	-122.34	26	2.8	100.0	25.0	4	4.8
CC17	47.2	-122.34	*63/14	2.6	100.0	75.0	14	3.8
CC18	47.2	-122.34	52	2.5	100.0	75.0	33	
CC19	47.2	-122.34	similar to last cross-section, not measured					
CC20	47.2	-122.34	39	2.6	100.0	56.0	22	3.8
CC21	47.21	-122.34	29	2.8	100.0	38.5	11	3.0

* Total channel width/active channel width

Prior to the start of the project, it was believed that the relationship would be developed between effective shade and elodea density. However, if elodea is growing at a site on Clarks Creek, it is almost always growing at a density of 100%. Therefore, because field staff measured the percent that substrate was covered by elodea at each cross-section, this data was used to develop the relationship between site effective shade and elodea coverage.

Figure D-3 shows the relationship between percent effective shade and the percent of the substrate coverage by elodea at each sampling site. The trendline indicates that higher percent effective shade (x-axis) results in lower percent coverage of substrate by elodea (y-axis) on Clarks Creek. The square data point is an outlier that was not considered as part of the trendline.

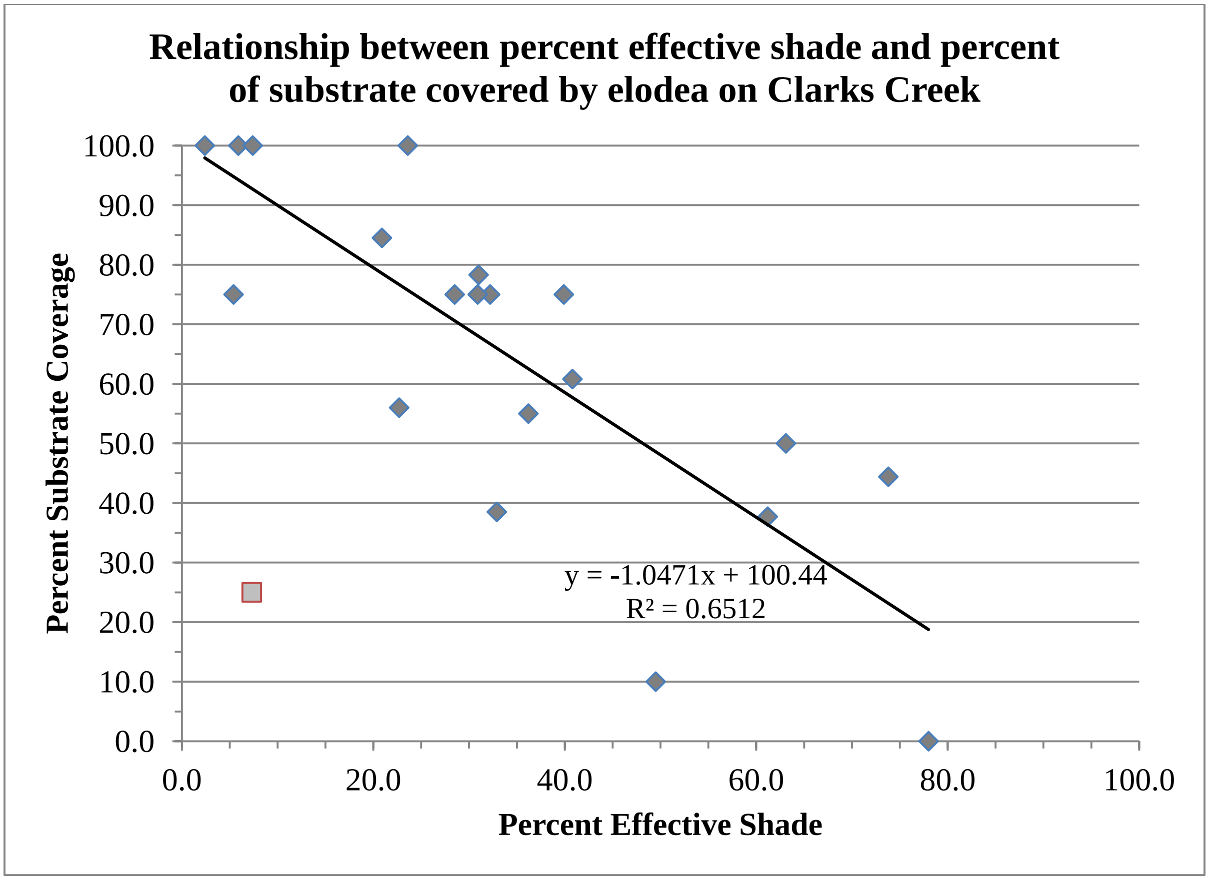

Figure D-3. Relationship between percent effective shade and substrate coverage of elodea in Clarks Creek.

Conclusions and Recommendations

The purpose of this project is to determine the effective shade needed to “shade out” elodea on Clarks Creek. The data indicate a relationship between effective shade and elodea coverage in Clarks Creek. The percent effective shade could be calculated in two ways:

1. Percent measured in the basin where the elodea is 0%. The field staff only took hemispherical photographs and surveyed one sampling site where there was no elodea. The effective shade at the site was 78%.
2. Percent calculated by the regression equation (trendline) where the elodea is 0%. This yields an effective shade of 95.9%.

It is recommended that the effective shade be determined based on the trendline calculated from the field measurements and effective shade determined for temperature TMDL studies completed in adjacent basins. Other Puget lowland streams, such as Bear-Evans and Green-Newaukum, indicate that based on Clarks Creek's width and vegetation characteristics, an effective shade of 85% is plausible and should "shade out" elodea.

It is recommended that field measurements, including hemispherical photographs and channel and elodea measurements, be repeated every 2-3 years to track progress as riparian vegetation is established along Clarks Creek and as the City of Puyallup continues to manage elodea growth through cutting and hand pulling.

References

Stohr, A. and D. Bilhimer, 2008. Standard Operating Procedures for hemispherical digital photography field surveys conducted as part of a temperature Total Maximum Daily Load (TMDL) or Forests and Fish Unit technical study. Washington State Department of Ecology, Olympia, WA. EAP No. EAP045. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_Hemispherical_%20Photography_Field_Survey_v2_0EAP045.pdf

Stohr, A. 2008. Standard Operating Procedures for the computer analysis of hemispherical digital images collected as part of a temperature Total Maximum Daily Load (TMDL) or Forests and Fish Unit technical study. Washington State Department of Ecology, Olympia, WA. EAP No. EAP046. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_046Hemispherical_Photography_Computer_Analysis.pdf

Figure D/A-1. Site CC1 - Clarks Creek below the foot bridge at the state trout hatchery.

Figure D/A-2. Site CC2 - Clarks Creek upstream of the 12th Ave bridge at Clarks Creek Park.

Figure D/A-3. Site CC3 - Clarks Creek downstreeam of the 12th Ave bridge at Clarks Creek Park.

Figure D/A-4. Site CC4 - Clarks Creek below 12th Ave, above the 1st bend after bridge.

Figure D/A-5. Site CC5 - Clarks Creek upstream of the Reese household.

Figure D/A-6. Site CC6 - Clarks Creek at the baseball fields and public access.

Figure D/A-7. Site CC7 - Clarks Creek upstream of the 7th Ave bridge.

Figure D/A-8. Site CC8 - Clarks Creek downstream of the 7th Ave bridge.

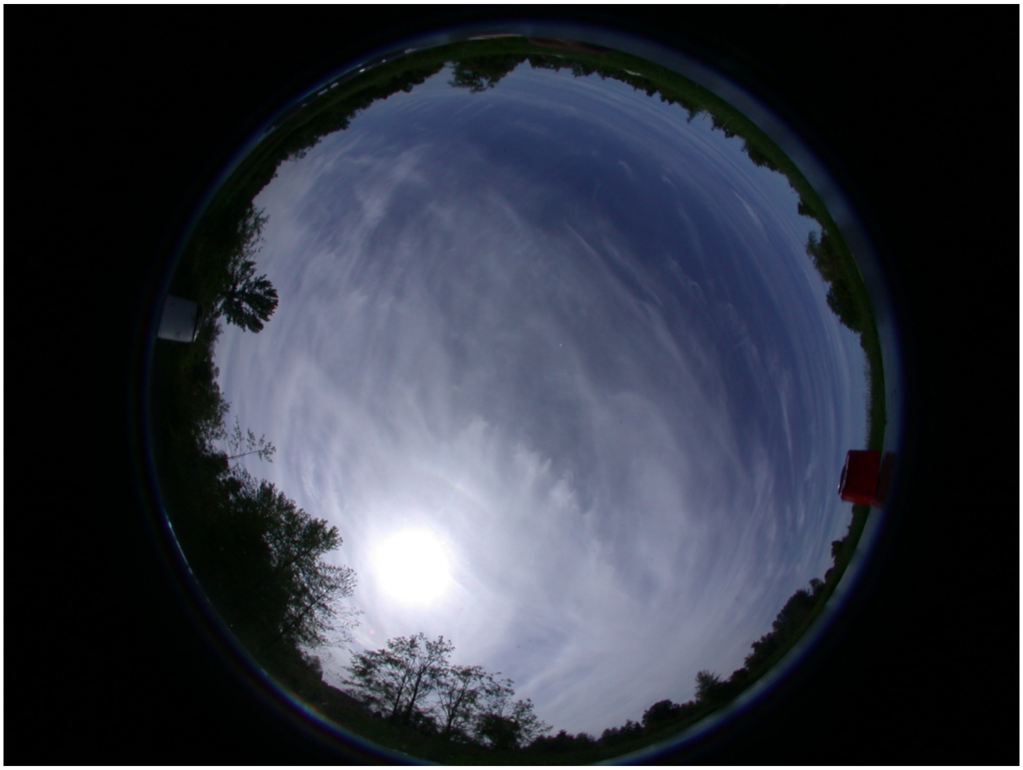

Figure D/A-9. Site CC9 - Clarks Creek downstream of DeCoursey Park outlet.

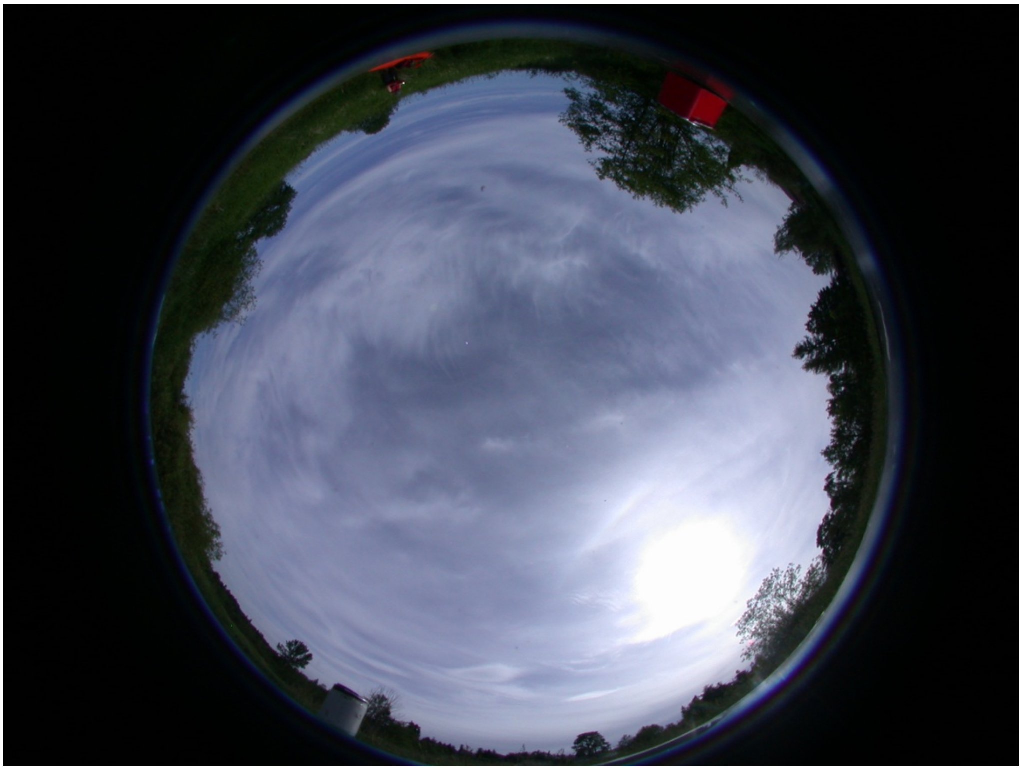

Figure D/A-10. Site CC10 - Clarks Creek ~675 ft downstream from CC9 (above Pioneer bridge).

Figure D/A-11. Site CC11 - Clarks Creek upstream of the Pioneer Ave bridge.

Figure D/A-12. Site CC12 - Clarks Creek downstream of the Pioneer Ave bridge.

Figure D/A-13. Site CC13 - Clarks Creek at obstruction #21.

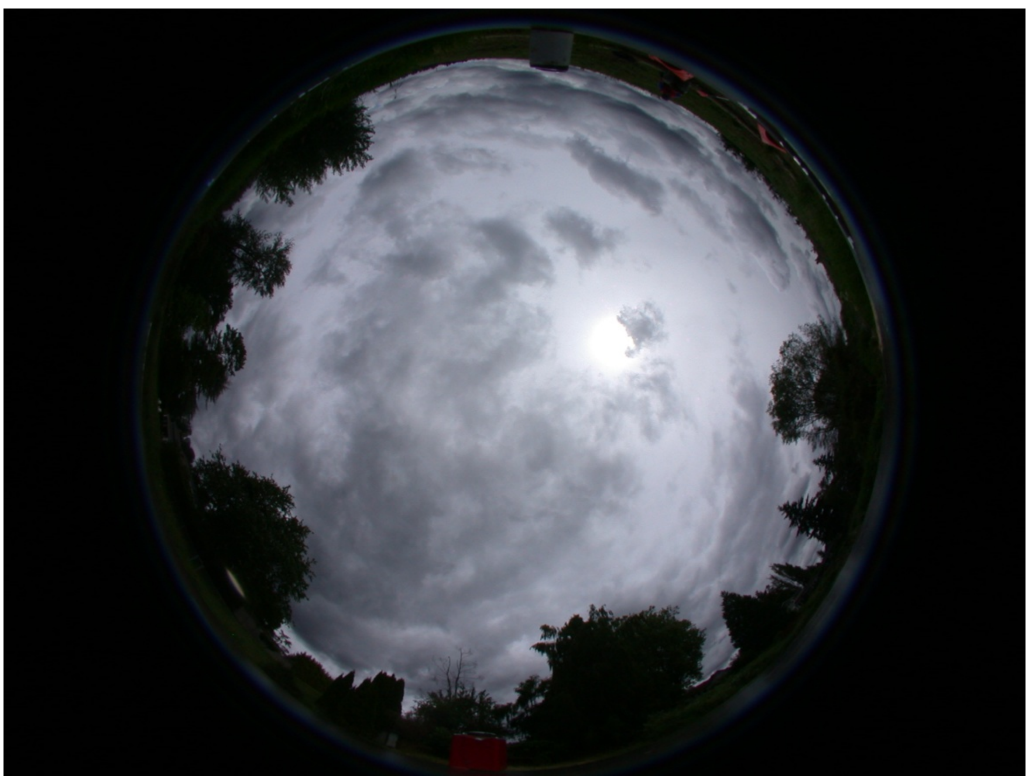

Figure D/A-14. Site CC14 - Clarks Creek at open area at WSU plot.

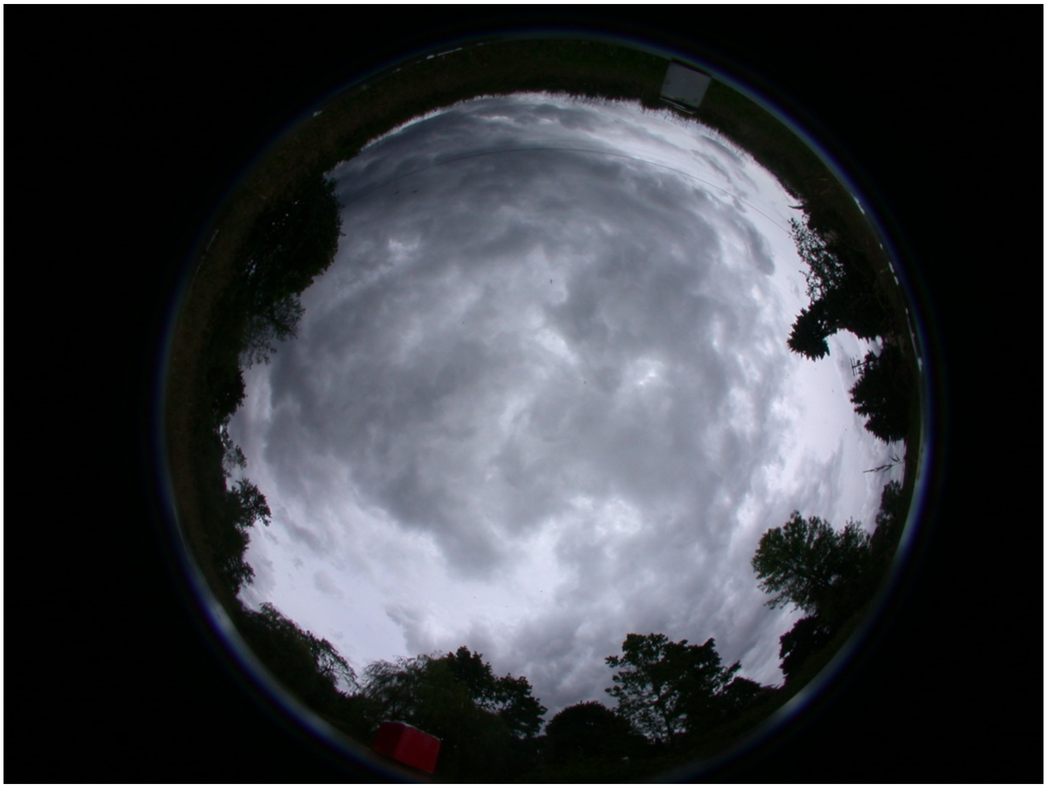

Figure D/A-15. Site CC15 - Clarks Creek at corner between obstruction #23 and #24.

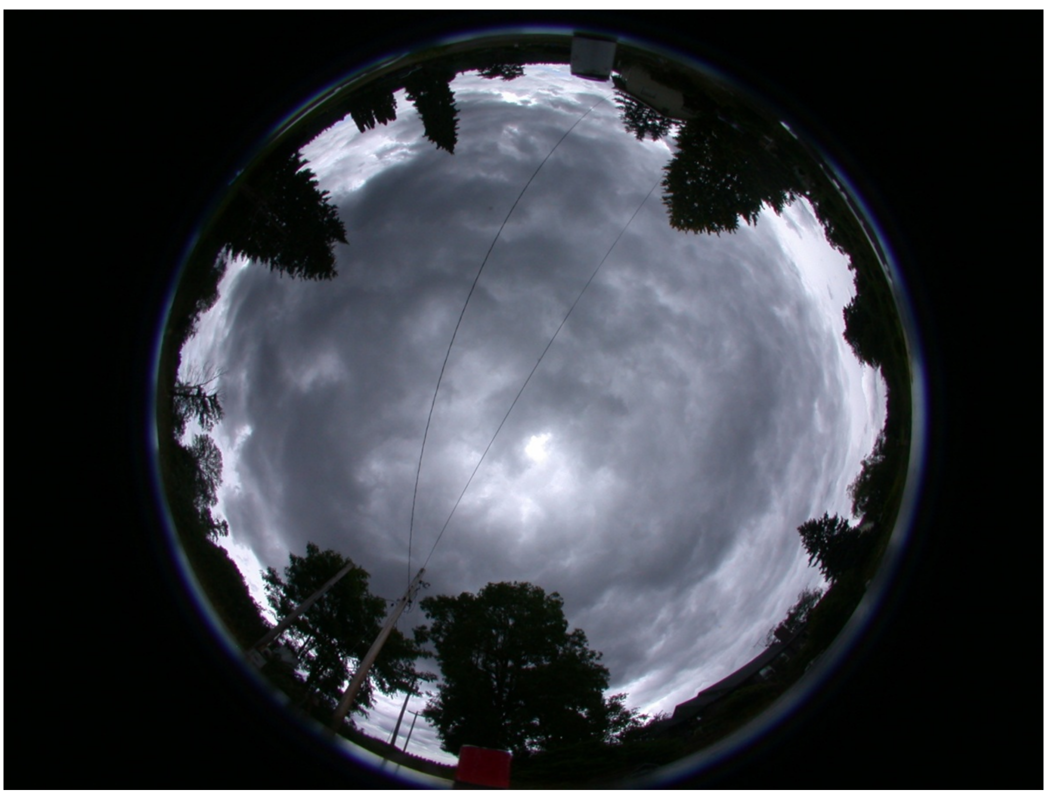

Figure D/A-16. Site CC16 - Clarks Creek at Tacoma Rd bridge.

Figure D/A-17. Site CC17 - Clarks Creek upstream of Stewart Ave.

Figure D/A-18. Site CC18 - Clarks Creek 500 feet below 66th crossing.

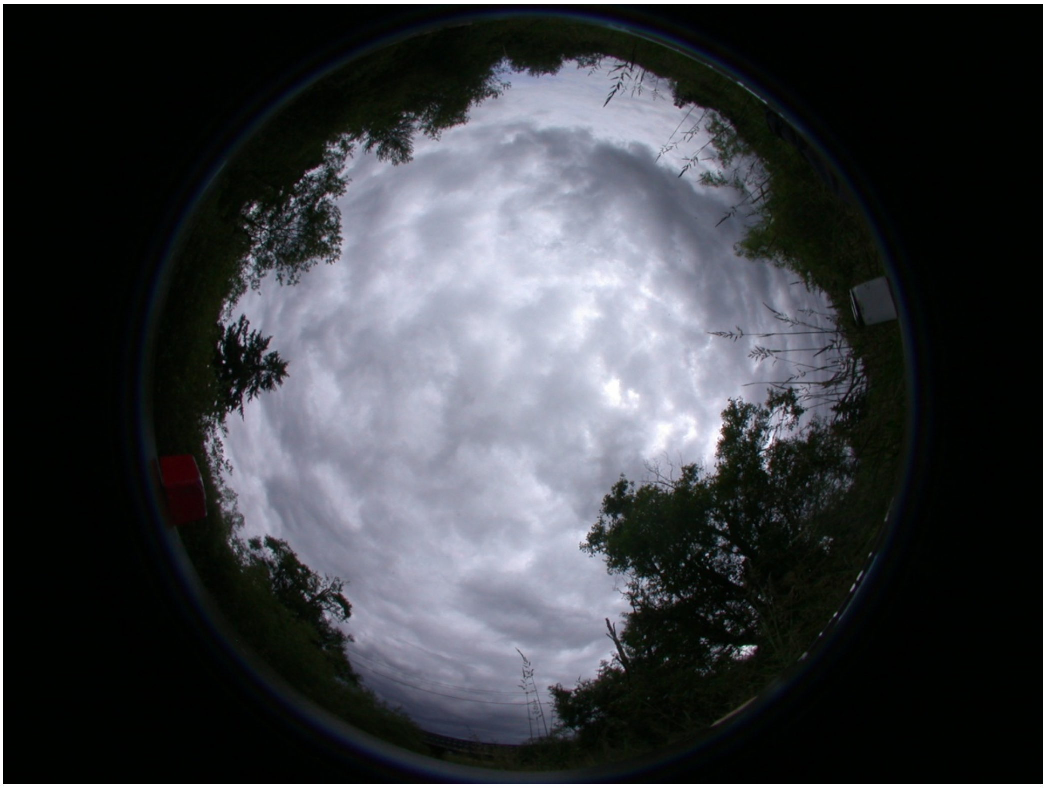

Figure D/A-19. Site CC19 - Clarks Creek at/above second 66th crossing.

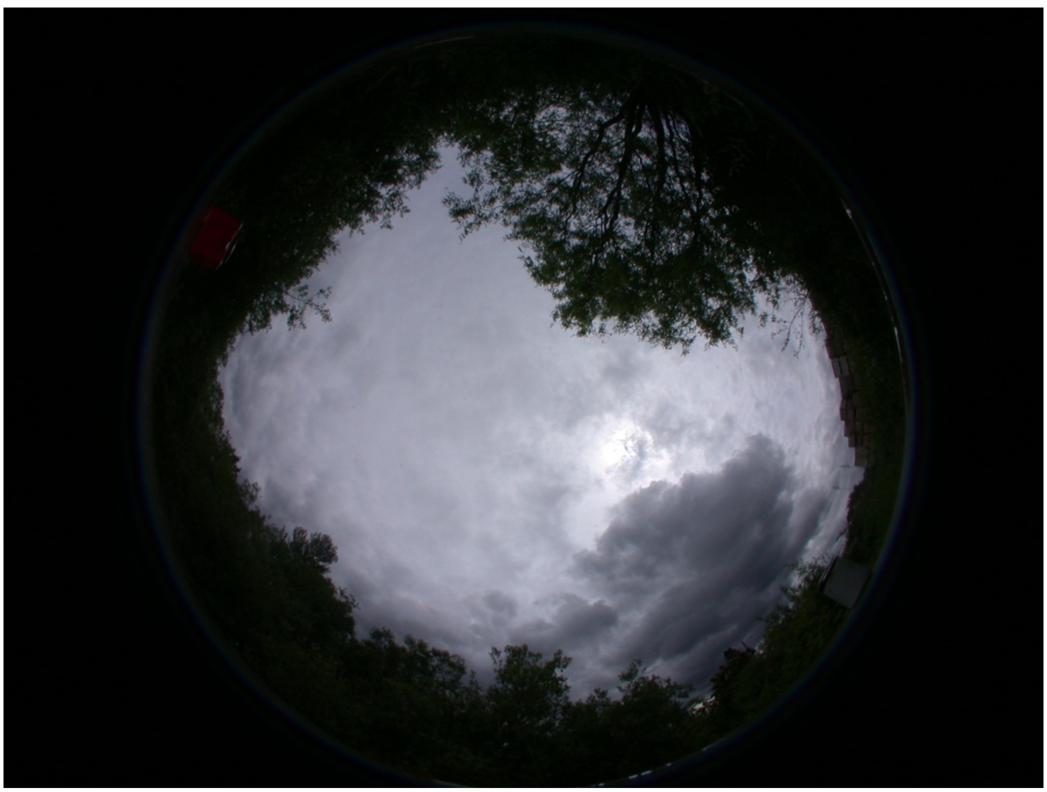

Figure D/A-20. Site CC20 - Clarks Creek upstream of the hatchery.

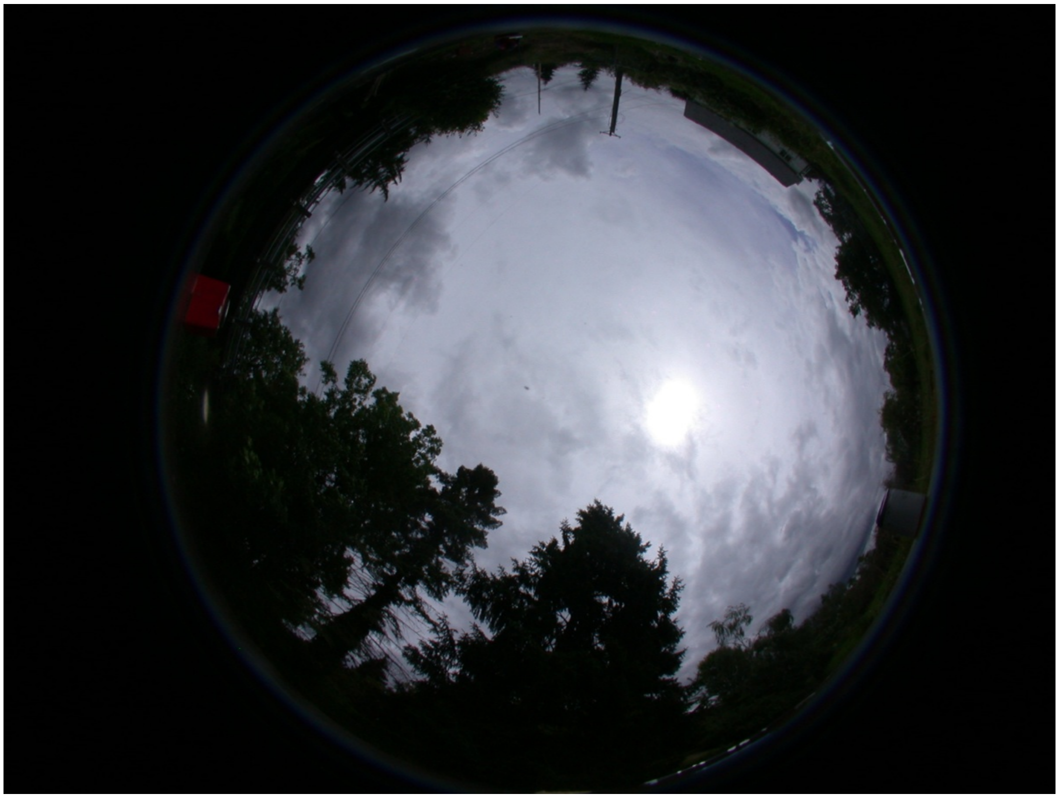

Figure D/A-21. Site CC21 - Clarks Creek at the 56th St. bridge.

Appendix E. Stormwater sampling in Clarks Creek

Stormwater Sampling in Clarks Creek, Puyallup – River Drainage (WRIA 10): Measuring Oxygen-Demanding Sources, final (Tetra Tech, 2012):

www.ecy.wa.gov/programs/wq/tmdl/ClarksCreek/ClarksCrStrmwtrRpt.pdf

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Appendix F. Detailed conceptual model

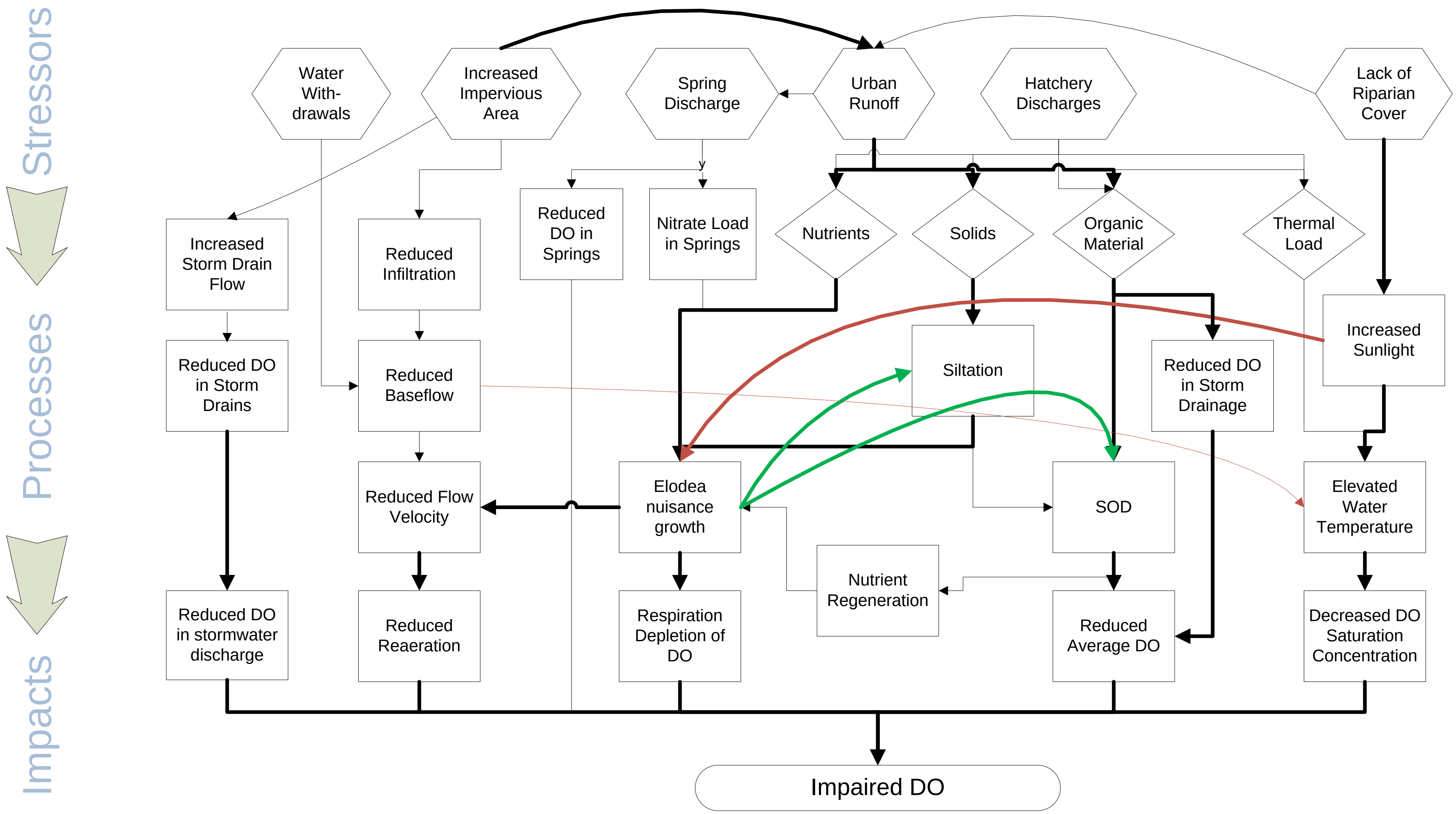

Figure F-1. Detailed conceptual model of DO impairment in Clarks Creek.

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Appendix G. DO deficit background

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DO deficit background

DO saturation concentration (DO_{sat}) is an important consideration when estimating assimilative capacity for DO. The value of DO_{sat} declines with increasing water temperature. In order to achieve high concentrations of DO in water it is essential to maintain low temperatures. In addition, the capacity of a water body to assimilate loads of pollutants that affect the oxygen balance varies as a function of water temperature. Thus, the assimilative capacity for oxygen-demanding pollutants (or other processes that deplete DO) declines with increasing temperature.

The difference between DO_{sat} and the actual DO concentration is known as the dissolved oxygen deficit (DOD). A high DOD indicates the presence of significant causes of DO depletion. DOD may also be negative, if DO concentration exceeds DO_{sat} (as often happens during periods of active photosynthesis in dense algal mats), which indicates supersaturated conditions and may trigger the "not to exceed 110%" dissolved gases criterion. The ideal situation is for DOD to be zero or close to zero. This would indicate the smallest deviation from the natural equilibrium level of DO_{sat}. Because DO_{sat} varies as a function of temperature, DOD also varies with temperature (Figure G-1).

Like DO itself, DOD can be converted to a load basis by multiplying by flow:

$$DOD\ (kg/d) = (DO_{sat} - DO) \times Q\ (cfs) \times 2.447 (\text{conversion factor})$$

DOD provides a basis for unified treatment of the different factors that alter DO in Clarks Creek. It is particularly useful for simultaneous consideration of factors that are directly translatable to upland loads (e.g., BOD in stormwater) and those that have an indirect long-term relationship to upland loads (e.g., SOD).

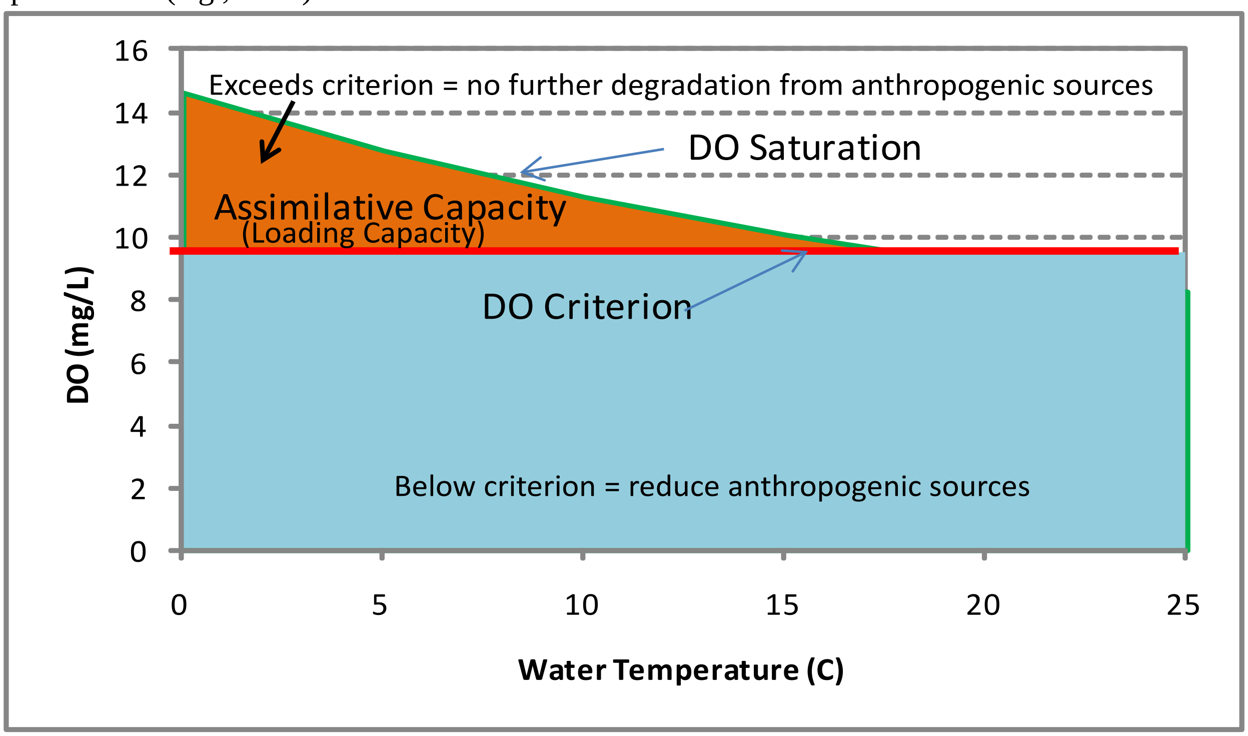

Figure G-1. Assimilative capacity as a function of DO saturation.

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Appendix H. Allocation accounting

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The following text is a reproduction of a memorandum produced by Tetra Tech on May 11, 2012.

Recap of the Stormwater Allocations

The Clarks Creek stormwater allocations have two components, stated as follows:

1. Reduce by 50% untreated stormwater volume (by reducing the volume or by treating) in Meeker Creek, 7th Avenue, Pioneer Way conveyances, Rody Creek, Diru Creek, Woodland Creek and tributaries.
2. Reduce geomorphically significant flows to Clarks Creek upstream of the State Hatchery and to Rody, Diru, Woodland and Silver Creeks.

It is important to note that these two components are separate from one another and defined in different ways – although a single BMP project could well count to the implementation of both components.

The stormwater volume reduction or treatment allocation is defined relative to the storm event of 10/21/2003, which has been analyzed with both the HSPF and QUAL2Kw models. Note that this allocation does *not* apply to Clarks Creek upstream of the State Hatchery nor to minor stormwater conveyances to the Clarks Creek mainstem other than those explicitly described above.

The geomorphically significant flows component addresses long term channel stability and is *not* specifically tied to the 10/21/2003 storm event. Instead, this component applies to the hydrograph resulting from all storm flow that enters the drainage system upstream of stream reaches identified as at risk of erosion. It should be noted that this component of the TMDL encourages BMPs that reduce stormwater flow in the upper watershed and tributaries compared with stormwater treatment, as erosive flows in these areas cause significant sediment loading in Clarks Creek.

Volume Reduction or Treatment Allocations

The storm flow volumes from which the volume reduction or treatment allocations are estimated for each jurisdiction are obtained from the HSPF model of the 10/21/2003 event. Specifically, the modeled unit-area flow generated by each hydrologic response unit or HRU (less the baseflow or groundwater component) are tabulated for October 21 and October 22, 2003 (as runoff persisted into the following day). This provides a quantitative basis for evaluating reduction needs and potential implementation projects. Other summation periods (or other watershed models) could have been chosen, but what is important is the use of a consistent basis for comparison.

The allocations consist first of wasteload allocations applied to the MS4 permits of the city of Puyallup, Pierce County, and WSDOT. There is also a general load allocation that applies to properties that drain directly to the stream network without entering the MS4 conveyance system.

To calculate the amount of stormwater flow volume that needs to be either treated or detained by a jurisdiction in a given drainage area, the WLA is set equal to one-half the stormwater flow volume predicted to be generated by the HSPF model for the 10/21/03 event from HRUs within that jurisdiction and drainage area. Table H-21 provides percent of drainage area represented by each jurisdiction. Table H-22 shows the total stormwater flow volume for the 10/21/03 event originating within each jurisdiction by conveyance. Table H-23 gives the wasteload allocations in terms of untreated stormwater flow volume (50% reduction of stormwater flow volumes from Table H-22) to be reduced.

Table H-21. Jurisdictional Responsibility for Clarks Creek Stormwater Volume Reduction or Treatment (Percentage of drainage area)

Jurisdiction	Whole watershed	Meeker	Pioneer + 7th	Woodland	Diru	Rody
City of Puyallup MS4	45.6%	70.9%	97.9%	17.4%	0.5%	0.0%
Pierce Co. MS4	38.2%	1.2%	0.0%	75.9%	93.1%	62.3%
WSDOT MS4	2.9%	4.3%	1.4%	2.8%	2.4%	2.9%
General LA	13.4%	23.7%	0.7%	3.9%	4.0%	34.8%

Table H-22. Total Stormwater Flow Volume by Conveyance and Jurisdiction (million gallons for 10/21/03 event)

Jurisdiction	Whole watershed	Meeker	Pioneer + 7th	Woodland	Diru	Rody
City of Puyallup MS4	82.9	26.9	12.7	6.2	0.1	0.0
Pierce Co. MS4	69.5	0.4	0.0	26.8	20.4	11.9
WSDOT MS4	5.2	1.6	0.2	1.0	0.5	0.6
General LA	24.4	9.0	<0.1	1.4	0.9	6.7

Table H-23. WLAs Expressed as Untreated Stormwater Flow Volume Reductions Needed for Meeker Creek Conveyance, Pioneer Way plus 7th Avenue Conveyance, Woodland Creek, Diru Creek, and Rody Creek (million gallons for 10/21/03 event, rounded)

Jurisdiction	Meeker	Pioneer + 7th	Woodland	Diru	Rody	Sum
City of Puyallup MS4	13.5	6.4	3.1	<0.1	0.0	23.1
Pierce Co. MS4	0.2	0.0	13.4	10.2	6.0	29.8
WSDOT MS4	0.8	0.1	0.5	0.3	0.3	2.0
General LA	4.5	<0.1	0.7	0.4	3.3	8.9

Geomorphically Significant Flows Allocations

The geomorphically significant flows allocations have not yet been fully defined, but are expected to emerge soon from the Puyallup Tribe's sediment reduction project. It is likely that these will focus on the steep portions of Clarks, Silver, Woodland, Rody, and Diru Creeks where they descend from the Vashon Till to the alluvial plain. The resulting allocations will likely be similar in approach to the Western Washington Stormwater Manual Standard Flow Control Requirement for new development in which storage is required to match developed discharge durations to pre-developed discharge rates from 50% of the 2-year peak flow up to the full 50-year peak flow. The difference from the Standard Flow Control Requirement is that it is unlikely that a full match to pre-developed discharge rates would be needed (or feasible for all existing development). Instead, this allocation is likely to require hydrograph matching to pre-development conditions under a different, potentially smaller range of flow recurrence intervals based on site-specific analysis of the stability of the stream channels. In particular, the allocation could define a lower bound for matching that is greater than the 0.5Q2 default, which could allow for a smaller total design storage volume, since an important constraint on the design volume is to provide sufficient storage or removal to draw down large storm events at rates below the lower bound for hydrograph matching.

Evaluating Projects Relative to the Stormwater Allocations

Evaluating Stormwater Volume Reduction or Treatment Allocations

The stormwater allocations are specified as a reduction in the volume of untreated stormwater. This can be achieved either by reducing the volume directly or by converting untreated stormwater to treated stormwater. Although the TMDL encourages BMPs that reduce flow volume, especially in the upper watershed, there are treatment BMPs that may also help meet the stormwater allocation targets and improve the habitat in Clarks Creek.

For implementation planning, an accounting method is needed to evaluate how far a given treatment approach goes toward meeting the overall stormwater allocation goal. For example, a stormwater diversion project yields a directly estimable reduction in volume. How can this be evaluated relative to filtration BMPs (which provide treatment but not volume reduction) or a riparian area restoration project (which provides some volume reduction and some treatment)? The following section proposes a method by which a variety of stormwater-treatment BMPs could be evaluated as to their ability to achieve stormwater allocations.

Evaluating the tradeoffs between volume reduction and treatment requires a definition of "treatment" and a method to convert between treatment and volume. For Clarks Creek, the reduction in untreated stormwater volume is intended to achieve a variety of benefits, including reductions in sediment loads, reductions in phosphorus loads that support elodea growth, and reductions in organic matter loads that contribute to SOD. Both phosphorus and organic matter loading are strongly associated with the washoff of particulate matter in stormwater. Therefore, it makes sense to account for treatment in terms of reductions in solids load.

A basis for conversion between volume reduction and treatment can then be established by specifying the solids reduction efficiency that constitutes adequate treatment. The draft Western Washington Hydrology Manual (Volume 5, Section 3.5) presents a Basic Treatment Menu (BTM) that applies to most projects and presents a variety of BMP facility designs. These designs are derived to be consistent with a performance goal, as the BTM facility choices "are intended to achieve 80% removal of total suspended solids for influent concentrations that are greater than 100 mg/L, but less than 200 mg/L. For influent concentrations greater than 200 mg/L, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/L, the facilities are intended to achieve an effluent goal of 20 mg/L total suspended solids. The performance goal applies to the water quality design storm volume or flow rate, whichever is applicable."

The BTM provides a baseline for evaluating whether a stormwater BMP performs well enough to achieve the desired "reduction in the volume of untreated stormwater."

Facilities that are designed consistent with the BTM are automatically assumed to meet the TMDL volume reduction or treatment allocation requirement. Stormwater that is treated by such a facility is accounted the same as if the stormwater had been removed from the system. Designs that are not in the BTM but can be demonstrated to achieve comparable levels of removal would also receive full credit (but not more than a 1:1 match). Note that the geomorphically significant flow allocation must also be met – which should provide an incentive for projects that provide retention or removal of flow in areas upstream of geomorphically sensitive reaches.

Other retrofit or stream improvement projects may not achieve the performance targets of the BTM, but should still receive partial credit toward the volume reduction or treatment goal. The accounting can be done on the basis of suspended solids removal. For example, consider a channel restoration project that is anticipated to achieve a 20 percent removal of solids on a storm flow (for the 10/21/03 event) of 100 MG. The credit toward the needed "reduction in the volume of untreated stormwater" can be calculated by comparing the design removal rate of 20 percent to the target removal rate of 80 percent. That is, the project would be accounted as meeting 100 MG x 20%/80% = 25 MG.

This approach will allow the comparison and crediting of all types of BMPs and improvements that may contribute to the overall load reductions and water quality improvement goals. In addition to flexibility, it provides a common metric that can be used in cost-benefit comparisons between different projects. A library of modeled unit area (per-acre) flows by HRU is available and can be used to evaluate any candidate project.

Evaluating Geomorphically Significant Flow Allocations

Details of the geomorphically significant flow allocations have not yet been finalized. However, it appears likely that progress toward this goal can be evaluated in a manner similar to the analysis proposed for Phase I retrofit projects in the draft Phase I permit. The Phase I permit analysis calculates a volume ratio, where the volume ratio is equal to the actual storage volume provided by the project divided by the storage volume required if the project had to meet the Standard Flow Control Requirement (matching the pre-development hydrograph between 0.5Q2 and Q50).

The geomorphically significant flows component of the Clarks Creek TMDL may involve a different range of flow controls than the Standard Flow Control Requirement for application to existing development. However, the associated storage volume to achieve the needed flow controls can be calculated in the same manner as in the Western Washington Hydrology Manual (e.g., with the WWHM). Further, the volume ratio approach can still be applied, in which a project is rated on the basis of the storage volume provided divided by the volume required if the project had met the geomorphically significant flow allocation requirement.

Once additional information is obtained on the at-risk reaches for which geomorphically significant flows need to be controlled, evaluation of total progress toward meeting the TMDL requirements can be estimated by comparing the storage volume provided by a project to that which would be required if the project provided the full storage volume that would meet the geomorphically significant flows target for that reach.

Note that the Standard Flow Control Requirement will still apply to most new development and redevelopment. For such projects, the more stringent of the two flow control requirements would apply. (It is anticipated but not yet certain that the Standard Flow Control Requirement will be more stringent.)

For accounting purposes, it is worthwhile to note that the majority of direct storm flows in the Clarks Creek watershed arise from effective impervious surface runoff. Therefore, the accounting or comparison between different projects that achieve progress toward geomorphically significant flows can use the volume ratio weighted by the fraction of existing impervious area contributing to the reach where such controls are needed.

Evaluating Individual Projects

Defining what counts as “treated” and equivalencing to sediment removal provides the key to effective analysis of both small and large projects and their summation towards a total implementation goal. How this might work in practice is best shown by preliminary analysis of some of the projects that are already under consideration.

Pierce County Projects

Pierce County has provided preliminary designs for two projects and has additional proposed projects described in the 2012 Grant Program Application.

59th Ave. E (R1)

This project was proposed to treat 2.54 acres of pervious developed land and 0.59 acres of impervious road surface on Rody Creek with filter cartridges, followed by an infiltration trench. This area would be subject to both the volume reduction or treatment and the control of geomorphically significant flows requirements.

Filter cartridges are not specifically included in the BTM; however, evidence is presented that the filter cartridges will achieve 80-90% removal of suspended solids; further, additional removal of suspended solids will occur in the infiltration trench. Therefore, this application should achieve the definition of fully “treated” for analysis of stormwater volume reduction relative to the 10/21/03 event.
Complete geospatial information on the site is not yet available, but the relevant HRUs for the pervious land and impervious land were tentatively identified and linked to the HSPF model output. Together, the stated acreage of these HRUs produces 0.0647 MG for the 10/21/03 event. The project thus achieves 0.0647/6.0 = 1.1% of the county’s obligation to reduce storm flow volume to Rody Creek or 0.0647/29.8 = 0.2% of the county’s total obligation to reduce storm flow (see Table H-23).

The project will also achieve some benefits on geomorphically significant flows, due to the use of the infiltration trench which is assumed to achieve a 50% reduction volume. This would be compared to the volume required to fully meet the geomorphically significant flows requirement for the 0.59 acres of impervious land treated.

A simple schematic representation of the evaluation of this project is shown in Figure 56.

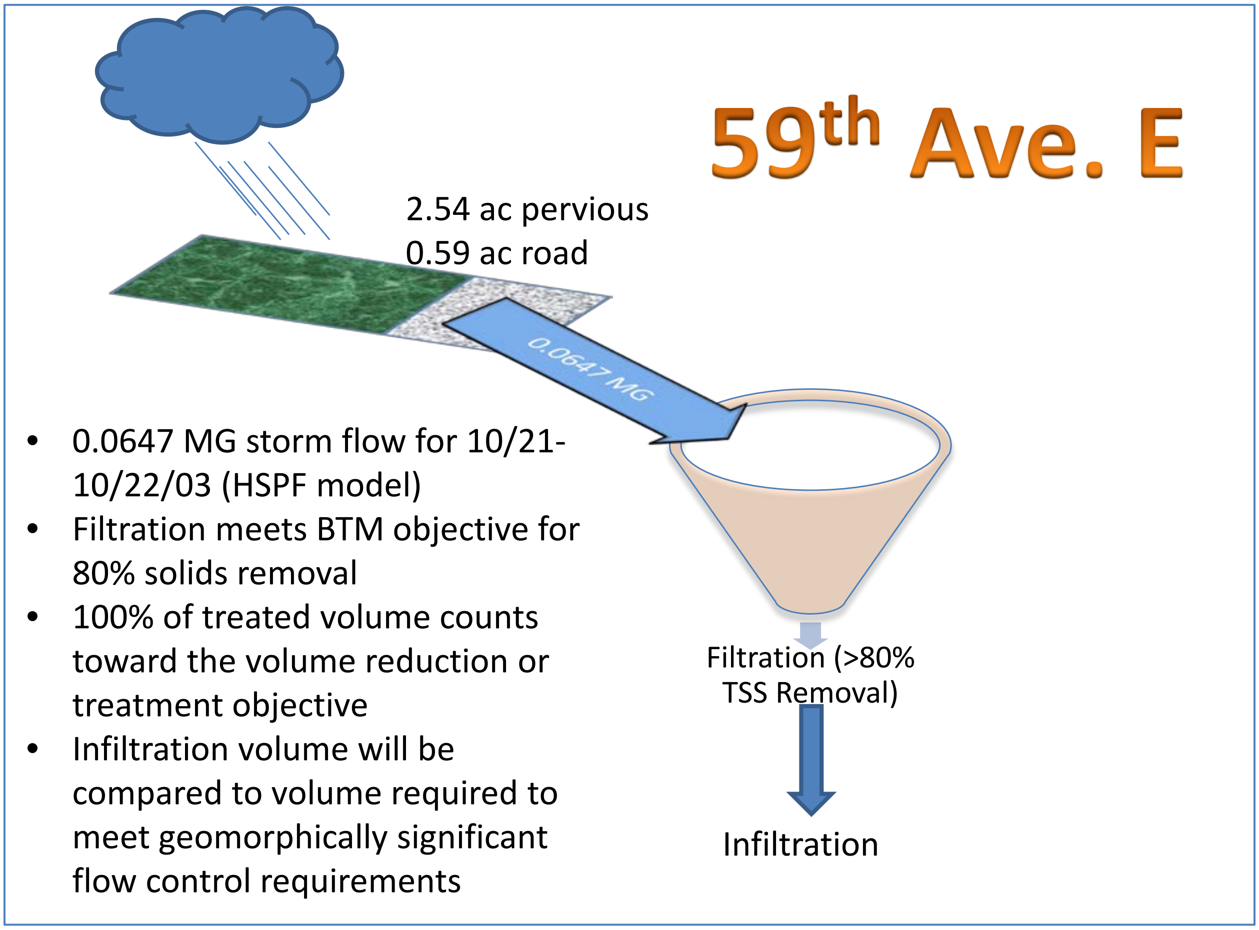

Figure 56. Schematic Representation of Pierce County Project R1

59th Ave. E /87th St. E (R2)

This project applies biofilter catchbasins with a backup cartridge system to 6.30 ac of medium density residential pervious land and 0.63 acres of impervious pavement draining to Rody Creek. Evidence is presented that the treatment train should achieve greater than 80 percent removal of solids. Analysis for volume reduction or treatment is similar to the previous project, with full credit for the treated flows of 0.087 MG for the 10/21/03 event, or 0.3% of the county's total reduction obligation.

Determination of any credit relative to geomorphically significant flows would require comparison of the storage volume of the catchbasins to the storage volume calculated with a hydraulic model to meet the geomorphically significant flow requirements.

Detention Pond on Woodland Creek (W3)

This project would install a wet detention pond at the outlet of model subbasin 147 – where Woodland Creek enters the city limits. If the pond is sized according to the BTM or otherwise achieves 80% TSS removal then volume reduction credit would apply to the entire drainage area upstream (if not, the credit would be pro-rated).

The analysis is complicated by the fact that the contributing watershed includes lands under the jurisdiction of each of the three permittees, as well as land draining directly to the creek. The model flows and percentages of the total reduction obligations are shown below (assuming the pond is designed to achieve 80 percent solids removal). This major project could achieve 72% of the County's total volume reduction target and nearly 50% of WSDOT's assignment, as shown in the following table.

	City	County	WSDOT	General Load Allocation
Total Treated/Detained Stormwater Flow (MG)	0.135	21.51	0.996	0.303
Percent of Total Volume ReductionTarget	0.42%	72.18%	49.78%	3.40%

It is not yet clear what geomorphically significant flow allocations will be developed for Woodland Creek above reach 147. However, if such allocations are established, the value of this project would be estimated using the volume ratio – that is, comparing the size of the proposed pond to the storage volume that would be needed to control geomorphically significant flows. There are estimated to be 164.7 acres of impervious surface upstream of the proposed detention pond out of the total 251.8 acres of impervious surface in the whole of the Woodland Creek watershed; however, the compliance point for geomorphically significant flows in Woodland Creek has not yet been established.

72nd St. E Stormwater Improvements

Pierce County's 2012 grant application includes a proposal to treat runoff at 72^{nd} St. E using filter cartridges. The contributing area drains "approximately 4.2 acres of mostly 4-lane arterial." While further detail is needed for a complete analysis, calculations of the volume reduction benefit are made, for example, assuming that the treated runoff is 4.2 acres of paved road and that the filtration system achieves BTM performance goals. These road surfaces are estimated to have produced 4.18 in of runoff during 10/21-10/22/2003, so the total treated volume from 4.2 acres is 0.477 MG. This is equal to 7.95% of the county's volume reduction target for Rody Creek and 1.60% of the county's total volume reduction target.

As only filtration is proposed, this project would presumably not receive credit toward control of geomorphically significant flows.

Rody Pond Retrofit and Bioretention/Biofiltration

Also as part of the 2012 grant application, Pierce County proposed to retrofit an existing pond on Rody Creek, while also providing bioretention and biofiltration for runoff from 30.2 acres of adjoining residential land. The residential land (all within the county jurisdiction) appears to be mostly high density on C soils with low slopes, and about 75 percent impervious (HRU 521). The pond retrofit is intended primarily to provide outlet control of the 2-yr, 10-yr, and 50-yr flows.

This project provides an example of some of the issues involved in evaluating treatment trains, as both the pond and the bioretention/biofiltration components will provide solids reduction, but the area to which bioretention/biofiltration is applied is upstream of the pond and should not be credited twice.

For the bioretention/biofiltration component, the net runoff for the 10/21/03 event from the pervious and impervious portions of HRU 521 is 2.49 in. Assuming the treatment is designed consistent with the BTM, this part of the project can receive credit for treating 2.042 MG – which is 34% of the county's volume reduction objective for Rody Creek and 6.85% of the county's total volume reduction objective.

The solids removal efficiency of the pond is not estimated, but the ratio of the pond area to upstream contributing area is about 0.012, so low efficiency is expected. For the purposes of example, a removal rate of 12 percent is used. Total upstream flow for the 10/21/03 event derives from county MS4, WSDOT, and direct drainage. Flow originating from the county MS4 is estimated as 8.715 MG; however, this is corrected downward by removing the 2.042 MG already credited for the bioretention/biofiltration component. The remaining flows would receive a volume reduction credit based on the ratio of anticipated solids removal to the BTM performance objective of 0.12/0.80 = 0.15:

	City	County	WSDOT	General Load Allocation
Total Flow (MG)	0	8.715	0.546	3.90
Credited Flow (MG)	0	(8.715-2.042)x0.15 (pond) + 2.042 (bioretention) = 3.042	0.546x0.15 = 0.082	3.90x0.15 = 0.585
Percent of Total Flow Reduction Target	0%	10.21%	4.10%	6.57%

This part of Rody Creek will also be subject to geomorphically significant flow targets, although these have not yet been determined.

City of Puyallup Projects

The City has already developed a plan for a major stormwater diversion, which would be a direct step toward meeting the TMDL volume reduction goals. Mark Palmer, City Engineer for Puyallup, has informally proposed a variety of other projects, which are also discussed below.

15th Street Diversion

The City of Puyallup has proposed diverting much of the storm flow from 15^{th} St. and Pioneer Avenue to the Puyallup River, removing it from Clarks Creek. This direct removal of storm flow is easily accounted on a volume basis, using the HSPF model simulation.

All flow above the diversion point is part of the City MS4 jurisdiction. For the event of 10/21/03, the simulated flow volume above the diversion is 17.9 MG – or 56 percent of the total volume reduction target assigned to the city.
This project is located in the alluvial plane and not subject to geomorphically significant flow requirements.

Stabilization of the Ravine Channel

The area ravine channel of the Clarks Creek mainstem, upstream of the State Hatchery, is not subject to the proposed stormwater volume reduction or treatment targets, but is a key area for the geomorphically significant flow requirements. In his email of March 6, 2012 Mark Palmer suggested that stabilization of the ravine channel is likely "to be more cost effective than trying to reduce the flows upstream of the ravine to the geomorphically significant flow… This would allow development to occur upstream, using the current standards… which would be actually moving the current flows closer and closer to the geomorphically significant flows over time."

At first glance, this project would not seem to fit into the assessment framework described in Section 0. However, a consistent analysis is possible. The primary impact of successful stream stabilization would be to change the amount of work done on the channel by a given flow – both by lowering velocities and changing the critical shear stress for channel degradation. In other words, stabilization (if approved) would potentially change the target for geomorphically significant flows, resulting in a revised target for hydrograph matching in the stabilized reaches. Thus, this project could be evaluated as a change in the target, and not as progress to the previously defined target. The recalculated geomorphically significant flow objective would still need to be met.

Hatchery Pond Retrofit

A proposal has been advanced to retrofit the pond at the WDFW Hatchery to provide better solids retention, among other benefits. Area constraints mean that even after retrofit the size and volume of the pond would be small relative to the drainage area, so a high rate of performance is not anticipated. Very preliminary analysis by Tetra Tech suggested that it might be possible to trap about 28.1 percent of the sediment originating upstream (including channel erosion in the ravine).

The specific location of the Hatchery Pond is not explicitly mentioned for either storm water volume reduction/treatment or control of geomorphically significant flows: The volume reduction or treatment requirement is not applied to flows from above the State Hatchery, and the stream segments at risk for channel degradation appear to be mostly upstream of the pond location. Although volume reduction or treatment is not required for storm flows originating above the State Hatchery, it is appropriate to allow some of the overall volume reduction or treatment targets (calculated from flows originating downstream of the WDFW Hatchery) to be achieved from the upstream reaches. Thus, the treatment of the 10/21/03 storm flows from upstream of this project would be credited toward the flow volume reduction or treatment targets using the ratio of 28.1%/80% = 0.351, with the following results:

	City	County	WSDOT	General Load Allocation
Total Flow (MG)	5.88	5.59	1.12	1.73
Credited Flow (MG)	2.07	1.96	0.39	0.61
Percent of Total Flow Reduction Target	6.46%	6.59%	19.65%	6.83%

Meeker Channel Restoration and Riparian Habitat

The city has a funded project on a 3-acre parcel to restore a natural channel form, provide access of storm flows to the flood plain, and do heavy riparian plantings. This point in the system is subject to volume reduction or treatment objectives but not the geomorphically significant flow objectives. The upstream drainage includes land area in all three MS4 jurisdictions as well as direct-drainage load allocations.

The project should result in increased deposition and retention of sediment on the flood plain during storm events. If information is developed to estimate the fraction of sediment load currently passing this point that will be trapped as a result of the restoration project then a credit relative to upstream flow volume could be estimated as follows:

1. Calculate total upstream storm flow for the 10/21/03 event using the model output.
2. Subtract storm flow already credited to upstream BMPs.
3. Multiply by the ratio of anticipated solids removal to the BTM objective of 80% removal.

It is likely, however, that it will be very difficult to develop an estimate of the long-term solids retention capabilities of the restored channel and riparian area with a high degree of assurance – in which case it may not be possible to assign a volume reduction credit to upstream flows.

The project can be credited as achieving treatment on the 3-acre parcel itself, which presumably is part of the general load allocation.

Riparian Plantings

The city suggests acquiring property or conservation easements along the creek and increasing riparian plantings, as well as additional riparian planting on property adjacent to the creek that is already owned by the city. These would result in volume reduction credits relative to the general load allocation and/or the city MS4 (depending on ownership). The amount of the credit would depend on the flow generated during the 10/21/03 event (as simulated by the model) and the amount of sediment reduction attained. If the riparian planting plans are sufficient to meet BTM designs for biofiltration, full credit could be applied; if not, the volume credit would be discounted as described above.

End-of-pipe Treatment

For other stormwater outlets to the creek, the City suggests retrofit with end-of-pipe water quality systems to reduce pollutant loading. “Due to iron bacteria issues, these will most likely consist of dynamic separator devices versus filter type treatment systems." Credits for these types of retrofits could again be assigned based on the documented device removal efficiency for solids relative to the BTM performance goal of 80 percent removal.

The allocations, as currently written, call for a reduction in untreated stormwater volume by 50% "in Meeker Creek, 7th Avenue, Pioneer Way conveyances, Rody Creek, Diru Creek, Woodland Creek and tributaries." Volume reductions or treatment are not explicitly required in small conveyances direct to the Clarks Creek mainstem that are not named in this list; however, these conveyances do contribute pollutants to the Creek. As with the Hatchery Pond project, discussed above, it is recommended to allow reductions on loads from these other small conveyances to count toward the total storm flow volume reduction or treatment goal.

Summary of Reductions

If all the projects described above were implemented, substantial progress would be achieved toward meeting the volume reduction or treatment objectives. Table H-24 provides a preliminary summation of volume reduction credit estimates and shows that if all the proposed projects were built a substantial portion of the target reductions could be achieved. (Note that these estimates are based on preliminary unverified assumptions. For example, the credit assigned to the Woodland Creek Pond could be substantially lower if the design does not achieve 80 percent solids removal.) Potential progress toward meeting the geomorphically significant flow target is less certain, as this aspect of the project has yet to be fully defined.

Table H-24. Preliminary Summary of Volume Reduction Credits (MG) from Proposed Projects

Project	City of Puyallup	Pierce County	WSDOT	General Load Allocation
59th Ave R1	-	0.066	-	-
59th Ave R2	-	0.087	-	-
Woodland Cr Pond W3	0.135	21.509	0.996	0.303
72nd St. E	-	0.477	-	-
Rody Pond	-	3.042	0.082	0.585
15th St. Diversion	17.936	-	-	-
Hatchery Pond	2.067	1.964	0.393	0.608
Ravine Stabilization	-	-	-	-
Meeker Channel	?	?	?	✓
Riparian Planting	✓			✓
End-of-pipe retrofits	✓			

Project	City of Puyallup	Pierce County	WSDOT	General Load Allocation
Total reduction	>20.138	27.145	1.471	>1.496
Percent of target reduction	>87.1%	91.1%	73.6%	>16.8%

Note: ✓ indicates that a credit is expected but has not yet been quantified; ? indicates that it is uncertain whether a credit will be generated.

Appendix I. Sediment reduction plan project sheets

Clarks Creek Sediment Reduction Action Plan, Final (Brown and Caldwell, 2013).

The project sheets are located in the “Action Plan” section of the document:

www.ecy.wa.gov/programs/wq/tmdl/ClarksCreek/ClarksCrSedReductionActionPlanFinal.pdf

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Appendix J. Record of public participation

Introduction

Ecology, Puyallup Tribe of Indians, U.S. Environmental Protection Agency, Pierce County and the City of Puyallup reached out to several local citizen groups to educate and get their input on what needed to be done in Clarks Creek. From 2009-2013 several educational and outreach opportunities were organized by the stakeholders. The TMDL was presented several times to the Puyallup Watershed Council and at Puyallup City Council meetings.

Summary of comments and responses

See appendix K

List of public meetings

In addition to the public meetings mentioned above in the introduction, a formal public comment meeting was held on June 10, 2014.

Outreach and announcements

A 30-day public comment period for this report will be held from May 22 through June 30, 2014.

A news release was sent to all local media in the Puyallup watershed area.

Advertisements were placed in the following publications:

- Tacoma News Tribune
- Puyallup Herald

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Appendix K. Response to public comments

The Response to Public Comments is located at
https://fortress.wa.gov/ecy/publications/publications/1410030part1.pdf