Clackamas County Water Environment Services

Clackamas County Service District #1

Benthic Macroinvertebrate and Geomorphological Monitoring Report 2017

REPORT- June 29, 2018

prepared by

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1.0 INTRODUCTION

Clackamas County Water Environment Services (WES) is one of several agencies responsible for wastewater and stormwater management in the region. To better understand the effects of these management activities on watershed health and the status of aquatic resources in the district, WES periodically assesses aquatic resource and physical habitat conditions as part of its watershed health focus and integrated watershed management approach. The main purposes of WES' monitoring programs include: meeting permit requirements, assessing existing conditions, documenting trends, determining the effectiveness of water resources management programs, informing the public, and providing guidance on the needs for future work.

WES performs stormwater management activities in two districts: Clackamas County Service District #1 (CCSD #1) and the Surface Water Management Agency of Clackamas County (SWMACC), both in northern Clackamas County (hereafter referred to as the Districts). Stream monitoring by the Districts includes water quality sampling, biotic surveys, streamflow and other hydrologic measurements, and monitoring the physical condition of streams (geomorphology). Among these, macroinvertebrate and geomorphic monitoring have been carried out every few years. Due to the close relationships between the physical habitat and the macroinvertebrate community, the two investigations have been carried out in conjunction with one another in 2009, 2011, and 2014 (Lemke and Cole 2010a; Lemke and Cole 2010b; Lemke et al. 2012a; Lemke et al. 2012b; Waterways 2015a; Waterways 2015b). Together, this report and a companion report (Waterways, 2018) document the results of the 2017 geomorphic and macroinvertebrate monitoring event in the two districts. This is the monitoring report for CCSD #1.

1.1 MONITORING NETWORK

Macroinvertebrate monitoring has been conducted at many sites since 2002, and geomorphic monitoring since 2009. Macroinvertebrate sampling work – including identification of macroinvertebrate communities, physical habitat characterization, and water chemistry –within the Districts occurred in the fall of 2002 (Cole 2003), 2007 (Lemke and Cole 2008a; Lemke and Cole 2008b), 2009 (Lemke and Cole 2010a; Lemke and Cole 2010b), 2011 (Lemke et al. 2012a; Lemke et al. 2012b), 2014 (Waterways 2015a; Waterways 2015b), and in 2017.

Starting in 2009, following the development of basin plans for the Kellogg-Mt. Scott and Rock Creek Watersheds, WES expanded their efforts to include assessments of stream geomorphology, which occurred in 2009, 2011, 2014, and 2017.

The sampling network has changed and expanded over the years; however, most of the monitoring sites have remained consistent. While there was some overlap in macroinvertebrate and geomorphic monitoring reaches in the 2009 monitoring event, a concerted effort was made in 2011 to co-locate more of the geomorphic and macroinvertebrate monitoring reaches. Macroinvertebrate monitoring within both districts expanded for the 2014 monitoring event (Waterways and Cole Ecological 2015a, Waterways and Cole Ecological 2015b). In 2017, the geomorphic monitoring network was further extended to include additional sites that were selected for scoring within the context of a Stream Health Index program being implemented by WES (Waterways, 2018).

1.2 SETTING

Most of the CCSD #1 area (Figure 1) is located within Portland's Urban Growth Boundary (UGB), on the east side of the Willamette River, and includes the Kellogg/Mt Scott Creek drainage, the Rock Creek watershed, and several smaller creeks that discharge directly into the Clackamas River. The Kellogg/Mt. Scott creeks watershed is the largest drainage predominantly contained within CCSD #1, draining 40.5 square kilometers, and flows in a westerly direction through heavy residential and commercial development to the Willamette River. Rock Creek, draining 25.0 square kilometers, located to the east of Mt. Scott Creek, has the next largest drainage area and empties into the Clackamas River. The CCSD #1 monitoring network also includes three smaller drainages to the west of Rock Creek —Carli Creek (1.4 square km drainage), Sieben Creek (5.3 square km drainage), and Cow Creek (3.3 square km drainage)— discharge directly into the Clackamas River, which bisects northern Clackamas County on its course to the Willamette River.

Geology in the CCSD #1 service area varies greatly by watershed, as can be seen in Figure 2 (Ma, et al., 2012). Upper Kellogg Creek, above the confluence with Mt. Scott Creek, occupies low ground along a southern section of the Portland Hills Fault, and drains low topography covered with fine-grained Missoula Flood deposits. In contrast, Mt. Scott and Rock Creeks drain steeper topography in and around Mount Scott and Scouter Mountain, which are extinct volcanoes from the Boring volcanic field. The Rock Creek drainage also contains large areas underlain by old river gravels from the ancestral Columbia River. Carli and Cow Creeks drain mostly flat topography on a series of Pleistocene Clackamas River terraces, whereas Sieben and Richardson Creeks drain steeper ground underlain by Boring volcanics and ancient Columbia River gravel. The geology and topography of the different watersheds contribute to differences in the type and amount of sediment supplied to the streams: Upper Kellogg, Carli, and Cow Creeks drain low relief areas underlain with mostly sand and finer grained sediment; whereas Mt. Scott, Rock, Sieben and Richardson Creeks have steeper topography and a more abundant supply of gravel.

Land use within the service district varies from urban to rural with some remaining tracts of forested and agricultural (upper half of Rock Creek watershed) lands, and some industrial areas. The Kellogg-Mt. Scott subbasin is a highly developed urban watershed that is approximately 34 percent impervious, while the Rock Creek subbasin was estimated to be approximately 13 percent impervious in 2007. Areas of more topographic relief within CCSD #1 are drained by streams with higher gradients, more heterogeneous habitat (riffle/pool complexes), and larger and more heterogeneous substrate; whereas areas with little or no topographic relief contain low-gradient streams with primarily pool and glide habitat and finer streambed substrate.

In most cases, stream channels within the study area have been impacted by current or past land uses and by direct channel modification, each of which have contributed to the alteration of natural hydrology and morphology of these systems. These changes have affected stream physical habitat and water quality, which in turn have led to varying degrees of degradation of aquatic communities. Given trends in future development of the Portland metropolitan area, it is likely that there will be increased pressure on streams and their watersheds in the CCSD #1 service area from urban and suburban development and a continued trend towards increasing hydromodification.

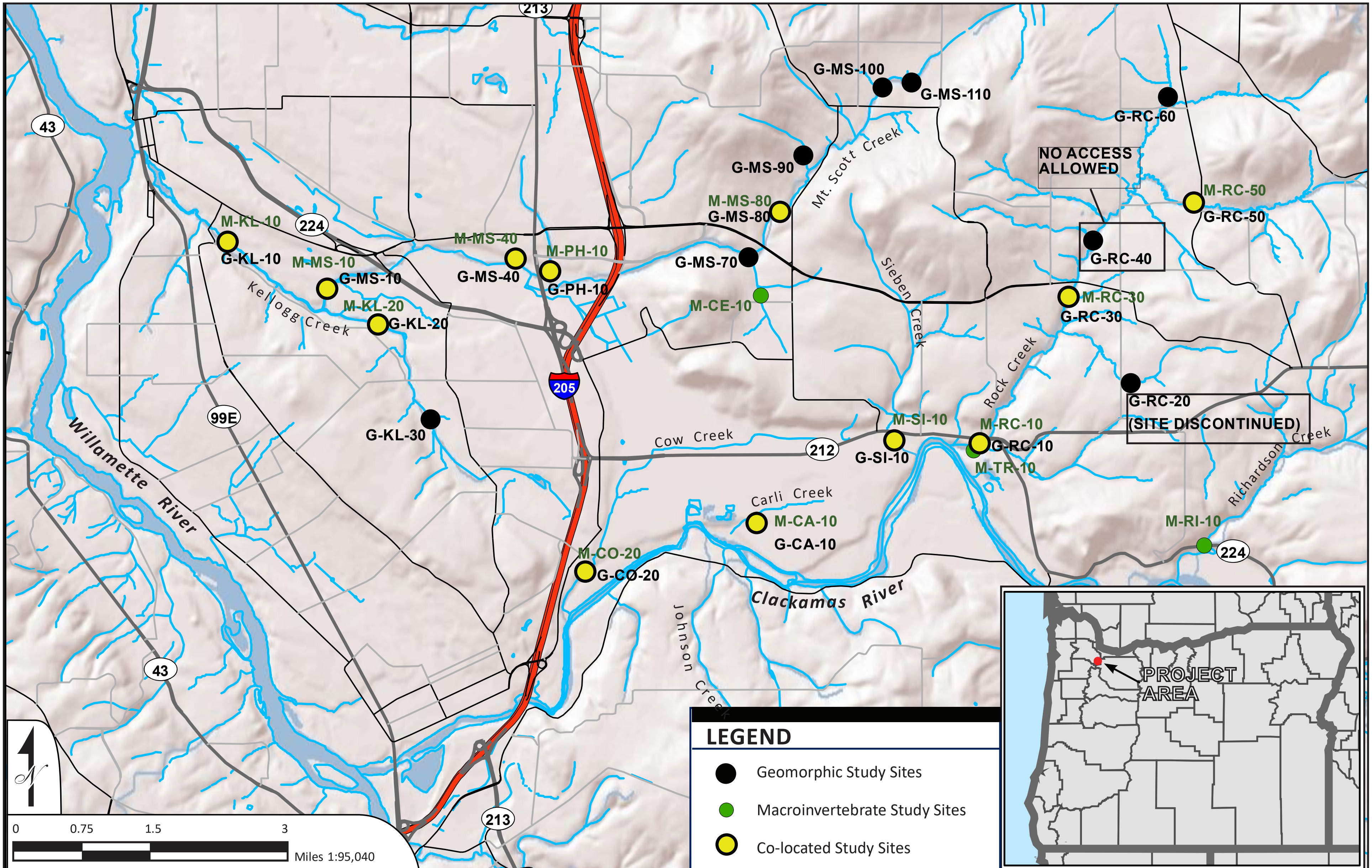

FIGURE 1

Geomorphic and Macroinvertebrate Study Sites for 2017 in Clackamas County's Service District 1 (SD1) near Portland, Oregon.

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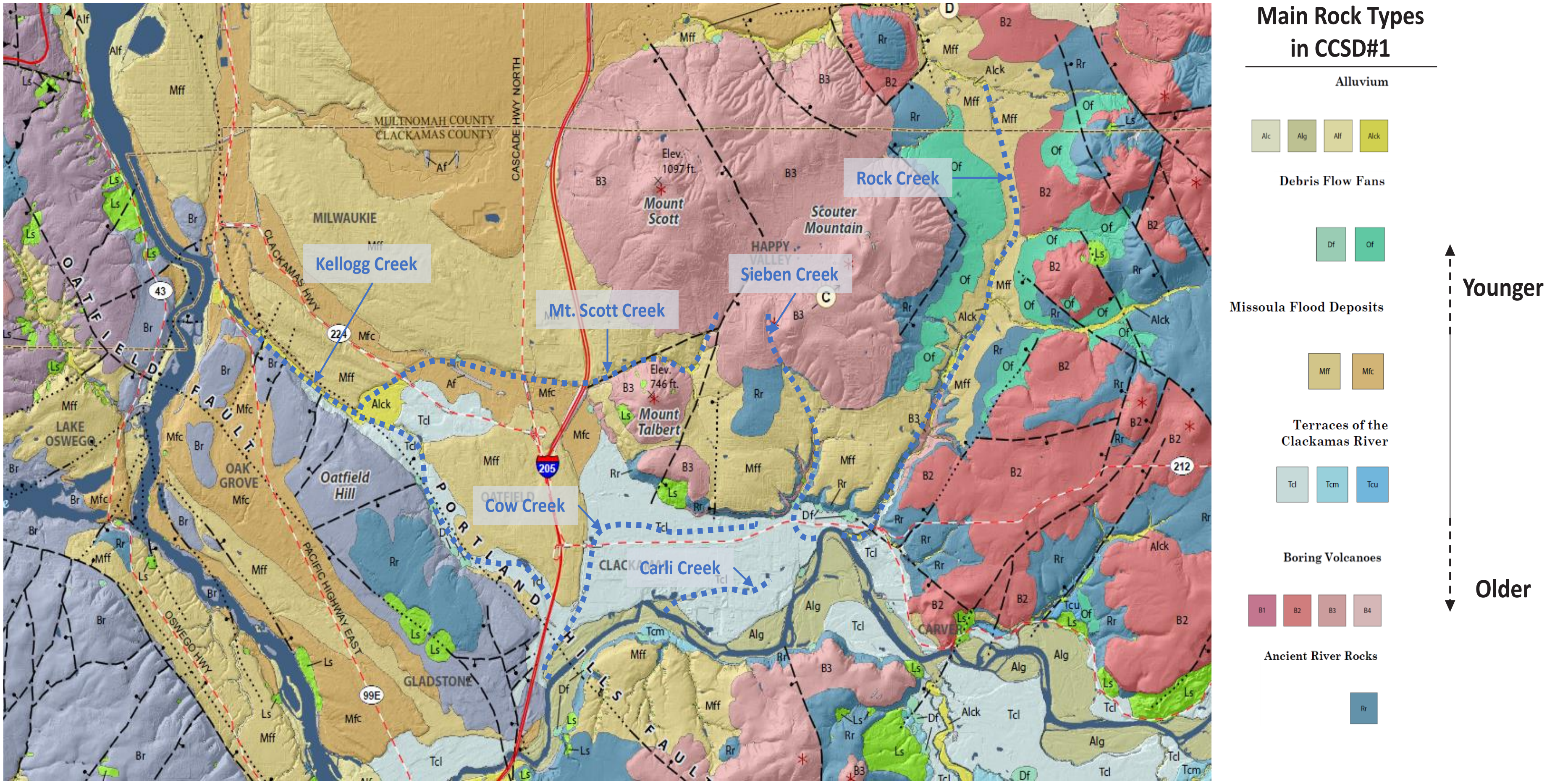

FIGURE 2

Surficial geology and streams in the CCSD#1 Service Area. Modified from Ma, et al. (2012)

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1.3 PROJECT OBJECTIVES

Much of the service area has been or is in the process of being urbanized. Historically, much of the watershed was converted from forest to agriculture, urban, suburban, commercial, and industrial land uses. Urbanization has resulted in an increase in the amount of impervious area on the landscape. Collectively, these land-use changes have modified the timing and magnitude of delivery of stormwater to stream channels, and have therefore altered streamflows, a process called hydromodification. Hydromodification has the potential to affect the morphologic character of stream channels that receive affected stormflows. The effects of hydromodification are often observed throughout the channel network since, in part, the geometry of a stream channel (e.g. – channel width, channel depth) responds to the discharge during flood stages (Dunne and Leopold, 1978).

When the hydrology of a watershed is modified, the changes may have a strong impact on the character of stream channels, both spatially and temporally. Headwater channels may incise, widen, and may experience headward migration. Erosion in these headwater channels can mobilize sediment that results in aggradation and widening of channels downstream. When the upstream reaches adjust and the upstream sediment supply decreases, the downstream channels may then narrow and incise, resulting in a situation with high, unstable banks and a disconnected floodplain terrace lacking mature vegetation. Typically, bank erosion is a significant issue in main stem channels in urbanizing areas as they aggrade and widen, and also when they narrow and incise. Ultimately, these hydrologic and geomorphic changes contribute to degradation of physical habitat and water quality conditions necessary to support healthy, diverse, native aquatic communities (fish and macroinvertebrates, in particular).

Evaluating the effects of hydromodification on stream channels requires a characterization of channel conditions over time. While a one-time evaluation provides some understanding of the extent to which channel conditions have deviated from a desired state as a result of hydromodification, the rate of change and trajectory of that change will remain unknown. To fully understand the effects of hydromodification on a watershed requires a time series of data.

In response to the need to understand how watershed conditions are changing over time and a desire to monitor the effectiveness of stormwater management practices and treatments designed to mitigate the impacts of hydromodification, WES retained Waterways Consulting, Inc. and Cole Ecological, Inc. to perform a comprehensive aquatic resource and geomorphic assessment within the CCSD #1 service area. This assessment was aimed at characterizing current conditions, and determining changes and trends in relation to past conditions. The results will also be used to compare with future surveys to continue to evaluate the effects of changing land use and stormwater management strategies over time. This report provides a detailed description of the methods, results, and interpretation of this comprehensive aquatic resource assessment conducted in 2017, as well as comparisons with previous years' monitoring programs. These results are used to identify changes in resource conditions over time and evaluate the need for management actions, particularly in relation to hydromodification, improving the capacity of streams to support diverse, native aquatic communities, and to improving overall watershed health.

2.0 METHODS

The assessment methodology was designed to establish and evaluate discrete sampling areas, or reaches, distributed throughout the CCSD #1 area, using a sampling approach that was efficient and repeatable to understand trends at both local (reach) and (to a certain degree) watershed scales. The results and interpretation of the data allow for inference of both reach-specific and watershed-scale conditions. Though some of the results may, in part, reflect site-specific effects from particular activities, the overall results are meant for general examination and detection of broad longitudinal (upstream to downstream) trends resulting from the cumulative net effects of both disturbance and restoration activities. The data from this study should not be used to make inferences regarding reach-specific conditions, channel instability, or degradation occurring *outside* of the discrete study reaches, without any field verification. A more complete inventory of reaches throughout these drainage networks would be necessary to understand conditions at the reach scale across the length of these networks.

In total, 21 reaches were sampled within the CCSD #1 area in 2017 (Figure 1, Table 1). Macroinvertebrate assessments were conducted in 15 reaches, while geomorphic assessments were conducted in 17 reaches; 12 of these monitoring reaches overlapped.

2.1 SITE SELECTION

A preliminary list of possible survey sites was prepared in 2009 based upon existing WES biological assessment sites and recommendations included in the Watershed Action Plans for Kellogg/Mt Scott and Rock Creeks. To refine the list, WES, Waterways Consulting, and ABR, Inc. team members met to discuss site access, monitoring goals, and the suitability of individual sites to the goal of long term monitoring. Before survey activities began, Waterways conducted field reconnaissance to evaluate access and other potential constraints at the targeted sites. Landowner outreach was performed by WES securing access permission for sites not located on public land. From these efforts a list of 18 targeted survey sites was agreed upon in 2009. One site was removed from the list (Site SD1-G16) because landowner access was not granted, resulting in a total of 17 sites surveyed in 2009.

In 2011, the monitoring sites surveyed in 2009 were revaluated by WES and ABR. In all but one case, the same sites were resurveyed in 2011. For 2011, site SD1-G15 was dropped because it was determined at a subsequent field visit that the original selection of the site as a reference condition for the rest of the SD1 sites was difficult to justify given the impacted condition of lower Richardson Creek. The same sites surveyed in 2011 were surveyed in 2014 with a few exceptions. Table 1 provides site information for the 2014 geomorphic and macroinvertebrate survey reaches.

Explanation of site codes.

To standardize the naming convention at each of the sites, a new site nomenclature system was developed following completion of the sampling in 2011. These site codes have been consistently applied since 2011. The first letter (M or G) identifies the sampling location as either a macroinvertebrate site or a geomorphic site. The second group of letters is a two-letter code representing the stream name. The numbers at the end of the code represent the proximity to the mouth of the stream relative to the overall length of the channel. Thus higher numbers indicate upstream sites on the same stream. Example:

Site Code: M-KL-10

Explanation:

- M: Macroinvertebrate Sampling Reach
- KL: Kellogg Creek
- 10: Approximately 10 percent of the total distance from the mouth to the headwaters.

Table 1. Site information for stream reaches where channel morphology assessment was conducted in Clackamas County Service District #1 (CCSD #1), Oregon.

Reach ID	Previous Site Codes	Stream	Reach Description	Latitude / Longitude	Years Sampled
Kellogg Creek Subbasin					
M-KL-10 G-KL-10	SD1-M18 SD1-G11	Kellogg Creek	Upstream of Kellogg Lake behind Rowe Middle School	-122.627590 / 45.431408	M: 09,11,14,17 G: 09,11,14,17
M-KL-20 G-KL-20	SD1-M12a	Kellogg Creek	Upstream of Rusk Road	-122.47233 / 45.39766	M: 11,14,17 G: 17
G-KL-30	SD1-G12	Kellogg Creek	Along Aldercrest Court	-122.595816 / 45.411825	G: 09,11,14,17
Mt. Scott Creek Subbasin					
M-MS-10 G-MS-10	SD1-M4a	Mt. Scott Creek	Mt. Scott Creek North Clackamas Park	-122.61228 / 45.42657	M: 11,14,17 G: 17
M-MS-40 G-MS-40	SD1-M3 SD1-G10	Mt. Scott Creek	Downstream of Route 213 behind N. Clackamas Aquatic Center, Three Creeks Natural Area	-122.581013 / 45.429195	M: 02,07,09,11,14,17 G: 09,11,14,17
G-MS-70	SD1-G5	Mt. Scott Creek	Downstream of SE Sunnyside Rd	-122.545050 / 45.430010	G: 09,11,14,17
M-MS-80 G-MS-80	SD1-M2 SD1-G6	Mt. Scott Creek	Upstream of 122nd and Sunnyside intersection; downstream of Spring Mountain dam removal project	-122.538525 / 45.435633	M: *02,*07,*09,11,14,17 G: 09,11,14,17
G-MS-90	SD1-G13	Mt. Scott Creek	Unnamed Tributary to Mt Scott Creek Along public footpath between SE Cedar Way and SE Otty Rd	-122.536271 / 45.441385	G: 09,11,14,17
G-MS-100	SD1-G7	Mt. Scott Creek	Upstream of King Rd; Happy Valley City Park	-122.523676 / 45.448990	G: 09,11,14,17
G-MS-110	SD1-G8	Mt. Scott Creek	Downstream of SE 145th Ave.; Happy Valley City Park	-122.518994 / 45.449554	G: 09,11,14,17
M-PH-10 G-PH-10	SD1-M5a SD1-G9	Phillips Creek	Upstream of SE 84th Ave.	-122.576544 / 45.428978	M: 02*,07*,09*,11,14,17 G: 09,11,14,17
M-CE-10	SD1-M15	Cedar Creek	Downstream of Mather Rd.	-122.54313 / 45.42570	M: 02, 07, 09, 11,17
Rock Creek Subbasin					
M-RC-10 G-RC-10	SD1-M10a SD1-G1	Rock Creek	~120 m upstream of the confluence with Trillium Creek	-122.507913 / 45.409126	M: 02*,07*,09*,11,14,17 G: 09,11,14,17
G-RC-20	SD1-G2	Rock Creek	Tributary to lower Rock Creek off of SE 172nd Ave.	-122.484009 / 45.415894	G: 09,11,14 Site Discontinued 2017
M-RC-30 G-RC-30	SD1-M11a SD1-G3	Rock Creek	Downstream of Sunnyside Rd.	-122.493493 / 45.426235	M: 02*,07*,09*,11,14,17 G: 09,11,14,17
G-RC-40	SD1-G4	Rock Creek	Downstream of SE 172nd Ave. South of Troge Rd	-122.490070 / 45.431893	G: 09,11,14 Site Not Accessed 2017

Reach ID	Previous Site Codes	Stream	Reach Description	Latitude / Longitude	Years Sampled
Table 1. Site information for stream reaches where channel morphology assessment was conducted in Clackamas County Service District #1 (CCSD #1), Oregon.					
M-RC-50 G-RC-50	SD1-M17 SD1-G17	Rock Creek	Tributary to Rock Creek Along Troge Rd at Foster Rd.	-122.472508 / 45.435700	M: 09,11,14,17 G: 09,11,14,17
G-RC-60	SD1-G18	Rock Creek	Tributary to upper Rock Creek upstream of SE Hemrick Rd.	-122.478122 / 45.447941	G: 09,11,14,17
M-TR-10	SD1-M7a	Trillium Creek	Near Confluence with Rock Creek	-122.50910 / 45.40830	M: 09,11,14,17
Tributaries to the Clackamas River					
M-CA-10 G-CA-10	SD1-M16	Carli Creek	~300m downstream of SE 120th Ave.	-122.54375 / 45.40056	M: 07,09,11,14,17 G: 17
M-CO-20 G-CO-20	SD1-M14a	Cow Creek	Downstream of private driveway off of SE Dean Drive	-122.57084 / 45.39488	M: 11,14,17 G: 17 (Site conditions not appropriate for geomorphic survey)
M-RI-10	SD1-M12	Richardson Creek	Upstream of Highway 224	-122.47233 / 45.39766	M: 02,07,09,11,14,17
M-SI-10 G-SI-10	SD1-M8 SD1-G14	Sieben Creek	Downstream of Hwy 212/224	-122.521944 / 45.409770	M: 02,07,09,11,14,17 G: 09,11,14,17

* asterisk in the "Years Macros Sampled" column indicates a shifted reach location, but not by more than 200m from 2014 reach Latitude/Longitude listed corresponds to the site benchmark recorded using a hand held GPS unit.
"M"=Macroinvertebrate, "G"=Geomorphic

2.2 GEOMORPHIC MONITORING

The geomorphic assessment at each of the sites included the following five elements:

- Longitudinal and cross section profile surveys;
- Measurement of surficial substrate conditions;
- Collection of a bulk sample of bed conditions;
- Measurement of pool characteristics; and
- Assessment of bank conditions at various sites throughout the CCSD #1 area.

The following sections provide detailed descriptions of the methods used for conducting the geomorphic monitoring.

Geomorphic Site Monumentation and Reoccupation

The primary objective of this geomorphic monitoring effort was and is to characterize baseline conditions and reoccupy the same locations in the future to assess rates of change over time. Consequently, establishing long-term monumentation that was not prone to vandalism but was easy to find and reoccupy was critical.

At each site, a permanent benchmark was established and monumented with a 3/8 x 12 inch rebar stake to establish a reference elevation of the study site for future monitoring efforts. Similarly, rebar stakes were used to monument cross section endpoints. In addition to a rebar stake, GPS points, photos and notes were collected further describing each benchmark and cross section endpoint locations in 2009. Benchmark locations were selected with accessibility and longevity in mind. The use of rebar allowed the ability to place the monument flush with the ground to prevent vandalism and the ability to relocate the monument with a metal detector for reoccupation of the same location. Where foot traffic was light, additional visual aids, such as flagging or wood lathe, were placed at the site to further aid relocation. Upon resurvey in 2017 some monuments had been disturbed or could not be located, in which case new rebar was set at the closest location possible using the available information. Elevation adjustment were made, where necessary, to account for any new monumentation that was established.

Geomorphic Field Data Collection

For the 2017 geomorphic monitoring year, field data was collected between 4 November 2017 and 17 December 2017. The following sections describe the methods and equipment used to perform longitudinal and cross section profile surveys, characterize surficial and bed substrate conditions, pool characteristics and bank conditions.

Longitudinal Profile Survey

A longitudinal profile was measured at each site by surveying the average thalweg profile. Surveys were conducted using an auto-level, 200 or 300 foot tape and a 25 foot rod. In reaches consisting of pool and riffle structure, profile points were measured mainly at riffle crests and tails. In instances where the reach structure consisted of glides or large or very deep pools, thalweg measurements were taken at changes in grade. The length of the thalweg profiles encompassed a minimum of 15-20 times the estimated average bankfull width. Site notes and photos were collected at the longitudinal profile endpoints.

The location of longitudinal profiles were chosen to capture geomorphic information in areas containing depositional features (riffles, bars, etc.), where feasible, or to identify features such as knickpoints[1]. Although the endpoints of the longitudinal profiles were not monumented, every attempt was made to survey the same segment of channel.

Cross Section Survey

Cross section surveys were conducted using an auto-level, 200 foot tape, stakes and a 25 foot rod. Section endpoints were monumented with 3/8 x 12 inch rebar stakes wherever possible. Notes and photos were also collected at the cross-section endpoints. Three cross sections were measured at each site, and where possible, each cross section was located near the head of a riffle. Cross sections included notes depicting major breaks in slope, tops of bank, toes, bankfull estimates, right edge of water, left edge of water and thalweg.

The locations of the cross sections were chosen based upon the form of the channel, observed geomorphic characteristics, line of sight, and accessibility. Sections were established perpendicular to the stream channel, preferably at pool tails or riffle crests when possible. If areas of incision or headcuts were observed, efforts were made to measure cross sections both upstream and downstream of these features.

[1] A knickpoint is a term to describe a location in a channel where there is a sharp change in channel slope resulting in a pronounced discontinuity in bed elevations downstream compared to upstream (i.e. – waterfall).

Pebble Counts

Pebble counts were conducted to characterize surficial substrate conditions on depositional features such as bars. The method employs the technique outlined by Wolman (1954). Assessments were conducted during low flow and counts were restricted to exposed depositional bar features. Depositional features were chosen because they represent grain sizes that are moving as bed load. In some cases, pebble counts of the active bed were not conducted due to a lack of exposed depositional features or where the streambed was dominated by sand, fines, or bedrock. A bulk sample of alluvial bed material was also collected, where feasible, (discussed below) to characterize surficial and subsurface conditions.

Pebble counts were conducted as follows: Sediment was characterized by measuring the median width of 100 random "pebbles" from each exposed bar. Measurements were made using a standard metric ruler and pebbles were collected randomly from the toe of each footstep while traversing the length of the depositional feature. In an effort to minimize personal bias, each pebble count involved collection of one-half of the data points (50 pebbles each) by the two survey team members. Any particle measuring less than 1 mm was recorded as "sand".

Bulk Sediment Sample Collection

To better quantify the degree to which fine sediment is impacting aquatic habitat, bulk bed samples were collected in pool tail-out locations using the technique outlined in McNeil and Ahnell (1964). Bulk samples were collected to characterize physical habitat conditions in a pool tail, a location that is important to salmonids. The McNeil sampler collects bed material from both the surface and subsurface and retains the fine fraction, which can be lost using other techniques (e.g. – shovel). Samples collected in the McNeil sampler were transferred to a doubled poly sample bag, labeled, and temporarily stored. Once all samples were collected they were sent to Professional Service Industries (PSI), Inc. in Portland, OR to be sorted and measured for volumetric size distribution (see Appendix D).

Pools Survey

Pools are an important indicator of the quality of aquatic habitat. Many degraded systems that have high fine sediment loads and lack structural elements are characterized by a lack of profile diversity. Pool characteristics, including the density of pools and their depth, are closely linked to geomorphic conditions and the ability of the system to create and maintain habitat quality. In an urban system, where hydromodification has occurred, a stream channel may lack deep, high quality pools because the channel has incised and formed a more homogeneous bed profile, or scoured to bedrock, and there are few to no structural elements present to encourage sediment storage and natural pool-riffle morphology. Similarly, early stages of hydromodification may have produced high rates of erosion in the upper tributaries of a watershed resulting in sedimentation of pools along higher order stream channels where deep pools were historically abundant. By monitoring pools long-term, the underlying geomorphic and sediment transport conditions can be qualitatively evaluated. Furthermore, WES' Stream Health Index (2018) uses a metric that quantifies "pool availability" as the function of the frequency and depth of pools in the survey reach.

To measure the availability of pools, both the maximum pool depth and maximum residual pool depth (maximum depth minus thalweg depth at pool tail) were recorded for each pool in the project reach. A stadia rod was used to measure pool depth. This approach provides important information about pool quality, the implications of hydromodification, and sediment transport conditions, but is much less intensive than an approach such as the V* rating (Lisle and Hilton, 1992) which requires intensive sampling at multiple pools in each project reach.

Bank Erosion Evaluation

The degree of bank erosion is a good indicator of the overall stability of the channel and can define the trajectory of channel conditions (e.g. – unstable but improving, stable but degrading, etc.). Stream channels that are subjected to hydromodification go through a well-defined evolutionary process that eventually leads to a new state of quasi-equilibrium (Simon, 1989). The extent and rate of bank erosion, combined with knowledge about the degree of incision and state of riparian vegetation, are key components in understanding what stage of development the channel is in and how it might behave in the future.

To establish a baseline and to understand how hydromodification has affected each of the project reaches, areas with active bank erosion were characterized and measured. Areas of active bank erosion were rated based upon a subjective scale of activity from 1 to 5, with 1 being slightly active and 5 being very active. Height and length estimates of bank erosion areas were quantified. Areas of active erosion were recorded independently for right and left banks.

Geomorphic Data Analysis

Data collected in the field was compiled and analyzed and compared with monitoring results collected in previous years. The following section outlines specific methods and calculations used to assemble the data and generate appropriate site metrics. Maps, photos, and results of the physical data collection are summarized, by site, in Appendix A. The field data sheets for each site are included in Appendix C. A report from PSI, Inc. summarizing the bulk sediment sample analysis results for each site is included as Appendix D.

Longitudinal Profile Survey

Information collected for average thalweg profiles is shown in a profile figure for all reaches surveyed. Average bed slope was determined by fitting a linear trend line to all points collected during the survey. Longitudinal profiles from 2009, 2011, 2014 and 2017 are compared by lining up their intersection with the upstream cross section at the site, as some small differences can arise from exactly how the tape is arranged throughout a reach from one monitoring year to the next. Longitudinal profile figures for each site are located in Appendix A.

Cross Section Survey

Each cross-section profile is presented in a figure in Appendix A oriented "looking downstream," with a station of 0 ft. being the river left start of the cross section. Bankfull width and depth were determined for each cross section based on slope breaks defining the bank tops, vegetation breaks, and indications from other cross sections within that reach. Bankfull depth was estimated as the difference between the average elevation of the two bank points and the average elevation of all the survey points located in the channel bed. A bankfull width to depth ratio (W/D) was calculated for each cross section. Bankfull values in Table 7 represent the average of all three cross sections surveyed at that site.

Pebble Counts

For each pebble count a particle size distribution was determined and particle diameters for D_{16}, D_{50} and D_{84} were calculated and presented in Appendix A. D_{16}, D_{50} and D_{84} describe a grain size distribution through a percent finer notation. For example, D_{16} describes the grain size at which 16 percent of the sample is finer than the noted value. The D_{16} is an indicator of the size of the finer sediment in the bed, the D_{84} is a commonly used indicator of the size of the coarsest particles, and D_{50} is the median grain size.

Bulk Sediment Sample Collection

All bulk sediment samples were collected in the field and evaluated based upon methods outlined in McNeil and Ahnell (1964). Samples collected for this work were evaluated in a laboratory by Professional Service Industries (PSI), Inc. in Portland, OR. Samples were dried to constant mass, washed over a #200 sieve and dried once more. Dried and washed samples were sorted using standard 12" sieves manufactured by Dual Manufacturing Co. in sizes 50.0mm (2"), 37.5mm (1½"), 31.5mm, (1¼"), 25.0mm (1"), 19.0mm (¾"), 12.5mm (½"), 9.5mm (3/8"), 6.30mm (1/4"), 4.75mm (No.4), 2.36mm (No.8), 2.0mm (No.10), 1.18mm (No.16), 0.85mm (No.20), 600µm (No.30), 425µm (No.40), 300µm (No.50),150µm (No.100), and 75µm (No.200). For the 2017 monitoring year, the 63 µm sieve (No. 230 sieve) was added to the grain size analysis to more accurately define the percent of fine-grained sediment in the bed material[2].

Once sorted, the volume of material retained in each sieve was determined using a 1000ml graduated cylinder and measuring the volume of displaced water to 1ml. Samples too large to fit within a 1000ml graduated cylinder (particles over 2") were measured using an overflow apparatus where overflow water displaced by the sample was collected in and measured with a graduated cylinder. Through 2014, bulk sample results were evaluated to determine percent of sediment matrix less than 6.30 mm and percent of matrix less than 0.85 mm. Starting in 2017, the table in Appendix A reports the percent of sediment smaller than 2.36 mm (representing the mass percent of sand and fines, since 2.36 mm sieve is the closest sieve to 2 mm, the size threshold separating gravel and sand), and the percent smaller than 0.063 mm (representing the mass percent of silt and clay).

Pools Survey

Data collected for pools was an overall tally observed at each site and a maximum depth and maximum residual depth for each pool. Maximum residual pool depth is defined as the maximum pool depth minus the depth of the pool at its tail and represents a measure of pool depth that is independent of discharge. Average maximum pool depth and average maximum residual pool depth for each site are summarized in Table 7.

[2] By geological definition, 62.5 µm is the size threshold separating sand (0.0625 – 2 mm) from silt (.004 – 0.0625 mm).

Bank Erosion Evaluation

Values of percent erosion were calculated for each study site. Estimates of the percent of banks eroding were calculated independently for each bank. The estimated percent erosion was calculated using an overall survey reach length determined from the longitudinal profile survey and total estimated active erosion length for each bank. Results are presented in Table 8.

2.3 MACROINVERTEBRATE MONITORING

Macroinvertebrate sampling contained the following elements:

- Instream physical habitat and riparian assessment
    - Habitat surveys
    - Cross Section Surveys
    - Riparian surveys
- Water Chemistry Sampling
- Macroinvertebrate community assessment
    - Field sampling

The following sections provide detailed descriptions of the methods utilized in conducting this assessment.

Macroinvertebrate Field Data Collection

Macroinvertebrate communities, physical habitat, and water chemistry were sampled at the 15 survey reaches between 15 September and 27 September 2017. First, each survey reach was marked and the reach length was measured. Each sample reach measured 20 times the average wetted width or 75-m, whichever length was greater. Waypoints were acquired for the start and end of each reach using a GPS unit and the reach length was measured.

Instream Physical Habitat and Riparian Assessment

Habitat surveys were performed in the reaches following a modified Rapid Stream Assessment Technique (RSAT) which consisted of data collection from individual channel habitat units, three channel cross sections, and the adjacent riparian zone (Table 2). First, the valley type within each survey reach was broadly classified as U-type, V-type, ponded, or floodplain. A plan view of the reach was sketched as the survey was performed. The physical habitat data were then collected using the following procedures:

Table 2. Environmental parameters measured in the field to characterize stream reaches in Clackamas County (CCSD #1), Oregon, in the fall of 2017.		
Variable	**Quantitative or Categorical**	**Visual Estimate or Measured Variable**
Reach length (m)	Q	M
Valley type	C	V
Channel unit gradient (percent)	Q	M
Wetted width (m)	Q	M
Bankfull width (m)	Q	M
Bankfull height (m)	Q	M
Floodprone width (m)	Q	M
Floodprone height (m)	Q	M
Mean water depth (cm)	Q	M
Rapids (percent of reach length)	Q	M
Riffles (percent of reach length)	Q	M
Glides (percent of reach length)	Q	M
Pools (percent of reach length)	Q	M
Substrate composition	Q	M
Riffle (or Glide) Substrate embeddedness (percent)	Q	M
Large wood tally	Q	M
Overhead canopy cover (percent)	Q	M
Reach-wide substrate embeddedness (percent)	Q	V
Eroding banks (percent)	Q	V
Undercut banks (percent)	Q	V
Mean riparian buffer width (m)	Q	V
Riparian zone tree cover (percent)	Q	V
Non-native riparian vegetation cover (percent)	Q	V
Dominant adjacent land use	C	V
Water temperature (°C)	Q	M
Specific conductance (µS/cm)	Q	M
Dissolved oxygen (mg/L)	Q	M

Habitat Units Survey

The number, length, width, maximum water depth, and gradient of pools, glides, riffles, and rapids were recorded in each reach. The following definitions were adapted from the Oregon Department of Fish and Wildlife's (ODFW) Methods for Stream Habitat Surveys (2002) and Armantrout (1998) and used for this study:

Pool: Water surface slope is usually zero. Pools are normally deeper and wider than aquatic habitats immediately upstream and downstream.

Glide: There is a general lack of consensus of the definition of glides (Hawkins et al. 1993). For the purposes of this study, a glide was defined as an area with generally uniform depth and flow with no surface turbulence. Glides have a low-gradient water surface profile of 0–1 percent slope. Glides may have some small scour areas but are distinguished from pools by their overall homogeneity and lack of structure. Glides are generally deeper than riffles with few major flow obstructions

Riffle: Fast, turbulent, shallow flow over submerged or partially submerged gravel and cobble substrates. Riffles generally have a broad, uniform cross section and a low-to-moderate water surface gradient, usually 0.5–2.0 percent slope and rarely up to 6 percent.

Rapids: Swift, turbulent flow including chutes and some hydraulic jumps swirling around boulders. Rapids often contain exposed substrate features composed of individual bedrock or boulders, boulder clusters, and partial bars. Rapids are moderately high gradient habitat, usually 2.0–4.0 percent slope and occasionally 7.0–8.0 percent. Rapids also include swift, turbulent, "sheeting" flow over smooth bedrock.

The following attributes were then measured or visually estimated in each channel unit. Substrate composition was visually estimated in each unit using substrate size classes adapted from the United States Environmental Protection Agency's (USEPA) Environmental Monitoring & Assessment Protocols (EMAP) protocols for wadeable streams (USEPA 2000). Percent actively eroding banks and percent undercut banks (both banks, combined) were each visually estimated. Water surface slope of each unit was measured with a clinometer. Additionally, all woody debris measuring at least 15 cm in diameter and 2 m in length was tallied for each unit and the configuration, type, location, and size of root wads and pieces of wood were noted. Overhead cover was measured with a spherical densiometer in four directions (upstream, downstream, right, and left) from the center of the stream at evenly spaced intervals along the length of the reach. Habitat features such as beaver activity, culverts, and potential fish passage barriers were noted by habitat unit.

Cross-section Surveys

Channel dimensions were measured at three transects occurring within each sample reach. The three habitat units were selected according to the following guidelines:

1. Three separate riffles were sampled if three or more riffles occurred in the reach.
2. If two riffles occurred in the reach, both riffles and a representative glide or pool (least preferred) were sampled. If riffles were of sufficient length (i.e. 10 percent of the reach length) then more than one set of cross-section measurements were made in the riffle to ensure that all measurements were taken from this habitat type.
3. If only one riffle occurred within the reach, two additional units that represented channel dimensions and substrate composition were sampled. If the riffle was longer than 20 m, then all three sets of measurements were taken from the riffle.
4. If no riffles occurred in the reach, three units that were representative of the channel dimensions and substrate composition occurring within the reach were sampled.

At each of the three channel cross sections, wetted width (WW), bankfull width (BFW), maximum bankfull height (BFHmax), the bankfull height at 25 percent, 50 percent, and 75 percent across the distance of the bankfull channel, and the flood-prone width (FPW) were measured with a tape measure and survey rod. From these channel-dimension data, width-to-depth and channel-entrenchment ratios were later calculated. Water depths were recorded at 10 percent, 30 percent, 50 percent, 70 percent, and 90 percent across the width of the wetted channel. The floodplain accessible height (as measured on the lower of the two banks) and bank angles were visually estimated.

Pebble counts were performed in riffles when they represented an adequate amount of the stream channel area to allow measurement of at least 100 substrate particles along transects. If riffles occupied less than 10 percent of the total habitat area in the reach (e.g., if macroinvertebrate samples were collected from glides), then pebble counts occurred in glides. Pebble counts were performed using the "heel-to-toe" method, starting at the bankfull edge on one side of the channel and walking heel-to-toe to the other edge (USEPA 2000). With each step, the surveyor looked away and touched the streambed at the tip of their toe. The size class and embeddedness of each piece of streambed substrate was estimated until at least 100 particles were counted.

Riparian Surveys

Adjacent riparian conditions were characterized beyond the left and right banks separately and according to a number of attributes. The dominant plant community type(s) (riparian forest, willow shrub-scrub, upland forest, etc.) occurring in the riparian zone to the edge of human-dominated activity was classified and recorded and the approximate width of each of these community types was visually estimated. The percent vegetative cover of the canopy layer (>5 m high), shrub layer (0.5 to 5 m high), and groundcover layer (<0.5 m high) was estimated, as well as the percent cover of invasive or non-native species as a single estimate across all three vegetative layers. The dominant adjacent land use outside of the vegetated riparian buffer was noted, and then a cross-sectional diagram of the riparian zone was sketched.

Water Chemistry Sampling

Water chemistry was measured during macroinvertebrate sampling from each reach. Water temperature (°C), dissolved oxygen saturation (percent), dissolved oxygen concentration (mg/L), conductivity (µS/cm), and specific conductance (µS/cm) were measured in situ with a YSI Model 556 multi-parameter water chemistry meter. Specific conductance is conductivity normalized to 25°C, thereby allowing more direct comparison of conductivity between water bodies or within a particular waterbody at different times. The YSI meter was calibrated daily for dissolved oxygen.

Macroinvertebrate Community Assessment

Field Sampling

Macroinvertebrates were collected using the Oregon Department of Environmental Quality's (DEQ) Benthic Macroinvertebrate Protocol for Wadeable Rivers and Streams (DEQ 2003). An 8-kick composite sample was collected from riffles in reaches that had sufficient riffle habitat; glides were sampled in reaches that lacked riffle habitat. Instream sampling points were selected to apportion the eight kick samples among as many as four habitat units. Macroinvertebrates were collected with a D-frame kicknet (30 cm wide, 500 µm mesh opening) from a 30 x 30 cm (1 x 1 ft.) area at each sampling point. Larger pieces of substrate, when encountered, were first hand-washed inside the net, and then placed outside of the sampled area. Then the area was thoroughly disturbed by hand (or by foot in deeper water) to a depth of ~10 cm.

The eight samples from the reach were composited and carefully washed through a 500 µm sieve to strain fine sediment and hand remove larger substrate and leaves after inspection for clinging macroinvertebrates. The composite sample was placed into one or more 1-L polyethylene wide-mouth bottles, labeled, and preserved with 80 percent denatured ethanol for later sorting and identification at the laboratory.

Sample Sorting and Macroinvertebrate Identification

Samples were sorted to remove a 500-organism subsample from each preserved sample following the procedures described in the DEQ Level 3 protocols (Water Quality Interagency Workgroup

[WQIW], 1999) and using a Caton gridded tray, as described by Caton (1991). Contents of the sample were first emptied onto the gridded tray and then floated with water to evenly distribute the sample material across the tray. Squares of material from the 30-square gridded tray were transferred to a Petri dish, which was examined under a dissecting microscope at 7–10X magnification to sort aquatic macroinvertebrates from the sample matrix. Macroinvertebrates were removed from each sample until at least 500 organisms were counted, or until the entire sample had been sorted.

Following sample sorting, macroinvertebrates were identified to standard levels of taxonomic resolution developed by the Pacific Northwest Aquatic Monitoring Partnership (PNAMP 2015). (WQIW 1999). Aquatic insects were keyed using Merritt, Cummins, and Berg (2008), Wiggins (1995), Stewart and Stark (2002), Thorp and Rogers (2015) and a number of regional and taxa-specific keys.

Quality Assurance

Following Level 3 protocols (WQIW 1999) duplicate composite samples were collected at two reaches, M-KL-10 and M-CA10A. These duplicate samples were compared to the original samples to assess within-reach sample variability attributable to both sampling error and spatial variability within the reach.

Macroinvertebrate Data Analysis

The 2017 CCSD #1 macroinvertebrate assessment marked the 6th year of sampling under WES's current macroinvertebrate monitoring program. With six years of data, temporal aspects of summarizing, analyzing, and interpreting the data are increasingly important and potentially informative. As such, all WES macroinvertebrate data from 2002 through 2017 were maintained and updated in a single database for consistency in naming conventions (as taxonomic names change over the years) and coding. Then, all multi-metric analyses were performed in R and the results were cross-validated with calculations performed in Excel. These results ensured thorough consistency in all aspects of data management and analysis across all WES monitoring years and facilitated examination of the data for temporal trends or other patterns.

Existing tools for analysis of macroinvertebrate data in western Oregon have been developed from, and therefore are only appropriate for, assessment of assemblages collected from coarse substrates in riffle habitat. However, riffle habitat is infrequent or absent from some stream types such as many of the low-gradient, fine-sediment-dominated streams of the Willamette River valley floor. Therefore, assessing macroinvertebrate communities of valley floor streams requires sampling from other habitats such as sand and silt-dominated glides. Glide and pool habitats are unlikely to support the same biological potential with respect to species richness as do riffle habitats because a number of characteristics known to influence macroinvertebrate community composition such as stream substrate, water velocity, and abundance and types of organic materials naturally differ between valley floor streams and valley foothill/Coast Range streams. Consequently, use of existing bioassessment tools and their attendant condition thresholds is inappropriate for assessing the condition of benthic communities in these valley floor streams. Analysis of glide samples collected from these streams with existing bioassessment tools would result in artificially lower index scores and corresponding impairment classifications. Consequently, analysis of macroinvertebrate taxonomic and count data differed between riffle and glide samples, as detailed below.

Analysis of riffle samples from higher-gradient reaches

Both multimetric analysis and predictive model analysis were used to analyze riffle sample data from higher-gradient reaches. Multimetric analysis employs a set of metrics, each of which describes an attribute of the macroinvertebrate community that has been shown to be associated with one or more types of pollution or habitat degradation. Each community metric is converted to a standardized score; standardized scores of all metrics are then summed to produce a single multimetric score that is an index of overall biological integrity. Reference condition data are required to develop and use this type of assessment tool. Metric sets and standardized metric scoring criteria are developed and calibrated for specific community types, based on both geographic location and stream/habitat type. The DEQ has developed and currently employs a 10-metric set for use with riffle samples from higher-gradient streams in western Oregon (WQIW 1999). Owing to the same difficulties of developing a predictive model for lower-gradient, valley floor streams, no multimetric index has been developed for use with macroinvertebrate communities from this stream type.

The DEQ 10-metric set includes six positive metrics that score higher with improved biological conditions, and four negative metrics that score lower with improved conditions (Table 3). The Modified Hilsenhoff Biotic Index (HBI), originally developed by Hilsenhoff (1982), computes an index to organic enrichment pollution based on the relative abundance of various taxa at a reach. Values of the index range from 1 to 10; higher scores are interpreted as an indication of a macroinvertebrate community more tolerant to fluctuations in water temperature, fine sediment inputs, and organic enrichment. Sensitive taxa are those that are intolerant of warm water temperatures, high sediment loads, and organic enrichment; tolerant taxa are adapted to persist under such adverse conditions. The DEQ taxa attribute coding system was used to assign these classifications to taxa in the data set (DEQ, unpublished information).

Metric values first were calculated for each riffle sample and then were converted to standardized scores using DEQ scoring criteria for riffle samples from western Oregon streams (Table 3). The standardized scores were summed to produce a multimetric score ranging between 10 and 50. Reaches were then assigned a level of impairment based on these total scores (Table 4).

Table 3: Metric set and scoring criteria (WQIW 1999) used to assess condition of macroinvertebrate communities sampled from riffles in stream reaches within Clackamas County (CCSD #1), Oregon, in the fall of 2017.

	Scoring Criteria		
Metric	**5 (good)**	**3 (fair)**	**1 (poor)**
POSITIVE METRICS			
Taxa richness	>35	19–35	<19
Mayfly richness	>8	4–8	<4
Stonefly richness	>5	3–5	<3
Caddisfly richness	>8	4–8	<4
Number sensitive taxa	>4	2–4	<2
Number sediment sensitive taxa	≥2	1	0
NEGATIVE METRICS			
Modified HBI[1]	<4.0	4.0–5.0	>5.0
percent Tolerant taxa	<15	15–45	>45
percent Sediment tolerant taxa	<10	10–25	>25
percent Dominant	<20	20–40	>40

[1] Modified HBI = Modified Hilsenhoff Biotic Index

Table 4. Multimetric score ranges for the assignment of macroinvertebrate community condition levels (WQIW 1999).

Level of Impairment	Score Range (scale of 10 - 50)
None	> 39
Slight	30–39
Moderate	20–29
Severe	< 20

PREDATOR (PREDictive Assessment Tool for Oregon) is a predictive model that evaluates macroinvertebrate community conditions based on a comparison of observed (O) to expected (E) taxa (Hawkins et al. 2000, Hubler 2008). The observed taxa are those that occurred at the reach, whereas the expected taxa are those commonly occurring (>50 percent probability of occurrence) at reference reaches. The expected taxa, therefore, are taxa that are predicted to occur within a reach in the absence of disturbance. Biological condition is determined by comparing the O/E score to the distribution of reference reach O/E scores. One major strength of PREDATOR over the multimetric approach is that a single predictive model can be constructed to assess biological conditions over a wide range of environmental gradients such as stream slope, longitude, or elevation, whereas separate multimetric tools would have to be developed to make accurately assess condition. PREDATOR is able to predict taxonomic composition across a range of naturally occurring environmental gradients with discriminant functions models (DFMs). Discriminant functions analysis is used during the model building phase to identify the environmental variables that are statistically related to natural gradients in macroinvertebrate community composition (Hawkins et al. 2000). These "predictor variables" are then used in the resulting model to predict macroinvertebrate community composition in the absence of disturbance. The model assigns a probability of class membership of each test site to the different classes of test sites specified in the model based on the environmental predictor variables that are input into the model. Once predictor variables and taxonomic data have been input into the model, the probability of occurrence of each taxon at a given test site (in the absence of disturbance) is calculated based on the frequency of occurrence of each taxon in each class of site weighted by the probability that the site belongs in each class.

Two PREDATOR models are currently in use in Oregon, including the Marine Western Coastal Forest (MWCF) model that encompasses the Coast Range and Willamette Valley (Hubler 2008). With this information, the model calculates the O/E score for each site. Using the MWCF biological condition thresholds (Hubler 2008), higher-gradient streams with O/E scores ≤0.85 (≤10th percentile of reference site scores) were classified as "most disturbed", 0.86 to 0.91 (>10th to 25th percentile) as "moderately disturbed", and 0.92 to 1.24 (25th to 95th percentile) as "least disturbed."

Analysis of glide samples from lower-gradient reaches

One CCSD1 macroinvertebrate sample was collected from a glide/pool in 2017. The glide/pool (depositional) sample was also analyzed using the multimetric analysis and the MWCF Predictive Model. However, disturbance classifications were not assigned. Nine metrics, some of which differ from those used for analysis of riffle samples, were used to evaluate the glide/pool sample from the low-gradient reach. In general, glides and pools (depositional habitats) support a lower diversity of aquatic macroinvertebrates and the organisms occurring in these habitats tend to be more tolerant of disturbance than are organisms occurring in riffles. Metrics that previously have been shown to effectively characterize macroinvertebrate communities in low-gradient streams (Cole 2002) and those that provided a range of values among glide samples were selected for inclusion in the set; metrics that showed little variation among low-gradient reaches, such as sensitive taxa richness, were excluded from the data set.

Table 5. Metric set used to assess condition of macroinvertebrate communities sampled from glides/pools in Clackamas County (CCSD #1), Oregon in the fall of 2017.

Metric
Taxa richness
EPT taxa richness
percent Dominant (1 taxon)
Modified HBI
percent Sediment tolerant taxa
percent Tolerant taxa
percent Chironomidae
percent Mollusca
percent Oligochaeta

Correlation Analysis

Relationships between benthic community condition scores (both multimetric scores and O/E scores) and selected environmental variables were examined using nonparametric correlation analysis. As an additional analysis, benthic community conditions were examined in relation to land use (calculated in 2012 using land use classes from National Land Cover Dataset, NLCD 2006) using correlation analysis. Spearman's Rho correlation analysis was used to determine the strength of association between measured environmental attributes and macroinvertebrate community condition. To increase the power of these statistical tests, the reaches where riffles were sampled were pooled across both CCSD #1 and SWMACC to increase the sample size for analysis. Correlation analysis was not conducted for data derived from glide samples due to a low sample size (n=6).

Stressor Identification

Following calculation of multimetric and O/E scores, relationships between multimetric and O/E scores and selected environmental variables were examined among higher-gradient and lower-gradient reaches separately using nonparametric correlation analysis (Spearman's Rho) to determine whether biological integrity is related to other measures of environmental conditions in CCSD #1 streams and to identify potential causative factors of impairment. Correlation analysis focused on variables previously known to correlate with macroinvertebrate community conditions (Lemke et al. 2011).

As in 2011, weighted-average inference models developed by the DEQ (Huff et al. 2006) and elements of a comprehensive stressor-identification framework named the Causal Analysis/ Diagnosis Decision Information System (CADDIS, USEPA 2010) were used in these analyses to further identify potential causes of measured stress to macroinvertebrate communities. Weighted-average inference models were developed by DEQ to identify shifts in assemblage composition that implicate either substrate degradation (i.e. fine sediment pollution) or temperature pollution. These weighted-average inference models for temperature and sediment are to be used as screening tools to identify likely sources of stress in wadeable Oregon streams. Site-specific temperature and sediment conditions are inferred from the macroinvertebrate community composition at a test site and are compared to conditions observed at regional reference sites to determine if there is a difference in assemblage-level preferences for temperature or fine sediment (Huff et al. 2006). The 90th percentile of the distribution of inferred temperature and fine-sediment values from regional reference sites is the value used to determine whether a particular site is potentially stressed by temperature or fine sediment.

In the analysis for this study, temperature stress and fine-sediment stress weighted-average inference models were first run to derive estimates of inferred water temperatures and sediment levels in each study reach. Both temperature and fine-sediment models were applied to riffle data from higher-gradient reaches, while only the temperature model was applied to glide data from lower-gradient reaches. Glide data were not run through the fine-sediment model because fine sediment levels would be expected to differ significantly between the higher- and lower-gradient reach types. For riffle samples from higher-gradient reaches, the DEQ's thresholds of 18.4 °C for temperature and 19 percent of fine sediment (90th percentile of the distribution of DEQ Willamette Valley reference site scores) were used to determine whether each was functioning as a potential stressor in each sample reach (Huff et al. 2006).

The Causal Analysis/Diagnosis Decision Information System (CADDIS) is an online application designed to help users conduct causal assessments, primarily in stream ecosystems (USEPA 2010). CADDIS provides a logical, step-by-step framework for Stressor Identification based on the U.S. EPA's Stressor Identification Guidance Document, as well as additional information and tools that can be used in these assessments. The core of the CADDIS framework is a five-step process that includes: 1) defining the case (effects to be analyzed and the geographic scope of the effects/analysis), 2) listing candidate causes, 3) evaluating data from the case (the field data from this study), 4) evaluating data from other sources, and 5) identifying probable causes of measured biological stress.

Elements of the CADDIS stressor identification framework were used to further assess the likelihood that the measured community disturbance was related to specific environmental conditions (stressors). This was achieved for higher-gradient reaches by first examining MWCF O/E and multimetric score condition classes to determine which reaches were classified as moderately disturbed or worse. These reaches were identified as priorities for further stressor identification exercises. Temperatures and fine-sediment stressor model results were then evaluated in relation to O/E and multimetric condition classes to determine whether one or both were potentially contributing to or producing the measured biological condition. Results of correlation analyses between macroinvertebrate scores and environmental gradients were used to further identify candidate causes and were used to determine what range of values of each environmental attribute was potentially associated with a particular biological condition.

Using the combined results of the overall community condition classes, stressor scores and classes, and relationships between environmental gradients and biological conditions, each candidate stressor (temperature, fine sediment, and dissolved oxygen for higher-gradient reaches) was assigned a likelihood class for each reach. Importantly, not all elements of the CADDIS framework were included in this process. In particular, not all potential stressors operating at different scales (nutrients, riparian conditions, landscape-level stressors, etc.) were assessed, either because data were lacking (as in the case of nutrients, metals, etc.) or because the stressors examined were assumed to serve as appropriate proximal surrogates for potential stressors such as reduced riparian functioning (temperature) or reduced habitat heterogeneity (fine-sediment levels). Furthermore, because the effects of elevated water temperature, fine sediment, and depleted dissolved oxygen on benthic communities are well documented, outside sources of information were not consulted to lend support to the determinations made using the study data. Finally, we did not score the stressors using the specific scoring system developed by CADDIS; rather, best professional judgment was used to evaluate reach-specific biological and environmental information and likelihood of cause was determined using a weight-of-evidence approach.

3.0 OBSERVATIONS AND RESULTS

3.1 SITE DESCRIPTIONS

The results of the analysis for each individual site are presented in Appendix A. The figures in Appendix A, representing longitudinal profiles and cross sections, are an important visual accompaniment to the following descriptions of the individual sites. The tables, in which multiple variables are presented, also aid in understanding the trends discussed below.

Lower Kellogg Creek: G-KL-10, M-KL-10

Geomorphology. The Lower Kellogg Creek site (Figure A1) is adjacent to Rowe Middle School. The survey reach begins at a constructed rock weir upstream from the school and extends downstream past a fence at the school property boundary. The moderate-gradient (0.6 percent) channel is straightened and armored with pockets of rip rap and large boulders along both banks. In the upper part of the reach, the bed may have scoured from 2009 to 2011, aggraded from 2011 to 2014, then partly aggraded and partly incised by 2017. These bed fluctuations of less than 2 feet probably represent some combination of survey differences and minor bed changes, not a geomorphic time trend such as aggradation or degradation. Six pools were counted in reach G-KL-10 in 2017, compared with three in previous monitoring years. The reason for the difference in the number of pools is not clear: it could reflect subjective differences between survey crew in identifying pools, or could represent actual formation of pools in the reach. Given the coarse boulder substrate in the reach, the former rather than the latter explanation is more likely. The bulk sediment sample results fluctuated over time as well, with a decrease in smaller sediments 2009 to 2011, an increase from 2011 to 2014, then a decrease in 2017. It is possible that a large storm event washed sediment out between 2009 and 2011 and that there is a source of fine sediment that is continuing to resupply this site. This can have implications on the macroinvertebrate community, as discussed below. The bed material consists mostly of very angular rock heavily armored by rip rap and placed boulders. The riparian canopy is patchy and narrow due to the presence of adjacent residential properties where vegetation is managed. This may result in higher than ideal water temperatures, negatively impacting habitat. A fallen tree at the lower extent of the reach has caused erosion on the right bank downstream of the school property.

Macroinvertebrates. Instream physical habitat is dominated by riffles (53.2 percent) in this reach, followed by glides (46.8 percent). Substrate in riffles comprises a heterogeneous mixture of coarse substrates ranging from fine gravels to boulders. Banks in this reach are primarily stable, as only 14 percent of the bank length was classified as actively eroding. While narrow, a riparian zone that includes mature trees and ornamental vegetation occurs on both banks and provides an estimated 80 percent canopy cover through the reach. Substrate embeddedness in riffles was moderately high at 20.8 percent.

Results of macroinvertebrate sampling in this reach have consistently indicated a community under duress. Macroinvertebrate communities in this reach have received MM scores ranging between 16 and 22 since sampling was initiated here in 2009. The reach has scored a 22, or moderately disturbed, in each year since 2011. MWCF O/E scores have ranged from 0.242 to 0.630 since 2009, all scores occurring in the most disturbed class. EPT richness in this reach is moderately low, as 2 mayfly, 0 stonefly, and 3 caddisfly taxa were sampled in 2017. Nearly half (41.3 percent) of the community is represented by taxa classified as generally tolerant to disturbance. The caddisfly *Cheumatopsyche* sp. was the dominant taxon in this reach, representing 26.3 percent of the total organism abundance in the sample. *Cheumatopsyche* is known to be tolerant to warm water, nutrient enrichment, sediment intrusion, and other disturbance. While it may naturally occur in abundance in larger streams in the Willamette Valley, its present dominance in lower Kellogg Creek suggests potential problems with nutrient enrichment. A moderately high modified HBI score of 5.2 from this reach further implicates nutrient enrichment as a potential stressor in this reach.

Since 2009, both fine sediment stressor (FSS) scores and temperature stressor (TS) scores have consistently implicated these two factors as likely stressors to macroinvertebrate communities in this reach; however, it is noteworthy that FSS scores have significantly improved and remained lower since 2009 (Figure 10).

Site Access. This site was accessed via the Rowe Middle School frontage. Call ahead and stop at main office to check in when on site.

Middle Kellogg Creek: G-KL-20, M-KL-20

Geomorphology. The Middle Kellogg Creek monitoring site (Figure A3), located about one-half mile upstream of the confluence with Mt. Scott Creek, consists of a section of Kellogg Creek that is highly managed by adjacent property owners. Most of the creek consists of a small, flat (essentially zero gradient), slightly meandering channel with armored bank, slightly inset into a much wider valley bottom/floodplain. The floodplain mostly consists of manicured lawn with intermittent shrubs and trees. The channel itself is inset into the floodplain 2 to 3 feet with streambanks constructed out of stocked rock or concrete rubble. The channel has very little planform or profile variability with only one significant pool in the reach, located just downstream of the culvert at Rusk Road. The reach has some eroding sections on the left bank where the stacked bank material is failing and hasn't been repaired. Approximately 50 percent of the bed substrate consists of sand or finer-grained sediment. There is a substantial amount of larger angular bed material that is either derived from the adjacent banks or from upstream. The floodplain in this reach floods frequently and has the potential for rapid riparian zone development due to its high degree of connectivity; but currently has little ecological function due to virtually no riparian cover and armored banks and bed. From a geomorphic, ecological, and engineering perspective, this reach would present a high-quality restoration opportunity to have a significant uplift to floodplain habitat with a low-cost project, however the adjacent landowners would need to be amenable to such a project, and they appear to be actively using the floodplain surface as lawn. This is a new site for geomorphology sampling, added because this site was included among the sites in WES' new Stream Health Index program (Waterways, 2018a).

Macroinvertebrates. The current middle Kellogg Creek (M-KL-20) reach has been included in the macroinvertebrate and physical habitat sampling portion of WES monitoring since 2011, when the reach was relocated approximately 600 m upstream from the reach sampled in 2002, 2007, and 2009. Geomorphic monitoring was previously not conducted at this site. The current reach occurs immediately upstream of Rusk Road, where it flows through a residential area and is bordered by maintained yards on both banks. This reach exhibits a moderately low gradient of 0.6 percent, and is dominated by slow-water habitats, accordingly. Pools and glides compose 87 percent of the reach habitat, while riffles represent 13 percent of the reach habitat. Substrate in riffles is dominated by coarse gravel and cobble habitat that is highly embedded at 23.0 percent. The riparian buffer in this reach is very narrow, averaging only approximately 4 m wide, as a result of maintained lawns occurring through most of this reach.

Macroinvertebrate communities in this reach exhibit conditions very similar to those in lower Kellogg Creek at M-KL-10, as MM scores have ranged between 18 and 22 between 2011 and 2017. MWCF O/E scores have ranged only between 0.533 and 0.582 in that same period. EPT richness is moderately low in this reach, as 4 mayfly, 0 stonefly, and 4 caddisfly taxa were sampled in 2014. As substrates are sufficiently coarse in this reach, the absence of stoneflies and sensitive taxa likely results from the combined effects of high substrate embeddedness, summertime thermal stress, and potentially low dissolved oxygen, particularly if organic enrichment is occurring. An HBI score of 5.4 is among the highest measured in 2017, indicative of a macroinvertebrate community that is relatively tolerant to organic enrichment pollution. FSS and TS scores from 2011 through 2017 have indicated that fine sediment and temperature are likely stressors in this reach. As further indication of the potential contribution of nutrient enrichment to biological stress in this reach, the community was heavily dominated by the relatively tolerant, filter-feeding caddisfly *Cheumatopsyche*, which represented nearly half of the total abundance (44.9 percent) of the sampled macroinvertebrate community.

Site Access. Site access off of SE Rusk Road between SE Aldercrest Lane and SE Eastbrook Drive.

Upper Kellogg Creek: G-KL-30

Geomorphology. Site G-KL-30 (Figure A5) is located along SE Aldercrest Ct in unincorporated Clackamas County. The upstream extent of the survey reach is a bridge at 6650 Aldercrest Ct and extends downstream to the bridge at 6450 Aldercrest Ct. The stream occupies a low trough created by a section of the Portland Hills Fault, and thus has a relatively flat gradient (0.4 percent slope) and a watershed dominantly underlain by fine-grained Missoula Flood sediments, with little gravel. The channel was historically straightened, and most of the survey reach flows in a ditch adjacent to the road. The bed consists mostly of compacted silt and sand with a minor component of gravel and angular cobble; sediment was not sampled as there are no appropriate riffle sections for sampling and no recent depositional features for pebble counts. The reach runs through residential area and lacks riparian canopy vegetation, with the exception of some cattail and small riparian trees. Reed canary grass and Himalayan blackberry encroach on the channel throughout the monitoring reach. In 2009, the homeowner at 6450 Aldercrest Ct mentioned that the creek has been aggrading over time and that the risk of flooding to his property and home has increased significantly. The channel bed has clearly scoured since 2009 over much of its length, though no clear migrating headcuts were observed. The channel capacity for 2014 was estimated to be less than the 2-year event, and the encroaching vegetation has most likely caused the channel capacity to decrease due to its effect on increasing the hydraulic roughness. Channel incision over the upper 250 feet of the reach may have partially moderated the loss in channel capacity due to the increased hydraulic roughness.

Site Access. This site has access along Aldercrest Ct. Check with the homeowner at 6450 Aldercrest Ct for access to the downstream portion of the survey reach.

Mt. Scott Creek at North Clackamas Park: G-MS-10, M-MS-10

Geomorphology. This monitoring reach (Figure A7) is located in a moderate gradient (0.6 percent slope) portion of lower Mt. Scott Creek less than one-half mile upstream of its confluence with Kellogg Creek. This is a new station for geomorphological sampling, added because lower Mt. Scott Creek was selected as one of the scoring sites in WES' Stream Health Index program (Waterways, 2018a). The upstream portion of the monitoring reach overlaps a restoration project completed by Water Environment Services in 2012 that consisted of installing large wood with rootwads along the left margin of the channel and extending approximately half way across the active channel. Qualitatively, the project appears to have been successful at accumulating gravel and scouring pools. The monitoring reach has a broad floodplain with a mosaic of off-channel wetlands and secondary channels that appear to be well-connected to the main channel at high flows. The reach has a good amount of complexity in its longitudinal profile, with a pool and riffle sequence that is influenced by the presence of natural and placed large wood, and channel constrictions associated with floodplain trees and other roughness elements. The only bank erosion present in the reach is located along the right bank at a private property where the riparian vegetation has been replaced with a manicured lawn.

Macroinvertebrates. This reach occurs in lower Mt. Scott Creek in a recently restored reach. First sampled in 2011, this reach occurs less than 200 m upstream of a reach sampled in 2002, 2007, and 2009. The existing reach occurs on a wide, low floodplain and exhibits a meandering pattern on a 0.5 percent reach gradient. While habitat is dominated by slow-water habitats (77.5 percent pools and glides), riffles occur in sufficient abundance to warrant macroinvertebrate sample collection from this habitat type. Riffle substrate was dominated by coarse gravel and cobbles, and embeddedness was moderately low at 11.2 percent. Owing to recent riparian planting throughout the reach, the buffer width averaged 53 m. Canopy cover averaged 78 percent through the reach.

Macroinvertebrate communities in this reach have received MM scores of 18 in 2011 and 22 in 2014 and 2017. MWCF O/E scores have also been low, ranging between 0.339 and 0.436 between 2011 and 2017 (0.388 in 2017). EPT richness is moderately low in this reach, with only 6 taxa sampled in 2017, and no sensitive or sediment sensitive taxa were sampled. A moderately high modified HBI score of 5.2 suggests that the community is tolerant to conditions associated with organic enrichment pollution, such as low dissolved oxygen and fouling of substrates by abundant algae. Nearly half (40.0 percent) of the community is represented by taxa classified as generally tolerant to disturbance. Since 2011, both fine sediment stressor scores and temperature stressor scores have consistently implicated these two factors as likely stressors to macroinvertebrate communities in this reach, although the 2014 and 2017 fine sediment stressor scores are approximately half the value of the 2009 and 2011 FSS scores, suggesting potential improvement in community conditions. As was the case with both Kellogg Creek reaches (M-KL-10 and M-KL-20), the community in M-MS-10 was dominated by the relatively tolerant, filter-feeding caddisfly *Cheumatopsyche*, which represented more than a third of the total abundance (33.8 percent) of the sampled macroinvertebrate community.

Site Access. Access the site from North Clackamas Park.

Mt. Scott Creek Downstream of SE 82nd Ave: G-MS-40, M-MS-40

Geomorphology. This site on Mt Scott Creek is located downstream of SE 82nd Ave, within the Three Creeks Natural Area. The survey reach is adjacent to a fenced, poplar remediation area and begins at a riffle approximately 400 feet upstream from a steel bridge crossing and extends downstream of the bridge. The channel has a relatively low gradient (0.5 percent) and contains long pools separated by small riffles (Figure A9). The channel is relatively straight and incised in most places. The upper two cross sections experienced little change between survey years, but, as of the 2014 monitoring report, the lower cross section had widened and aggraded between 2009 and 2014, and this was accompanied by an increase in bank erosion, especially in the downstream extents of the reach. The 2017 survey did not show much change in the cross sections or longitudinal profile elevation, and the 2017 survey did not record the active bank erosion on the right bank seen in the 2011 and 2014 surveys. The longitudinal profile neither aggraded nor degraded, but the depths and locations of pools appears to have changed slightly since the last surveys; it is possible that some of these changes may be due to survey stationing in the two surveys; however, it is also possible that the changes reflect normal fluctuations in the stream over a few years. The channel can contain a flow equivalent to between the 2-year and 5-year peak flow, suggesting the channel may be slightly incised compared with similar streams, which flood approximately every 2 years. Bed conditions consist of mixed gravels and fines with small exposed depositional bar features. There was a small but statistically significant increase seen in the mean particle size from the pebble counts from 2009 to 2014, but not from 2011 to 2014 or from 2014 to 2017. The survey reach includes a healthy riparian zone with diverse plant species.

Macroinvertebrates. Habitat in this reach comprises primarily riffle (37.1 percent) and pool (47.6 percent) habitat. Substrate in riffles was heavily dominated by coarse gravel and secondarily by fine gravels and a modest proportion of cobble. Embeddedness was moderate in these substrates, at 13 percent, while incised banks along this reach were primarily in an actively eroding condition (71 percent eroding banks). Canopy cover was heavy in this reach (94 percent), and a wide riparian buffer occurs on each side of the creek.

Macroinvertebrate communities have consistently received MM scores between 14 and 20 in the six years of monitoring work since 2002, including a score of 20 in 2017. 2014 and 2017 represented the first years that the multimetric index scored better than severely disturbed. MWCF O/E scores have ranged between 0.291 and 0.581, the highest score received in 2014, while an intermediate score of 0.440 was produced in 2017. Eight EPT taxa were sampled from this reach in 2017, yet more than half of the organisms in the sample (61.6 percent) were classified as generally tolerant to disturbance. The tolerant caddisfly *Cheumatopsyche* was the dominant taxon in this sample, representing nearly half of the total abundance (48.9 percent). *Cheumatopsyche* is known to be tolerant to warm water, nutrient enrichment, sediment intrusion, and other disturbance. While it may naturally occur in abundance in larger streams in the Willamette Valley, its dominance in Mt. Scott Creek suggests potential problems with nutrient enrichment. A moderately high modified HBI score of 5.2 from this reach further implicates nutrient enrichment as a potential stressor in this reach.

Since 2002, both fine sediment stressor scores and temperature stressor scores have consistently implicated these two factors as likely stressors to macroinvertebrate communities in this reach, although the 2014 and 2017 fine sediment stressor score have been lower than scores from earlier years by a considerable margin (Figure 10).

Site Access. This reach was accessed via foot trails from the North Clackamas Aquatic Park parking lot.

Mt Scott Creek Downstream of SE Sunnyside Road: G-MS-70

Geomorphology. This site (Figure A11) is located within Mt. Talbert Nature Park downstream of SE Sunnyside Rd. The upstream end of the survey reach is located underneath the pedestrian bridge. This low-gradient (0.6 percent), sinuous channel is slightly incised and contains sections of exposed bedrock as well as good pool/riffle sequences, depositional features, and distinct pool features. A slight overall change in channel morphology or substrate was observed at this reach between survey years 2009 and 2011 (pools filled and reduction in profile complexity), between 2011 and 2014 (scour and formation of at least 2 pools at the upstream and downstream ends of the reach). Between 2014 and 2017, a deep pool surveyed in 2014 at the upstream end of the reach had filled with gravel, and a pool near the downstream end of the reach had enlarged. The pebble counts suggest that channel bed material coarsened between 2011 and 2014, and remained almost the same in 2017. The reason for the coarsening is not clear and it is not yet clear if this is a long term change or whether it reflects simple year-to-year variability. The bulk sample in 2014 had a higher proportion of fines than the 2011 sample, but the 2017 sample contained a similar, small proportion of fines, similar to 2011. These differences between years probably reflects transient changes in bed material composition following stormflows of differing size. This section of Mt Scott Creek flows along the margin of Mt Talbert Nature Park and is bounded by a mature wooded riparian zone and dense ground cover.

Site Access. The site was accessed via a hiking/nature trail whose trailhead exists within the Miramont Pointe parking lot south of SE Sunnyside Rd.

Mt. Scott Creek near SE 122nd Ave: G-MS-80, M-MS-80

Geomorphology. This site (Figure A13) is located on Mt Scott Creek along SE 122nd Ave in an area where restoration work was completed prior to 2009 to remove an earthen dam and restore the stream channel to a more natural condition. The geomorphic survey reach extends upstream from the pedestrian bridge within the restored section, while the biological survey reach occurs in its historic (dating back to 2002) location on the downstream side of the foot bridge, just below the restored reach. This section of Mt Scott Creek is steep (about 2.5 to 3 percent gradient), relatively straight and dominated by engineered pool/riffle structures comprised of cobbles and boulders, effectively armoring most of the channel. This reach experienced little change in the upper and lower extents between 2009 and 2014, but appears to have deepened and narrowed at the middle cross section. In the 2017 survey, however, substantial erosion appears to have occurred at cross section 1 (upper end of reach), and substantial deposition occurred at cross section 2 (Figure A13). The apparent aggradation in the middle of the survey reach was notable in the field, where the banks are less than one foot high and tree trunks appear to be buried along this part of the channel. The longitudinal profile in 2014 suggested that there may be the start of a headcut or an area of scour just upstream of the bridge, but this was not observed in 2017. Given that the reach is comprised of coarse cobble-size material, headcut migration will likely be slow if it continues to move upstream. There is a healthy riparian zone throughout the survey reach.

Macroinvertebrates. Habitat in the long-term biological monitoring reach primarily consists of riffles (54 percent of reach length) and step-pool habitat occurring on a channel gradient of approximately 3.5 percent. Embeddedness in riffles was measured at 21.5 percent in 2017; riffle substrate is dominated by cobbles and secondarily by coarse gravels. The adjacent riparian zone is forested for distance of approximately 40-50 m on each bank, providing approximately 70 percent canopy cover to the channel. Macroinvertebrate community MM scores have ranged between 20 and 28 (moderately disturbed) since 2009, while 2002 and 2007 scores were 16 each year. MWCF O/E scores have ranged between 0.387 and 0.586 since 2002, with no obvious trending evident during this time period. Eleven EPT taxa were sampled from this reach in 2017, nearly twice as many EPT taxa as were sampled in 2014, and including two taxa classified as sensitive to disturbance: the mayfly *Cinygma* sp, and immature stoneflies belonging to the family Capniidae. Results of this year's sampling suggest that some improvement to macroinvertebrates in this reach has potentially occurred. However, since 2002, fine sediment scores in all assessment years and temperature stress scores in most years (including 2017) indicate that both fine sediment and temperature are likely stressors in this reach.

Site Access. The site was accessed via trail/bridge access along SE 122nd Ave.

Tributary to Mt. Scott Creek: G-MS-90

Geomorphology. Site G-MS-90 (Figure A15) is located on a tributary to Mt Scott Creek and is adjacent to a paved pedestrian path that connects SE Cedar Way and SE Otty Rd in Happy Valley. The survey reach is a small, steep (>6 percent slope) channel that appears to have been constructed as part of the housing developments occurring on either side. Stabilization work was completed on this reach in September 2014, a couple of months prior to the monitoring survey, to address the channel instability observed between 2009 and 2011. Prior to stabilization, this reach was experiencing heavy erosion and localized areas of scour and deposition, as can be seen in the cross sections in Figure A15. In areas of aggradation, the footpath that runs along the creek was at a lower elevation than the creek bed and flooded frequently. With further aggradation, the flooding would have increased and threatened local infrastructure. As part of the stabilization project, a series of rock grade control weirs was installed to stabilize the channel, prevent further erosion, and contain it at high flows. The project also removed non-native species and re-planting the riparian corridor. The stabilization project appears to have had the intended effect, and no measurable changes were observed between the 2014 and 2017 surveys.

Site Access. The site is accessed via pedestrian footpath from SE Cedar Way.

Mt. Scott Creek near Happy Valley Park: G-MS-100

Geomorphology. Site G-MS-100 (Figure A17) is located along Mt Scott Creek between King Rd and Happy Valley Park. The survey reach is located downstream from the southern park boundary beginning at a barbed wire fence across the stream channel and extending downstream. In general, the channel has a moderate gradient with a slope of 1.5 percent, consists of pool/riffle sequences and has exposed bedrock in the channel bed throughout the reach. No significant channel changes have occurred throughout the monitoring period since 2009. Evidence of headcuts are present in the upstream extents of the reach, but these are mostly stabilized, and most areas are dominated by bedrock with a thin veneer of angular rock and some fine sediment. An increase in the width to depth ratio indicates a widening and flattening of the channel which is most likely due to bedrock preventing downward erosion. No depositional features were observed, and consequently, no pebble counts have been measured in the reach. Thick riparian vegetation is present along the entire survey reach but is largely dominated by blackberry in the understory. In many cases lateral erosion along bedrock has weakened root structures, increasing deposition, and causing trees to fall over into the channel.

Site Access. This site was accessed from the southern end of the Happy Valley Park.

Mt. Scott Creek Downstream of SE 145th Avenue: G-MS-110

Geomorphology. The furthest upstream site on Mt Scott Creek is located near SE 145th Ave within the Happy Valley Wetland Park (adjacent to the Happy Valley Park) (Figure A19). The survey reach is located downstream of a constructed duck pond. The channel within this reach is small and low gradient consisting of glide habitat with a bed dominated by fines and clay. Bulk sediment analysis from 2009 and 2011 monitoring years shows the channel bed is dominated by fines, with 99 percent smaller than 6.3mm and about 90 percent smaller than 0.85 mm. Bulk sediment analysis was not performed at this site in 2014 or 2017 due to the high proportion of fine sediments present, and lack of gravel. This area was probably a historic marsh/meadow/wetland, in which a single thread channel was artificially created to increase farming acreage. Urbanization has resulted in additional flow to the area, further contributing to the development of a single thread channel. The channel appears to have moved slightly laterally in 2014 and again in 2017, but the survey shows little change overall. The 2017 longitudinal profile shows one to 1.5 feet of aggradation, likely due to a debris jams that slows water and trapped sediments upstream. An increase in the number of pools counted in the survey may also be due to the large number of debris jams at this site. The reach contains a riparian zone consisting mostly of woody vegetation and grasses and is likely partially inundated during the rainy season.

Site Access. This site was accessed from the Happy Valley Park using the boardwalk system, but could easily be accessed from other entry points into the Happy Valley Wetland Park area near SE 145th Ave.

Phillips Creek: G-PH-10, M-PH-10

Geomorphology. Site G-PH-10 on Philips Creek (Figure A21) is located downstream of SE Sunnybrook Blvd along SE 84th Ave. The survey reach begins at the Sunnybrook Blvd culvert and extends downstream, ending at a culvert at SE 84th. This steep channel is heavily influenced by urbanization, confined by gabion walls in the upstream half, bridge abutments, and culverts at both ends and a low bridge in the middle of the reach. Nevertheless, within the confines of the gabion walls and embankments, a relatively functional channel and narrow floodplain are present. The channel provides reasonable channel complexity with riffles and a few deep pools, and a narrow hydraulically connected floodplain and mature trees. A large depositional feature is present at the downstream end of the study reach, suggesting that the culverts under SE 84th are undersized, resulting in backwatering and deposition of bed load during peak flow events. The lower half of the reach appears to be aggrading, as seen in the increase in elevation of the lower half of the longitudinal profile from 2011 to 2014. Although the thalweg profile did not aggrade substantially between 2014 and 2017, overall aggradation of the lower part of the reach appears to have continued: cross section 3 shows aggradation of more than 2 feet of gravel in the channel leading into the right culvert (Figure A21), concentrating more of the flow towards the left culvert, and possibly increasing the frequency of culvert backwatering and the probability of road flooding. Although this aggradation behind the culvert may cause a slight increase in nuisance flooding, aggrading streams tend to provide better habitat and this is consistent with the observations on the field visit. In 2017, a riffle near the bottom end of the reach just above the culvert contained reasonably high content of fines (24 percent sand and 4 percent silt and finer), and this could be related to fines deposition during backwater condition at the culvert.

Macroinvertebrates. Habitat in this reach includes 41.0 percent riffles and 52 percent glides. Riffles in this reach are heavily dominated by coarse gravel and cobbles; these coarse substrates averaged 7.6 percent embeddedness in riffles. A narrow riparian buffer occurs along this reach, averaging only 9 m wide on each side of the stream, and some mortality to these trees since the last survey resulted in a slightly lower canopy cover from 84 percent in 2014 of 75 percent in 2017. Riparian invasive plant species, including reed canary grass and Himalayan blackberry, was estimated to represent 30 percent of the riparian vegetative cover.

Macroinvertebrate communities have received MM scores of 16 (2011) and 22 (2014 and 2017) in the three years this reach has been sampled. MWCF O/E scores have scored exclusively in the "most disturbed" class, ranging from 0.387 to 0.436 (0.388 in 2017). EPT richness included 1 mayfly taxon, no stonefly taxa, and 1 caddisfly taxon in 2017. No sensitive taxa or sediment sensitive taxa were sampled from the reach in 2017. The modified HBI score of 5.8 was the among highest from CCSD #1 macroinvertebrate samples collected in 2017, indicating a community that is largely tolerant to organic enrichment pollution. The two "weed" taxa, *Baetis tricaudatus* and *Simulium* sp. represented approximately half of the total abundance in this sample, which can be an indicator of a recent disturbance event, such as dewatering or scour, or of the presence of toxins. Fine sediment stressor scores from 2011 through 2017 have consistently indicated that fine sediment is a likely stressor to biological communities in this reach, yet embeddedness of riffle substrates was low. Furthermore, the 2017 temperature stressor score did not exceed the likely-stressor threshold for Willamette Valley streams, suggesting that temperature may not be a significant stressor in this reach. The overall degraded community condition without an attendant signal of significant thermal (or even sediment-induced) stress is unusual, and warrants continued monitoring.

Site Access. This site is accessed via the Costco parking lot off SE 84th Ave.

Cedar Creek: M-CE-10A

Macroinvertebrates. This site is exclusively a macroinvertebrate monitoring reach that was sampled for the first time in 2017. This reach occurs approximately 100 m downstream of a previous monitoring reach in Cedar Creek that had insufficient flow in both 2017 and the last sampling year (2014) to allow sampling. The survey reach was relocated to immediately downstream of the confluence with Mel Brook, where late-summer flows appear to be more reliable.

The reach occurs on a long and narrow parcel owned by WES downstream of Mather Road. A narrow strip of riparian forest occurs on both banks, providing heavy canopy cover (98 percent) through the reach. Reach gradient is approximately 1 percent, resulting in sufficient riffle habitat (49 percent by reach length) for targeted macroinvertebrate sampling from this habitat type. Riffle substrates were dominated by coarse gravels (45.9 percent) and secondarily by cobble (26.2 percent). These coarse substrates exhibited a moderate level of embeddedness of 14.6 percent.

As previous surveys in the upstream reach had indicated from 2002 through 2011, the macroinvertebrate community received both multimetric and MWCF O/E scores corresponding to the most disturbed conditions class for each model (Table 12). A modest number (6) of EPT taxa were sampled from the reach, including one sensitive taxon, a single immature nymph belonging to the Capniidae stonefly family. However, a high modified HBI score of 5.7 and a high dominance by tolerant taxa (53.1 percent) indicate a stressed community in this reach. Temperature stress and fine sediment stress models suggest each as a likely source of stress to macroinvertebrate communities in this reach.

Site Access. Site access is via a North Clackamas Parks & Rec Dept property on the east side of Cedar Park Drive.

Lower Rock Creek: G-RC-10, M-RC-10

Geomorphology. This site (Figure A23) is located in the lower section of Rock Creek between Hwy 212/224 and the confluence with the Clackamas River. Below the highway bridge is a small gorge, the lower end of which is where the survey reach was established. Downstream of the mouth of the gorge, the stream channel is very dynamic with large depositional features and large accumulations of woody debris. A restoration project was recently constructed between the downstream end of the monitoring reach and the mouth at the Clackamas River. Within the monitoring reach, the channel is incised to bedrock, and there is a small abandoned floodplain terrace, suggesting the channel incised to bedrock in response to urbanization but bedrock will impede further degradation in the future. Patches of gravel are present over bedrock, especially in the shadow of hydraulic obstructions and in the downstream end of the reach. The longitudinal profile appears to have aggraded one to two feet over much of the reach since the 2014 survey, and about one foot of aggradation is evident at cross section 2 and 3, which could be seen as an improvement in habitat conditions in the reach. However, due to the presence of bedrock in the channel and the lack of active floodplain, it is likely that these are temporary accumulations of sediment that will be removed relatively soon. Pebble count substrate size increased significantly from 2009 to 2011 (D50 from 31 to 61 mm), did not change from 2011 to 2014, and decreased (D50 of 49mm) in 2017. Fine sediment from the bulk sample also increased from 2009 to 2011 but experienced little change since then. A significant amount of gravel appears to move through this reach, as evidenced by the pebble count, although very little storage occurs in this reach due to the confined nature of the channel. Bank toes are well protected by bedrock and there was no active bank erosion present in any survey year although some bedrock slabs, composed primarily of siltstone, have failed, resulting in the delivery of a large amount of material and wood to the streambed.

Macroinvertebrates. Beginning in 2011, macroinvertebrate sampling and concurrent physical habitat sampling have occurred primarily in the small gorge below the Highway 212/224 Bridge. While this sampling occurred in the recently restored section (prior to restoration) from 2002 and

2009, the reach has been relocated approximately 90 m upstream and no longer includes the restored stream section. Accordingly, the biological monitoring results for this section of Rock Creek across all years from 2002 to 2014 exclude any potential effects of the restoration project.

Habitat in this reach primarily comprises riffles (34.2 percent) and pools (53.0 percent). Channel gradient in this reach is approximately 1 percent. Riffle substrate is dominated by coarse gravels and cobble that average 12.9 percent embeddedness. A mature and relatively wide (75 m average width) riparian buffer occurs on both sides of this reach, providing a measured 86 percent canopy cover.

Since 2007, macroinvertebrate communities in this reach have consistently received multimetric scores corresponding to slightly disturbed conditions (range of scores = 30 to 34 across 5 years of sampling). MWCF O/E scores have varied more widely (0.678 to 0.918) than have MM scores, and corresponding condition classes have ranged between least and most disturbed, including an O/E score of 0.678 and classification of most disturbed in 2017. The reach presently supports a relatively diverse EPT community, as 5 mayfly, 5 stonefly, and 6 caddisfly taxa were sampled from the reach in 2014, relative to 2017 reach group means of 3.7, 2.1, and 3.4, respectively. Two stonefly taxa classified as sensitive to disturbance, immature Capniidae *and Despaxia augusta*, were sampled from the reach in 2017. However, the sample was dominated by the ubiquitous and relatively tolerant mayfly, *Baetis tricaudatus* and by the tolerant filter-feeding caddisfly Hydropsyche sp., resulting in tolerant individuals representing 23.3 percent of the total abundance in the 2017 sample from this site. Temperature stress scores have consistently flirted around the 18.4°C benchmark (including 18.2 in 2017), resulting in temperature being classified as a potential biological stressor in this reach. However, sediment stressor scores since 2007, including a score of 7.5 in 2017, continue to be among the lowest measured across the CCSD #1 reaches. These consistently low fine sediment stressor scores, and the geomorphic surveys observations that little fine sediment storage occurs in the reach result fine sediment as currently being classified in this reach as an unlikely stressor.

Site Access. The site was accessed via unofficial footpaths/trails through CCSD #1 Conservation Easement parcel property that is located just west of the 224/212 bridge over Rock Creek. Trails are steep and can be slick in wet conditions.

Tributary to Lower Rock Creek: G-RC-20

Geomorphology. This site was discontinued in 2017 after a reconnaissance visit and subsequent discussion with WES. The site on an ephemeral tributary to Lower Rock Creek traverses a field with no riparian vegetation except blackberry; the channel has a uniform profile and not much habitat value; and geomorphic change is limited by lack of flow and coarse angular substrate.

Rock Creek Downstream of Sunnyside Road: G-RC-30, M-RC-30

Geomorphology. This site is located on Rock Creek downstream of SE Sunnyside Rd; the upstream extent of the survey reach is at a bedrock riffle just downstream of the Sunnyside Rd Bridge. The survey reach is dominated by bedrock and boulders with little to no stored sediment within the channel bed. The channel is moderately steep with a gradient of 1.4 percent in 2017. The longitudinal profile in 2017 is similar to the 2014 profile. The channel is very straight in this area and lacks structure. No depositional features were present suitable for a pebble count, and the bed consisted mainly of bedrock with boulders and small pockets of gravel. The channel banks are well vegetated and riparian vegetation density and quality increases with distance downstream from the bridge. The survey reach is located immediately downstream of an area where restoration activities had recently taken place, including underneath the Sunnyside Road bridge. The instream restoration activity likely was performed in association with bridge construction or maintenance, and it appears as though some of the constructed elements in that reach have failed.

Macroinvertebrates. Physical habitat in this reach is dominated by riffles (51.3 percent) followed by pools (33.3 percent). A highly heterogeneous composition of substrates occurs in riffles sampled for macroinvertebrates and includes moderately embedded (14.6 percent) gravels, cobbles, boulders, and bedrock. Canopy cover, provided by a wide forested riparian buffer on each bank, averaged 89 percent throughout the reach.

Macroinvertebrate communities scored as moderately disturbed (24) with the multimetric index and as most disturbed (0.677) with the MWCF O/E model. While 2014 scores from each of these assessment tools indicated less-disturbed conditions and potential improvement over recent historic conditions, 2017 scores returned to recent historic averages. It's worth noting that this reach was one of only a few reaches sampled following the September 20th rain event, and was the largest reach among those sampled after the event. While it's possible that flushing flows from that event had an effect on benthic community conditions when the sampling occurred, macroinvertebrate densities exceeded 3,400 individuals/m^2 in sample collected from the reach, which would indicate that significant scour had not occurred. Additional data points in future years will allow determination of whether this this variation in community condition persists, which would suggest a system likely subjected to regular disturbance from scouring flows resulting from significant hydromodification.

EPT richness (13) was still moderately high in the reach, and included 6 caddisfly taxa, which may indicate a lack of significant fine sediment effects. Temperature and fine sediment stressor scores suggest that each is acting as a likely stressor in the reach, yet fine sediment scores continue to be substantially lower than they were in the first few assessment of years 2002 and 2007.

Site Access. The site is accessed via CCSD #1 owned parcel adjacent to the storm and sewer district construction road (Rock Creek Interceptor Project) to the north of the Sunnyside Rd Bridge. It may also be accessed through the parking lot owned by the Sunnyside Veterinary Hospital south of the Sunnyside Road Bridge and west of Rock Creek.

Rock Creek Downstream of 172nd Avenue: G-RC-40

Geomorphology. This geomorphic monitoring site was not accessed in 2017 because landowner permission was not granted, as the site was under construction during the survey period. However, since the landowner has indicated permission will likely be granted in the next survey year, the CCSD #1 site description from 2014 is provided below:

Rock Creek flows through the old Pleasant Valley Golf Course at this site. The survey reach begins just downstream of a small check dam and extends downstream past the golf course boundary. The low gradient channel consists of a pool and riffle morphology created by natural boulder weirs and deposition of coarse sediment. The channel bed consists of bedrock and small gravels armored by large gravel and boulders. The channel experienced scour from 2009 to 2011 but experienced subsequent aggradation between 2011 and 2014. The depositional features and the pool tails coarsened from 2009 to 2011 and subsequently got smaller, on average, between 2011 and 2014. In addition, the fines from the bulk sample increased from 2011 to 2014 into the high sediment intrusion rating. This indicates an added source of sediment upstream of the reach, potentially associated with bank erosion or construction activities at 172nd Avenue.

This channel was previously listed in the recommendations of this report as 'at risk' due to a coarsening of depositional features and exposed bedrock. The alluvial layer became finer from 2011 to 2014 and the reach appears to be aggrading, indicating that the reach is stabilizing. That being said, the channel is estimated to hold somewhere between the 5-year and 10-year event. This reach could benefit from increased floodplain connectivity especially given that the site has little adjacent infrastructure. A portion of the creek along the right bank borders a previously mowed area (historic fairway of a golf course) and the margin along that bank consists mostly of grassy vegetation. The remainder of the banks and floodplain contain a more diverse inventory of riparian vegetation as well as areas of thick blackberry.

Site Access. The site was accessed in 2014 via golf course boundary near SE 172nd Ave.

Rock Creek at Troge Road Downstream of SE Foster Rd: G-RC-50, M-RC-50

Geomorphology. Site G-RC-50 on Rock Creek (Figure A27) is located downstream of SE Foster Rd and runs parallel Troge Rd. The survey reach starts at the downstream end of a private driveway bridge and extends to a fence marking the property boundary. This is a moderately steep and incised channel with a slope of 1.5 percent. The survey reach is transport dominated with few depositional bars above the low water elevation, and the bed consists of armored cobble with a few patches of gravel. In 2017, the longitudinal profile survey was extended downstream about 30 feet to a beaver dam almost two feet high, that creates a backwater area causing sediment deposition in 2017. The bulk sediment sample data, collected towards the bottom of the reach but apparently above the influence of the beaver dam, consisted of about 30 percent sand and 6 percent silt and clay. No active bank erosion was observed in 2017 and only small areas of erosion were mapped in 2011 and 2014. The survey reach currently has a narrow riparian area with a mix of native and non-native vegetation.

Macroinvertebrates. Physical habitat in this reach is dominated by small pools (60.0 percent) and secondarily by short riffles (32.2 percent). Riffle substrate consists primarily of coarse gravel and cobbles that were 12.4 percent embedded by fines in 2014. Owing to the presence of Troge Road on the right bank and a yard on the left bank, the vegetated riparian zone only averages only 6 m wide. However, tree and shrub cover are sufficient to provide 85 percent canopy cover through the reach.

Between 2009 and 2014, macroinvertebrate communities have exclusively received moderately disturbed MM scores. This score increased to 34 and a corresponding slightly-disturbed condition classification. Similarly, the MWCF O/E score improved to least disturbed (1.064) in 2017 after having scored exclusively in the moderately and most disturbed classes from 2009 to 2014. The 2017 sample collected from this reach included 20 EPT taxa, the highest EPT richness among all of the 2017 CCDS#1 reach samples. Furthermore, the reach sample included an abundance of the long-lived elmid beetle *Optioservus* sp. and lesser numbers of three other elmid beetle taxa, indicating a lack of any recent significant disturbances such as dewatering, scouring flows, or thermal stress that can interfere with the life cycles of longer-lived (two or more years) organisms. In general, the community in the reach exhibits a remarkable balance in the number of individuals across taxa; no single or few taxa show a particularly high dominance, as further indication of the lack of any recent significant stress. An HBI score of 3.5 in 2017 was the lowest HBI score measured from CCSD #1 reaches in 2017, indicative of a community less tolerant to organic enrichment pollution than those occurring in most other CCSD #1 reaches. While both TS and FSS scores have consistently indicated that each of these factors is a likely biological stressor in this reach, 2017 FSS scores were the lowest measured across the four survey years at M-RC-50. Future monitoring of this reach should reveal whether these improved conditions are maintained or if the reach is only experiencing a shorter period of relatively narrow peak flows and other environmental extremes.

Site Access. The survey reach is easily accessed from the property driveway off of Troge Road.

Upper Rock Creek: G-RC-60

Geomorphology. Site G-RC-60 on upper Rock Creek is located upstream of SE Hemrick Rd between SE 172nd Ave and SE Foster Rd. The incised, low gradient (0.4 percent), and very straight survey reach is located entirely within a single private property dominated by unmowed grass along the creek banks. A thick growth of reed canary grass extends into and across the entire stream channel and much of the survey reach is backwatered by a private road culvert and debris jam. Bed conditions on this low gradient channel reach are mostly masked by the heavy growth of grass and deposition of fine sediment, and no depositional gravel bar features were observed. In the few small areas that were not deep pools behind obstructions, or heavy grass, bed conditions were observed to consist of mixed gravels and fines. No active bank erosion was observed in 2009, 2014, or 2017 (in 2011 some active erosion was mapped on the banks just above the downstream culvert at a small rock weir). The reach appears to have established inset benches due to past incision and widening and subsequent incision. This being said, the channel appears to be aggrading, except at the pool at the downstream end of the reach which appears to have scoured behind the road culvert.

This reach was further investigated by Waterways in 2013 as part of a stream repair feasibility assessment. This reach was previously listed as 'at risk' in the recommendations section but was later moved to the 'stable-at risk' category due to the landowners efforts to replant the site with native vegetation. The upstream end of this site, at the property boundary, has a headcut that should continue to be monitored in future years. If the knickpoints begin to headcut further upstream, further action should be taken.

Site Access. The survey reached is easily accessed from both banks at 17951 SE Hemrick Rd.

Trillium Creek: M-TR-10

Macroinvertebrates. Trillium Creek is a tributary stream that enters Rock Creek from river left in the restoration reach immediately downstream of G-RC-10. This small stream occurs in a narrow valley confined by steep valley walls. The stream channel is straight, appears incised, and is actively eroding. Eroding banks occurred along 94 percent of the reach length. The reach gradient is currently 1.8 percent. A large amount of large woody debris has been deposited in this reach since the last surveys were performed 2014, resulting in the highest LWD density among the CCSD #1 reaches. This wood has created more depositional habitat (43 percent) in the reach; riffles (56 percent) still dominate the reach habitat. Substrate in these riffles is heavily dominated by coarse gravel and cobbles that average a moderately high 21 percent embeddedness by fine materials. A wooded riparian buffer averages 48 m wide through the reach, but is narrower on the river left side as a result of recent home construction.

Macroinvertebrate communities in this reach received an MM score of 30, corresponding to the first slightly disturbed classification that this reach has received in four sampling years, and a notable improvement over the 2014 score of 18. The MWCF O/E score was the same as that received in 2014, suggesting the potentially lower sensitivity of the MWCF model to the changes that have occurred in this reach. Thirteen EPT taxa were sampled from this reach in 2017, a marked increase over the 6 EPT taxa sampled in 2014. The increased habitat heterogeneity and potential ameliorative effects against scour afforded by the abundant large woody debris is likely driving this increase in taxonomic richness. Two sediment-sensitive caddisfly taxa – *Wormaldia* sp. and *Glossosoma* sp. – were sampled from the reach in 2017. Despite moderately high embeddedness in this reach, fine sediment stressor scores have not yet implicated fine sediment as a stressor. The low FSS score, considered with the high caddisfly richness that includes two sediment sensitive taxa results in fine sediment being classified as a potential stressor in the reach. Temperature stress scores have been marginally on either side of the temperature stress threshold value, resulting in temperature also being classified as a potential stressor in this reach.

Site Access. This site is located immediately upstream of the confluence with Rock Creek, which is between reach M-RC-10 and the Clackamas River. Access is via unofficial footpaths/trails through CCSD #1 Conservation Easement parcel property that is located just west of the 224/212 bridge over Rock Creek. Trails are steep and can be slick in wet conditions.

Carli Creek: G-CA-10, M-CA-10

Geomorphology. The Carli Creek geomorphic monitoring reach (Figure A31) was added in 2017 at the request of WES. The geomorphic monitoring reach is upstream of the stream restoration section that accompanied the Carli Creek water quality project built by WES in summer 2017. The downstream end of the monitoring reach is at the most upstream wood installation, and extends about 300 feet upstream. The reach consists of a complex meandering channel with a frequently-flooded vegetated floodplain covered with mature trees and abundant blackberry. The channel itself through the reach contains forced pools at bedrock obstructions, and alternating gravel bars, riffles and pools elsewhere. As 2017 was the first survey year for this reach, it was not possible to document time trends in bed elevation (aggradation, degradation, and headcutting); however, based on the current condition, the reach appears to be dynamic but relatively stable. A bulk sample of riffle near the downstream end of the reach contained about 9 percent sand and 2 percent silt and clay.

Macroinvertebrates. Carli Creek is a small tributary to the lower Clackamas River. The lower reaches of this creek flow through a heavily commercialized/industrialized area, the lowest extent of which is undergoing active restoration on a land parcel recently acquired by WES. The macroinvertebrate survey reach was relocated approximately 200 m downstream of the 2007-2014 survey reach to be outside of the direct influence of the temporary local disturbance from the restoration project, which was being constructed at the time the macroinvertebrate sampling event and would have dominated the signal at the previous sampling location. The character of this new reach is very similar to that of the former reach just upstream. The new survey reach occurs in a stream valley bordered beyond the right bank by industrial land uses and by undeveloped land on the left bank. A narrow riparian forested zone averaging approximately 35 m occurs on both sides of the creek. Resulting canopy cover over the stream channel is a favorable 94 percent. The reach flows in a relatively straight path through this narrow valley, within which a small floodplain also occurs. The channel gradient averages 1.9 percent through this reach and habitat is dominated by riffles (67.6 percent) and secondarily by pools. Substrate in riffle habitats is dominated by coarse gravel and cobbles, which averaged 14.3 percent embeddedness.

Because the reach was relocated by only 200 m from reach M-CA-10, and no significant tributaries or other potential influences occur in the intervening distance, comparisons with previous years' results are valid. Between the two reach locations, macroinvertebrate communities scored exclusively as severely disturbed by MM scores and most disturbed by MWCF O/E scores since sampling was initiated here in 2007. 2017 scores occur directly in the middle of the range of scores by both tools across the prior years. Only one EPT taxon, the nearly ubiquitous mayfly *Baetis tricaudatus*, was sampled from this reach in 2017. The reach was heavily dominated by the relatively tolerant crustaceans *Crangonyx* sp. and *Lirceus* sp., and a modified HBI score of 6.2 is indicative of a community highly tolerant to organic enrichment pollution. The temperature stress score was lower than the 18.2°C threshold for the second time since sampling was initiated in 2007, but the stressor models exclude both *Crangonyx* and *Lirceus*. As these two taxa were so numerically dominant in the sample, the temperature and fine sediment stress results are not considered indicative of actual present conditions as they relate to community tolerance/sensitivity to these two stressors at this site.

In addition to the sampling in the new M-CA-10A reach, a stand-alone macroinvertebrate sample was collected another 250 meters downstream in the reach currently undergoing restoration. Owing to the extent of channel disturbance that was occurring during sample collection, this sample was depauperate with respect to both numbers of individuals and numbers of taxa. The total density was only 245 individuals/m^2, the lowest density measured in 2017 by a wide margin; and only six taxa were sampled from this site, including immature larvae of the relatively tolerant caddisfly family, Hydropsychidae (the individuals were either *Cheumatopsyche* or *Hydropsyche*, but were too immature to render a confident identification). Continued sampling in this reach following restoration should allow for documentation of biological recovery, but bearing in mind that recovery will likely only improve to conditions measured directly upstream, which are also disturbed.

Site Access. This site is located south of SE Jennifer St around SE 114th Ave. Access is via SE 120th Ave and Capps Road, through an unimproved parcel owned by Clackamas County Development Agency.

Cow Creek: G-CO-20, M-CO-20

Geomorphology. This monitoring reach consists of a low gradient reach of Cow Creek that flows along the margins of the historic Clackamas River floodplain. It is likely that the channel either occupies an historic side channel of the Clackamas River or was ditched along the margin of the valley to accommodate farming. It flows along agricultural fields with banks and streamside vegetation that primarily consists of reed canary grass and blackberry. At the time of the site visit, the small, meandering channel and adjacent narrow floodplain was mostly backwatered by either an agricultural dam that is used to withdraw irrigation water, or a series of beaver dams. Cross sections and a longitudinal profile were not collected at the site because of deep water and unconsolidated sediments that made it impossible to safely cross the channel.

Macroinvertebrates. Cow Creek is a small tributary to the lower Clackamas River. The lower reaches of this creek flow through agricultural lands and are bordered by residential development beyond a steeply-sloped and narrow riparian buffer on the river right bank. The channel in this reach is low gradient (0.5 percent) slightly sinuous, single-threaded, and flows through a narrow floodplain dominated by reed canary grass. Habitat in this reach consisted of habitat classified as pools in 2017, owing primarily to the lack of any discernible flow through the reach. Substrate is exclusively sand and fines overlain by a thick accumulation of fine organic debris throughout.

The monitoring reach in Cow Creek was re-sited upstream by approximately 600 m to its present location in 2011 following access issues to the reach sampled in 2007 and 2009. For trending purposes, the biological conditions results from both reaches are considered together. The 2017 MWCF O/E score from this reach was 0.34, intermediate of the range of scores lower Cow Creek has received from 2007 through 2014. No EPT taxa were sampled from the Cow Creek reach in 2017, relative to two having been sampled in 2014: *Baetis tricaudatus* and *Hydropsyche* sp. As a result of the pond-like condition in the reach during the time of sampling, the 2107 sample was dominated by taxa that typically inhabit wetland or pond habitats, including an abundance of aquatic worms, hemipterans (Corixidae), and midge genera that would normally occur in these habitats (e.g., *Chironomus* sp.). An HBI of 7.2 indicates a community that is highly tolerant to organic enrichment pollution and its attendant problems such as low dissolved oxygen. Improvement of biological conditions in this reach will likely require significant improvements to both hydrologic regime and habitat condition.

Site Access. The survey reach can be accessed off of SE Fish Hatchery Road, a narrow, one lane road off of SE 82nd Drive at the Harmony Road Music Center of Oregon. Follow SE Fish Hatchery Road until it crosses Cow Creek. The survey reach is downstream of the crossing.

Richardson Creek: M-RI-10

Macroinvertebrates. Richardson Creek is a tributary to the Clackamas River. The Richardson Creek reach immediately upstream of Highway 224 has been sampled by WES in every monitoring year since 2002. The reach was selected for inclusion in the monitoring program to represent locally least-disturbed biological stream conditions. While the percent forested area in the drainage basin is not the highest among the CCSD #1 study sites, the Richardson Creek system's relatively less disturbed ecological condition results from the abundance of intact riparian forest occurring throughout most of its middle and lower reaches.

The reach upstream of Highway 224 is a higher-gradient section of stream (2.7 percent) and is dominated by riffle habitat (74.0 percent) interspersed with small pools and glides. Riffle Substrate in this reach is dominated by coarse gravel and cobbles, averaging 8.1 percent embeddedness. A wide riparian buffer zone extends laterally by over 100 m on each bank, offering ample riparian tree cover (>72 percent) and canopy cover (86 percent).

From 2002 through 2017, macroinvertebrate communities in this reach have consistently scored in the slightly disturbed range using the multimetric index, with scores ranging from 30 to 38 (32 in 2017). MWCF O/E disturbance classes have been less consistent, ranging from most to least disturbed, yet the score range has been relatively narrow (0.774 to 0.920). The MWCF O/E was 0.920 in 2017, corresponding at a least disturbed classification. Nineteen EPT taxa were sampled from the reach in 2017, including 7 mayfly taxa, 9 stonefly taxa, and 3 caddisfly taxa. The nine stonefly taxa is the highest richness of this order sampled from any of the CCSD #1 streams, and is noteworthy because the stonefly order is considered the most sensitive among the three EPT orders. Stoneflies are often the first to decrease in richness and abundance in response to disturbance, as evidenced by the generally lower stonefly richness than mayfly or caddisfly richness across the CCSD #1 sites. Furthermore, the stoneflies sampled from this site include four taxa within the family Nemouridae, known as "forest flies", which are shredders, deriving their food from the leaf fall from the heathy riparian zone bordering much of Richardson Creek. The stoneflies also include several predator taxa, also an indication of a balanced and robust benthic community.

Three taxa classified as sensitive to disturbance were also sampled from this reach, including the stoneflies Capniidae (immature), *Despaxia augusta*, and *Zapada frigida*. A modified HBI of 4.9 was notably higher than that received in 2014 (3.9), and appears to result largely in the dominance by the relatively tolerant mayfly *Baetis tricaudatus* and caddisfly *Hydropsyche* sp. in 2017. Since 2002, sediment stressor scores have never exceeded the 19 percent threshold, and temperature stress scores are marginally above and below the temperature stress threshold of 18.4ºC; suggesting that neither temperature nor fine sediment are likely biological stressors in this system at present. Likely, the most significant stressor present in the Richardson Creek system is a partially disrupted hydrology that results in more frequent bedload movement, less complex habitat, and less nutrient retention than would have occurred prior to development of the watershed.

Site Access. This site is accessed via the upstream side of Hwy 224.

Sieben Creek: G-SI-10/M-MS-10

Geomorphology. Sieben Creek flows directly into the Clackamas River and is confined between the Shadowbrook Mobile Home Park and adjacent neighborhood to the east. The survey reach is low-gradient (0.8 percent), straight and incised to bedrock 10 feet below the adjacent terrace containing the mobile home park. A patchy thin alluvial layer is present in some areas consisting primarily of gravel and sand. The creek has a muted pool and riffle sequence with some small pools cut in bedrock. A few depositional features persist within the 216-foot survey reach, allowing bulk sample (no pebble count), despite how incised the reach is. Bank erosion is prevalent in many locations due to the high banks. Between 2011 and 2014, the upper section showed erosion and scouring while the lower section experienced deposition, and in 2017, about one-half foot of erosion had occurred throughout the reach. Within the deep, incised channel there is little to no riparian vegetation. The top of bank areas are directly adjacent to Shadowbrook properties with a small "buffer zone" adjacent to housing along the left bank. Most bank vegetation consists of thick blackberry and mature native and non-native trees. The reach is impaired from the perspective of geomorphic diversity and process, and there is little instream habitat.

Macroinvertebrates. The marginal instream habitat continues to consist of a relatively even distribution of riffles, shallow glides, and small pools. Riffle habitat was dominated by gravel and cobble substrates averaging 16.9 percent embeddedness. Much of the reach outside the riffle areas that were sampled is eroded to bedrock/hardpan, as a result of the high degree of hydromodification occurring here. Owing to the highly disturbed setting within which this reach occurs, the riparian-zone vegetation was dominated by the invasive Himalayan blackberry, which grows very thick directly to the stream's surface through much of the reach.

Macroinvertebrate communities in this reach have consistently scored between the upper end of the severely disturbed values range and the lower end of the moderately disturbed values range, most recently having received an MM score of 22 in 2017. These results suggest that the reach has maintained a consistently stressed macroinvertebrate community condition since monitoring was initiated in 2002. As in 2014, 5 EPT taxa were again sampled from this reach in 2017. Two caddisfly taxa, *Lepidostoma* sp. and *Dicosmoecus* sp., each of which are less tolerant to disturbance, were samples from the reach. Their presence suggests an upstream source of more sensitive taxa, which are likely displaced into this reach from upstream, but which never establish owing to the disruptive effects of storm flows and simplified habitat through this highly confined reach. The reach was dominated by rapidly colonizing blackflies (*Simulium* sp.), suggesting the potential regularity with which this reach undergoes significant scouring flows. Temperature stress results values have been lower than the 18.4ºC threshold in four of six years measured and the two exceedances were only marginal, resulting in temperature currently being classified as an unlikely biological stressor in this reach. Conversely, fine sediment stressor scores have straddled the FSS score threshold of 19 percent, including a 2017 FFS score of 24.8, resulting in fine sediment currently being classified as a potential stressor in this reach.

Site Access. This survey reach is accessed along the east end of the Shadowbrook Mobile Home Park behind a utility shed.

3.2 DATA SUMMARY

In Section 3.1, spatial and temporal trends in the data were interpreted for each site for both geomorphic and macroinvertebrate parameters, as appropriate. Geomorphic parameters are dominated by both local and watershed-wide controls and the monitoring has occurred since 2009. Because of the limited data and many controlling variables it is difficult to examine spatial and temporal trends quantitatively using statistical methods. Macroinvertebrates, conversely, are considered as a relatively robust environmental health indicator for streams, and monitoring has been occurring since 2002. Therefore the macroinvertebrate data sets provide more opportunity to assess longer-term changes and trends in biological conditions. In this section the geomorphic data from 2017 are summarized briefly, followed by a more extensive statistical analysis of the macroinvertebrate data.

Both the geomorphic and macroinvertebrate data are affected by episodic flood events, so the recent flood history is summarized for context. Annual peak flow data was compiled from the USGS National Water Information System (NWIS) for four locations on Rock Creek (2 sites), Kellogg Creek, and Mt. Scott Creek (Figure 3). These sites do not have recording flow gages, but the NWIS site reports annual peak flows for some water years at these locations, presumably the result of post-high-flow field surveys and flow-area estimations of peak flows.

The Rock Creek at Sunnyside Road site (14210830) is coincident with geomorphic and macroinvertebrate monitoring reach G-RC-30/M-RC-30. The flows at that site correlate with those at both the Mt. Scott Creek (14211350) (close to site G-MS-10/M-MS-10) and at Rock Creek near

Carver (close to site G-RC-10/M-RC-10)[3]. Although no data are reported for the 2017, regionally, large floods were also recorded in the WY 2017. For that reason, it may be expected that the 2017 geomorphic and macroinvertebrate surveys represent conditions following flood events in which the bed material was recently mobilized.

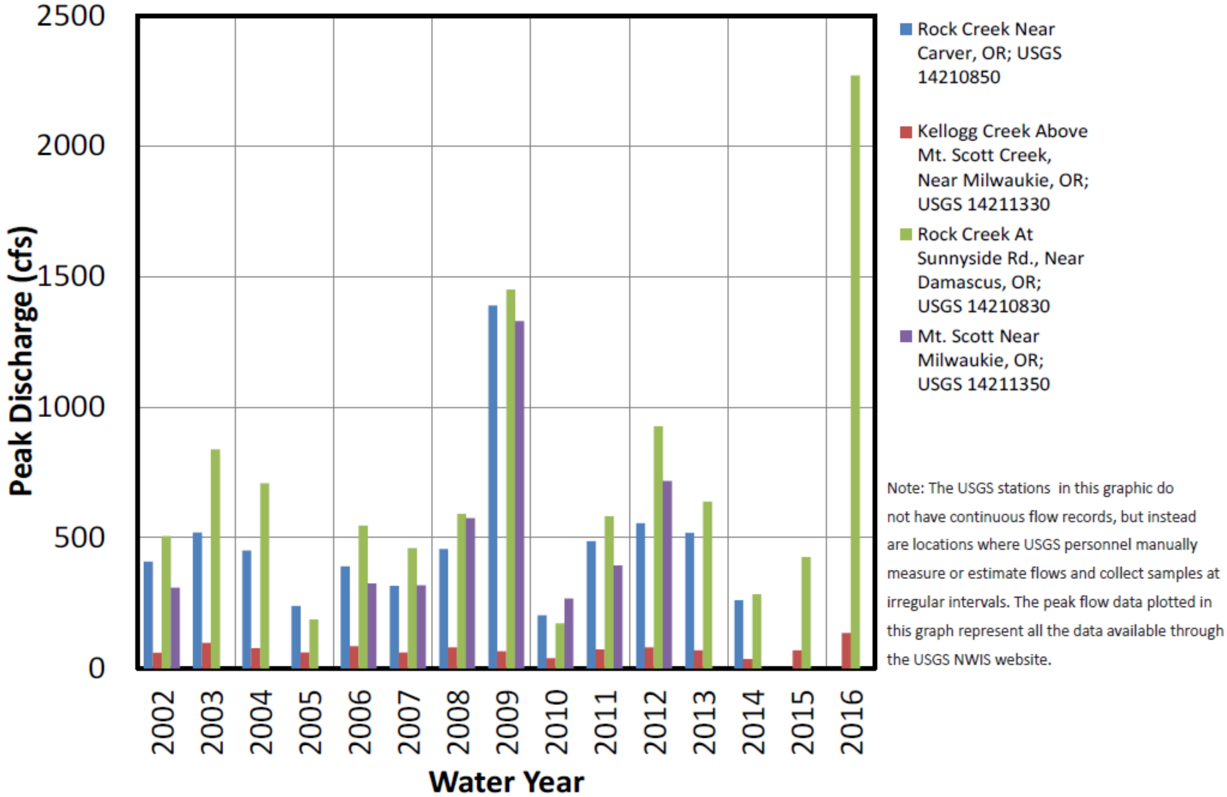


Figure 3. *Annual peak flow data for CCSD #1*

Geomorphic Monitoring Data Summary

Table 6 lists the types of geomorphic information collected at each of the 19 CCSD #1 geomorphic monitoring sites in 2017. Key geomorphic data from all the site surveys are summarized in Tables 7 and 8, and some of the key geomorphic data for the CCSD #1 region are summarized graphically in Figure 4.

The variability in geomorphology among the sites reflects a wide array of factors, both natural and human-caused. Some of the geomorphic parameters may represent larger watershed-scale, cumulative effects, whereas others are reflecting localized conditions. Distinguishing watershed impacts from local-scale influences on channel geomorphology is a complex project that is beyond the scope of this monitoring report. WES recently developed a Stream Health Index (Waterways, 2018) in which a "geomorphic health index" is proposed for streams in the region. The index

[3] The watershed draining to the site at Kellogg Creek above Mt. Scott Creek (14211330) (close to G-KL-20/M-KL-20) is small and contains mostly low elevation area, and this explains the apparent lack of responsiveness of this site to significant rainstorms.

combines information on pools, banks, bed material, cross section shape, and longer-term trends to attempt to synthesize this type of data and used the WES geomorphic monitoring data through 2014. Measurements for eight of the CCSD #1 sites are included in that analysis (Waterways, 2018).

As explained above, there are too many controlling variables and not enough data to permit a thorough statistical analysis of the geomorphic data. Nevertheless, some of the data are plotted in Figure 5, attempting to discern any dominant trends.

Figure 5A plots the percent sand, silt, and clay size sediment (collectively referred here as fines) in the gravel bed as the dependent variable against four potential explanatory variables. A high percent fines is generally considered to be a negative trait, as fines infiltration in gravel is a detriment to salmon spawning. Middle Kellogg Creek contains an unusually high proportion of fines (48 percent) compared with the rest of those in the Clackamas River basin (CCSD #1), mostly due to the distinct geology (mostly sedimentary deposits) and topography (generally flat) of the drainage basin of Kellogg Creek upstream of Mt. Scott Creek. [This is also the reason why the peak streamflows in this reach do not generally respond much to large storms (Figure 3)]. In this data set, the width-to-depth ratio is the most powerful explanatory variable for fines infiltration in the bed (R^2=0.44), perhaps reflecting that narrow, deep channels supply more fines through bank erosion. The percent fines also correlates with the average pool depth in the reach (R2=0.40); the reason for this is not clear, but it implies that deeper pools may have more fines in their tails. The percent fines also show a correlation to the percent of the bankline that is eroding (R^2=0.40), which may provide a ready source of fine sediment that could accumulate in the pool tail out locations. Finally, the percent fines show a weak negative correlation (R^2=0.12) with the channel gradient, reflecting a higher ability of steeper reaches to transport fines. The correlation between gradient and percent fines is less strong than we expected.

Figure 5B examines correlations between the amount of bank erosion and several geomorphic variables. The amount of bank erosion correlates weakly with the bankfull depth (R^2=0.20), as might be expected, because higher banks are more likely to be unstable. Bank erosion does not strongly correlate with the channel gradient, pool depth, W/D ratio, or any of the other measured geomorphic parameters. Instead, based on our observations, the amount of bank erosion in these streams is mostly determined by the intactness of the riparian buffer immediately along the bankline, or to the presence of riprap, the which stabilize streambanks in the CCSD #1 area.

Table 6. Geomorphic data collected in 2017 for long-term monitoring- Clackamas County Service District (CCSD #1), Oregon.

Site ID	Longitudinal Profile	Cross Sections	Bank Erosion	Pool Depths	Bulk Sample[2]	Pebble Count[3]
Kellogg Creek Subbasin						
G-KL-10	X	X	X	X	X	
G-KL-20[1]	X	X	X		X	
G-KL-30	X	X	X	X		
Mt. Scott Creek Subbasin						
G-MS-10[1]	X	X	X	X	X	
G-MS-40	X	X	X	X		X
G-MS-70	X	X	X	X	X	X
G-MS-80	X	X	X	X		X
G-MS-90	X	X				
G-MS-100	X	X		X		
G-MS-110	X	X		X		
Phillips Creek Subbasin						
G-PH-10	X	X		X	X	
Rock Creek Subbasin						
G-RC-10	X	X	X	X	X	X
G-RC-20	Site Discontinued in 2017					
G-RC-30	X	X		X		
G-RC-40	Site Access Not Allowed in 2017					
G-RC-50	X	X		X	X	
G-RC-60	X	X	X	X		
Carli Creek Subbasin						
G-CA-10[1]	X	X	X	X	X	
Cow Creek Subbasin						
G-CO-20[1]						
Tributaries to the Clackamas River						
G-SI-10	X	X	X	X	X	

Notes:

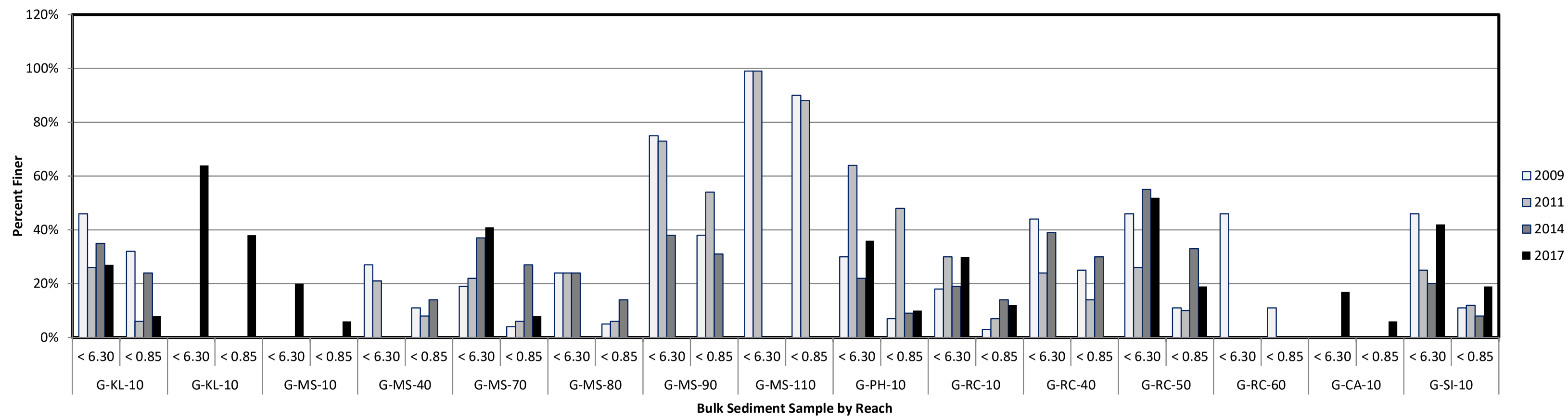
1. Site added for 2017; Cow Creek was not surveyed because site conditions did not allow for safe wading in the creek bed.
2. Bulk samples were not collected at sites that lacked significant alluvial material or were dominated by bedrock.
3. Pebble counts were only taken at sites where exposed depositional features were present.

Table 7. Channel parameters calculated for each study reach in 2017 - Clackamas County Service District #1 (CCSD #1), Oregon.

Site ID	Channel Slope (percent)	Bankfull Width (ft.)	Bankfull Depth (ft.)	Bankfull W/D Ratio	Avg. Max Pool Depth (ft.)	Avg. Max Res. Pool Depth (ft.)
Kellogg Creek Subbasin						
G-KL-10	0.6	41.8	3.1	13.6	1.9	1.2
G-KL-20	0.2	13.5	2.3	5.9	N/A	N/A
G-KL-30	0.4	13.5	2.3	6.0	2.0	0.3
Mt. Scott Creek Subbasin						
G-MS-10	0.6	37.7	2.5	15.3	3.3	2.8
G-MS-40	0.5	27.0	4.1	6.8	1.9	1.4
G-MS-70	0.6	27.5	2.6	11.5	1.7	1.2
G-MS-80	2.5	19.4	2.0	14.9	1.6	1.2
G-MS-90	6.1	8.6	1.7	5.2	N/A	N/A
G-MS-100	1.5	17.8	1.7	10.4	1.2	0.9
G-MS-110	1.5	9.5	1.7	5.4	1.1	0.8
Phillips Creek Subbasin						
G-PH-10	1.6	29.0	4.1	7.6	N/A	N/A
Rock Creek Subbasin						
G-RC-10	1.6	44.3	5.3	8.4	2.0	1.6
G-RC-30	1.4	32.5	3.5	9.6	1.5	1.1
G-RC-40						
G-RC-50	1.4	29.3	2.9	10.1	2.4	0.8
G-RC-60	0.4	29.3	4.5	6.5	2.2	1.7
Carli Creek Subbasin						
G-CA-10	1.8	30.1	3.3	9.6	2.0	1.4
Cow Creek Subbasin						
G-CO-20						
Tributaries to the Clackamas River						
G-SI-10	0.8	21.3	9.4	2.3	1.5	1.1

Table 8. Bed substrate and bank conditions in 2017 for each study reach - Clackamas County Service District #1 (CCSD #1), Oregon.

Site Code	percent Left Bank Erosion	percent Right Bank Erosion	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	percent Bulk Sample < 2.36mm	percent Bulk Sample < 0.063mm
Kellogg Creek Subbasin							
G-KL-10	0.9	3.8	-	-	-	15	1
G-KL-20	28.5	0	-	-	-	48	3
G-KL-30	0	0	-	-	-	-	-
Mt. Scott Creek Subbasin							
G-MS-10	0.3	7.3	-	-	-	12	1
G-MS-40	3.3	0	15	32	47	-	-
G-MS-70	3.4	0	26	56	82	28	2
G-MS-80	0	6.2	19	45	112	-	-
G-MS-90	N/A	N/A	-	-	-	-	-
G-MS-100	0	0	-	-	-	-	-
G-MS-110	0	0	-	-	-	-	-
Phillips Creek Subbasin							
G-PH-10	N/A	N/A	-	-	-	24	4
Rock Creek Subbasin							
G-RC-10	0	0	20	49	78	25	4
G-RC-30	0	0	-	-	-	-	-
G-RC-40							
G-RC-50	0	0	-	-	-	36	6
G-RC-60	0	0	-	-	-	-	-
Carli Creek Subbasin							
G-CA-10	0	0	-	-	-	11	2
Cow Creek Subbasin							
G-CO-20			-	-	-	-	-
Tributaries to the Clackamas River							
G-SI-10	0	28.0				35	3



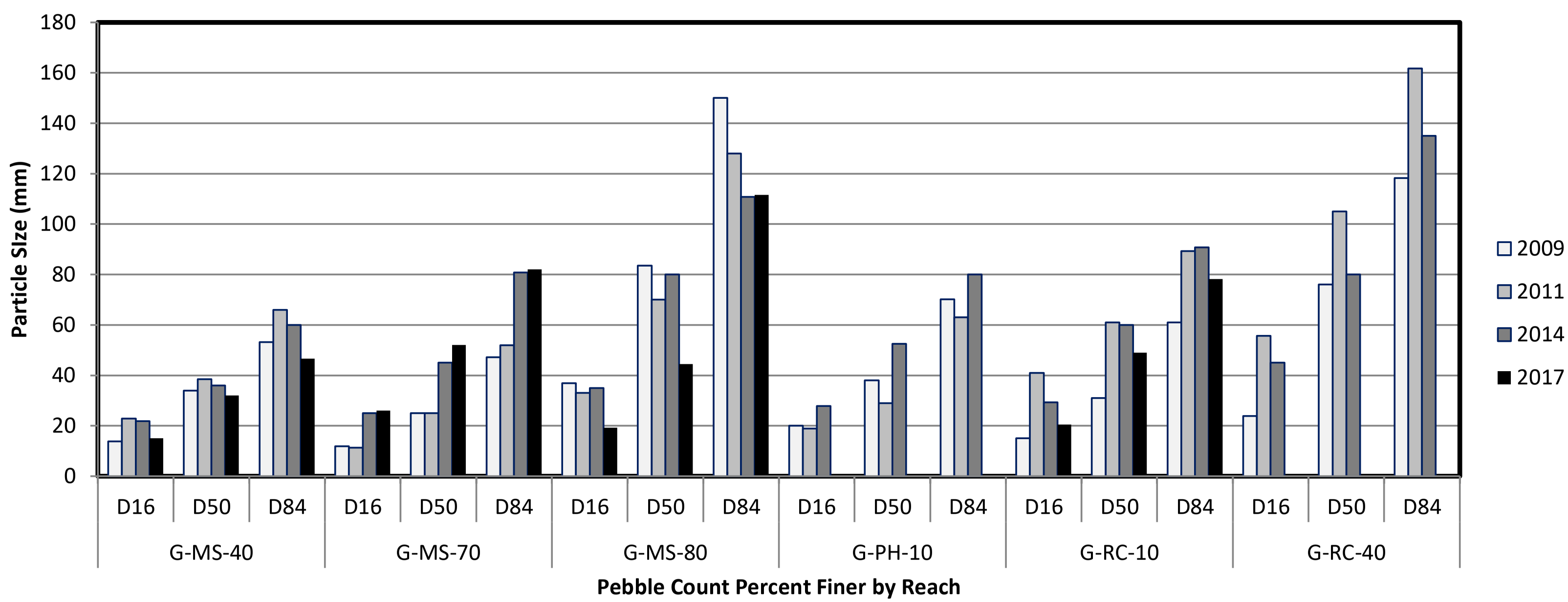


FIGURE 4

Bulk sample results (top graph) and pebble count results (bottom graph) sampled from reaches in Clackamas County (CCSD#1), Oregon in the fall of 2009, 2011, 2014, and 2017

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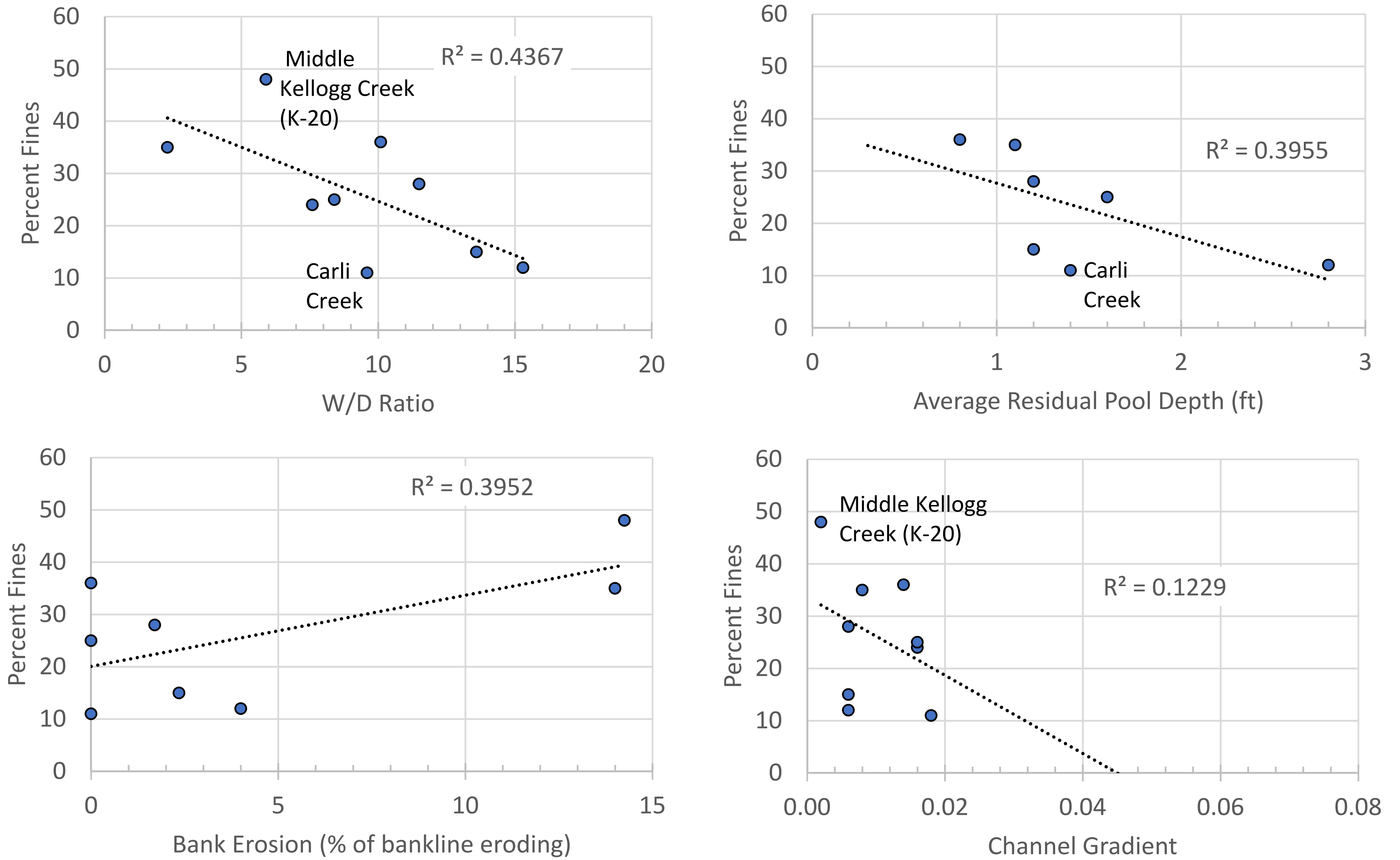

FIGURE **5A**

Correlation between geomorphic parameters and percent fines sampled from reaches in Clackamas County (CCSD#1), Oregon in the fall of 2017

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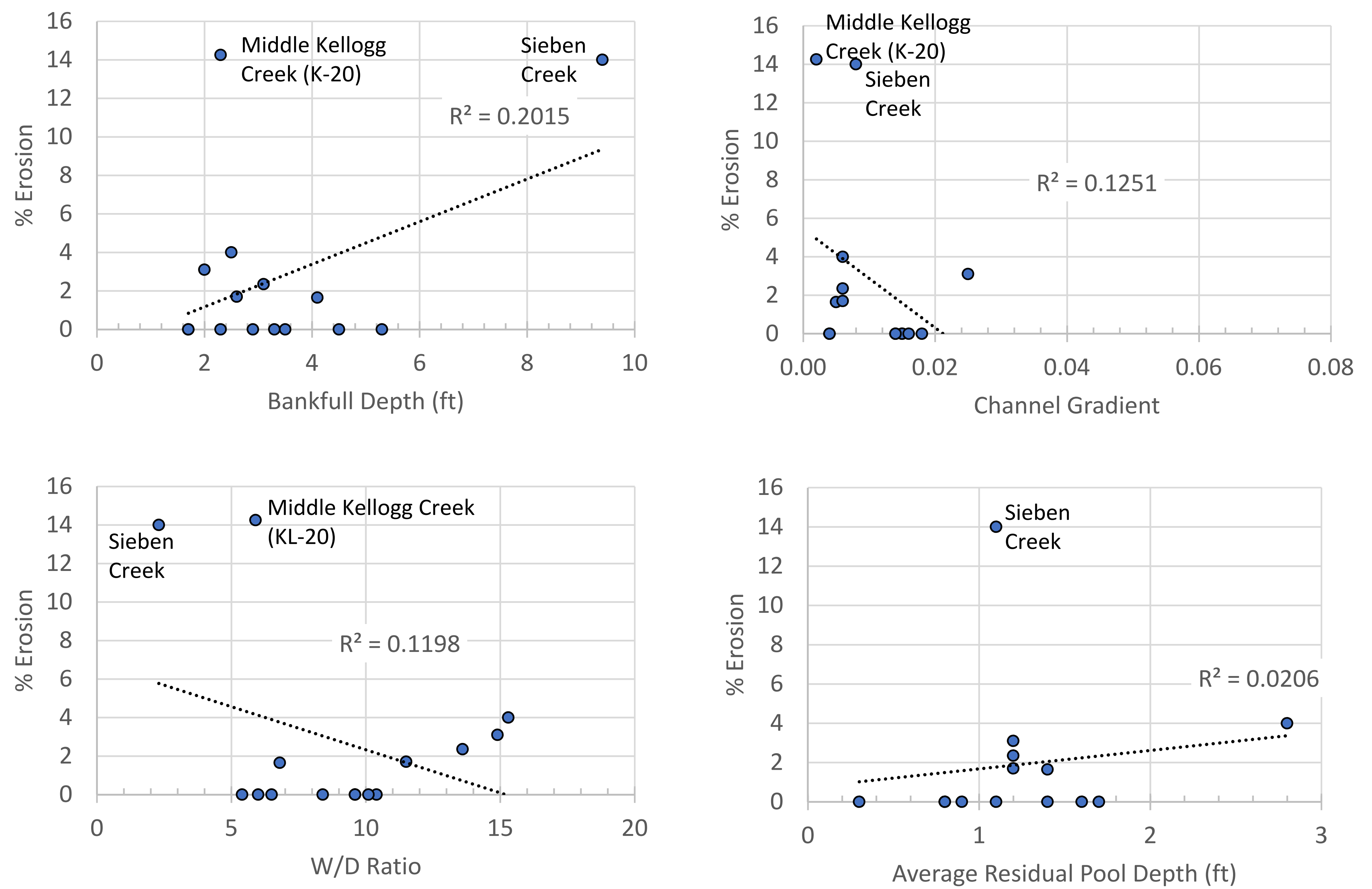

FIGURE **5B**

Correlation between geomorphic parameters and percent of eroding bank sampled from reaches in Clackamas County (CCSD#1), Oregon in the fall of 2017

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Macroinvertebrate Monitoring Data Summary

Instream Physical Habitat and Associated Environmental Conditions

In 2014, all 13 reaches in which macroinvertebrates were sampled from riffles were analyzed together as "higher-gradient reaches" to produce summary statistics of the range of instream and riparian conditions across the CCSD #1 reaches. The one reach in Cow Creek (M-CO-20) from which only a glide sample was collected was considered separately. The 13 reaches from which riffles were sampled had channel slopes ranging from 0.5 to 3.4 percent (mean: 1.4 percent) with riffles comprising 12.5 to 74.0 percent (mean: 44.2 percent) of the instream habitat (Table 11). The Cow Creek reach (M-CO-10) was classified as a lower-gradient reach with a slope of 0.5 percent and occupied exclusively pool habitat. The Mt. Scott Creek reach at N Clackamas Park (M-MS-10) and the Kellogg Creek reach upstream of Rusk Road (M-KL-20) exhibited channel characteristic that are intermediate of higher- and lower-gradient reaches with an average channel slope of 0.5 percent and 0.6 percent and riffle habitat, respectively, but were included with the higher-gradient reaches for analysis owing to the prevalence of riffle habitat and coarse substrates in both reaches.

Higher-gradient reaches had a high proportion of coarse substrates within riffles (mean: 96.3 percent; range: 85.2 to 100.0 percent) and a low proportion of fine substrates (mean: 2.5 percent; range: 0.0 to 10.5 percent) when compared to the substrate within lower-gradient Cow Creek reach habitats (M-CO-10; coarse substrate: 0.0 percent; fine substrate: 85.6 percent). Glide Substrate embeddedness in this reach was high (91.8 percent) while riffle substrate embeddedness in the higher-gradient reaches was relatively low (mean: 15.2 percent; range: 7.6 to 23.0 percent; Table 11).

The lower-gradient Cow Creek reach (M-CO-10) had a narrower riparian buffer (18 m) and lower overhead canopy cover (54 percent) as compared to most of the higher-gradient reaches. Among the higher-gradient reaches, average left/right riparian buffer widths ranged from 4 to 100+ m (mean: 44 m), while overhead cover ranged from 74 to 98 percent (mean: 87 percent; Table 11).

A number of water chemistry parameters were measured during macroinvertebrate sample collection within each reach. . While water temperatures were consistently lower than 18ºC across all sites, and dissolved oxygen concentrations ranged from 8.59 mg/L to 10.74 mg/L (Table 11). Based on calculations made in 2011, urban land use is lowest in the drainage basin upstream of the Richardson Creek reach (M-RI-10) and highest in the drainage basin upstream of the lower Carli Creek reach (M-CA-10; Table 10). At the subbasin level, urban land use was highest in the Kellogg Creek subbasin (91.7 percent), followed closely by the tributaries to the Clackamas River (89.6 percent) and the Mt. Scott Creek subbasin (88.3 percent). Urban land use in the Rock Creek subbasin was 36.3 percent. While the data are limited to the drainage basins upstream of the survey reaches within each subbasin, they are representative of the overall land use within each subbasin.

As in all previous sampling years, the highest-quality habitat occurred in the Richardson Creek reach (M-RI-10), considered a reference reach. This reach is dominated by fast-water habitat (74.0 percent), a high percentage of coarse substrate (99.0 percent), and intact riparian buffers with high percentages of tree cover (72.5 percent) and overhead canopy cover (86 percent).

Table 9. Environmental conditions of a lower reach (Cow Creek; M-CO-10), from which glides were sampled and 13 higher-gradient stream reaches in which riffles were sampled for macroinvertebrates in Clackamas County (CCSD #1), Oregon in the fall of 2017.

	Lower-gradient	Higher-Gradient (n= 13)			
Environmental parameter	**M-CO-20**	**Mean**	**SD**	**Min**	**Max**
Channel slope (percent)	0.5	1.4	0.8	0.5	3.5
Wetted width (m)	2.1	3.4	2.4	1.2	7.8
Bankfull width (m)	2.9	6.7	2.4	3.7	11.1
Percent pools	100.0	36.8	18.0	0.0	60.0
Percent glides/runs	0.0	18.9	11.0	7.0	46.8
Percent riffles	0.0	44.2	17.0	12.5	74.0
Percent rapid	0.0	0.1	0.4	0.0	1.3
Percent coarse substrate in glides	0.0				
Percent fine substrate in glides	85.6				
Substrate embeddedness in glides	91.8				
Percent coarse substrate in riffles		96.3	4.5	85.2	100.0
Percent fine substrate in riffles		2.5	2.8	0.0	10.5
Substrate embeddedness in riffles		15.2	4.9	7.6	23.0
Eroding banks	0	45	32	8	95
Undercut banks	0	6	7	0	24
Large wood tally (#/100m)	13.00	10.47	7.82	0.96	28.00
Overhead cover (percent)	54	87	7	74	98
Mean riparian width (m)	18	44	30	4	100
Riparian zone tree cover (percent)	0	62	17	28	90
Riparian zone non-native Veg. Cover (	100	23	14	10	60
Water temperature (°C)	15.6	14.3	1.5	12.1	17.5
Dissolved oxygen (percent)	85.8	92.7	4.6	83.6	100.9
Dissolved oxygen (mg/L)	8.56	9.50	0.56	8.59	10.74

Table 10. Land uses in the drainage basin upstream of monitoring reaches sampled in Clackamas County (CCSD #1), Oregon in the fall of 2017. Land use data derived from the 2006 National Land Cover Dataset.

			Land Use (Percent)				
Reach ID	**Previous Site Code**	**Stream**	**Urban**	**Forest**	**Agriculture**	**Water**	**Total**
Kellogg Creek Subbasin							
M-KL-10	SD1-M18	Kellogg Creek	88.9	9.1	1.8	0.3	100.0
M-KL-20	SD1-M13a	Kellogg Creek	94.6	5.4	0.0	0.0	100.0
Mt. Scott Creek Subbasin							
M-MS-10	SD1-M4a	Mt. Scott Creek	88.7	8.7	2.3	0.4	100.0
M-MS-40	SD1-M3	Mt. Scott Creek	85.0	12.1	2.6	0.4	100.0
M-MS-80	SD1-M2	Mt. Scott Creek	84.2	11.4	4.3	0.1	100.0
M-PH-10	SD1-M5a	Phillips Creek	93.5	6.1	0.0	0.4	100.0
M-CE-10	SD1-M15	Cedar Creek	89.9	9.9	0.1	0.0	100.0
Rock Creek Subbasin							
M-RC-10	SD1-M10a	Rock Creek	40.2	27.1	32.7	0.1	100.0
M-RC-30	SD1-M11a	Rock Creek	35.5	31.0	33.4	0.1	100.0
M-RC-50	SD1-M17	Rock Creek	29.3	35.8	34.9	0.0	100.0
M-TR-10	SD1-M7a	Trillium Creek	40.3	27.0	32.6	0.1	100.0
Tributaries to the Clackamas River							
M-SI-10	SD1-M8	Sieben Creek	81.0	13.9	5.1	0.0	100.0
M-CA-10	SD1-M16	Carli Creek	98.9	1.1	0.0	0.0	100.0
M-CO-20	SD1-M14a	Cow Creek	89.0	8.5	2.3	0.2	100.0
M-RI-10	SD1-M12	Richardson Creek	42.0	22.0	35.9	0.1	100.0

Macroinvertebrate Community Conditions – Riffle Samples

Riffle samples were collected from 11 higher-gradient stream reaches and two reaches that exhibited intermediate characteristics of both lower- and higher-gradient stream reaches (M-KL-20 and M-MS-10; Table 11). Stream flow conditions were generally at their seasonal averages for the weeks prior to and during most of the macroinvertebrate sampling in 2017. A rain event occurred on September 20th which resulted in significant increases in stream discharge across the region, and precluded sampling in the one remaining larger sample reach (M-RI-30) until September 25th, when flows had returned to seasonal norms in larger streams. Most reaches were sampled prior to the storm, but Carli Creek was sampled on the day following the overnight event because flows in Carli were almost unaffected. Sieben Creek was sampled on September 22nd, after its flows had returned to seasonal norms. The biological communities at each of these three reaches sampled following the rain event supported communities that were very similar to those sampled in past years; therefore, the data are considered representative of the seasonal norm for 2017 and are suitable for comparison with those data from previous years. The benthic community in the Sieben Creek reach is likely chronically affected by the rapid increases and decreases ("flashiness") of flows observed in this reach (Gail Shaloum, WES, personal communication).

DEQ multimetric scores from riffle macroinvertebrate samples ranged from 14 to 34 in 2017, compared to 18 to 38 in 2014. The range of 2017 MM scores indicates that macroinvertebrate community conditions range from severely to slightly disturbed among the survey reaches (Table 12), and most reaches (8 of 13) are currently classified as moderately disturbed. In 2017, the Carli Creek reach (M-CA-10) received the lowest multimetric score of 14 and a corresponding condition class of severely disturbed (Table 12). Across all higher-gradient CCSD #1 reaches, multimetric scores remained the same in 4 reaches, increased in 6, and decreased in 3 (Table 13). Most reaches (10 of 13) exhibited a change of 6 or fewer MM score points, while 2 Rock Creek reaches (M-RC-30 and M-RC-50) and Trillium Creek (M-TR-10), exhibited changes of 8 or more MM score points, indicating the potential for real change to have occurred since the last sampling round in 2014. Conditions of macroinvertebrate communities in both the upper Rock Creek reach (M-RC-50) and the Trillium Creek reach (M-TR-10) appear to have improved in 2017. The apparent decline in condition at middle Rock Creek (M-RC-30) may have resulted from sampling not long after the September 20th storm event, but as 2017 scores from M-RC-30 are on par with historic norms, that scenario seems unlikely.

Table 11. Habitats from which macroinvertebrate samples were collected in monitoring reaches sampled in Clackamas County (CCSD #1), Oregon in the fall of 2002, 2007, 2009, 2011, 2014, and 2017.

	Year Sampled					
Reach Code	**2002**	**2007**	**2009**	**2011**	**2014**	**2017**
Kellogg Creek Subbasin						
M-KL-10			Riffle	Riffle	Riffle	Riffle
M-KL-20				Riffle/Glide	Riffle	Riffle
Mt. Scott Creek Subbasin						
M-MS-10	Riffle/Glide	Riffle/Glide	Riffle/Glide	Riffle/Glide	Riffle	Riffle
M-MS-40	Riffle/Glide	Riffle/Glide	Riffle/Glide	Riffle	Riffle	Riffle
M-MS-80	Riffle	Riffle	Riffle	Riffle	Riffle	Riffle
M-PH-10				Riffle	Riffle	Riffle
M-CE-10	Riffle/Glide	Riffle/Glide	Riffle	Riffle		
M-CE-10A						Riffle
Rock Creek Subbasin						
M-RC-10	Riffle	Riffle	Riffle	Riffle	Riffle	Riffle
M-RC-30	Riffle	Riffle	Riffle	Riffle	Riffle	Riffle
M-RC-50			Riffle	Riffle	Riffle	Riffle
M-TR-10			Riffle	Riffle	Riffle	Riffle
Tributaries to the Clackamas River						
M-SI-10	Riffle	Riffle	Riffle	Riffle	Riffle	Riffle
M-CA-10		Riffle	Riffle	Riffle	Riffle	
M-CA-10A						Riffle
M-CA-10B						Riffle
M-CO-20				Glide	Glide	Pool
M-RI-10	Riffle	Riffle	Riffle	Riffle	Riffle	Riffle

The Richardson Creek reach (M-RI-10), used as a local reference reach to represent best attainable local biological conditions, received the highest multimetric scores in 2002 (30 points), 2007 (34 points), 2009 (38 points), 2011 (32 points), and 2014 (38 points; Table 12), and the second highest score in 2017 (32 points versus 34 points from lower Rock Creek). The reach has been classified as slightly disturbed in each assessment year. Using the PREDATOR MWCF model, the Richardson Creek reach was classified as "most disturbed" in 2002 and 2007, moderately disturbed in 2009 and 2014, and as least disturbed in 2011 and 2017. The upper Rock Creek reach received the highest MWCF O/E score on 1.064 in 2017, resulting in only the second "least disturbed" classification of a CCSD #1 reach outside of Richardson Creek by the MWCF model. The remaining 12 reaches uniformly received "most disturbed" classification by the MWCF model (Table 12).

Using both 2011 through 2017 data, MWCF O/E scores most often resulted in a more severe biological condition classification than did MM scores (Figure 6). Among 32 riffle samples collected from 2011 through 2017 and classified by the MWCF model as "most disturbed", only 10 of these received a corresponding "severely disturbed" MM score, 18 received a "moderately disturbed" MM score, and 4 received a "slightly disturbed" MM score (Figure 6). These results highlight the need to carefully examine the combined results of both assessment tools to ascertain biological conditions, potential causation of observed conditions, and spatial and temporal patterns in those conditions.

Table 12. Western Oregon multimetric scores and PREDATOR MWCF O/E scores calculated from macroinvertebrate samples collected from riffles in 13 stream reaches in Clackamas County (CCSD #1), Oregon, in the fall of 2017.

Reach Code	MM Score	MM Disturbance Class	O/E Score	O/E Disturbance Class
Kellogg Creek Subbasin				
M-KL-10	22	Mod	0.388	Most
M-KL-20	22	Mod	0.582	Most
Mt. Scott Creek Subbasin				
M-MS-10	22	Mod	0.388	Most
M-MS-40	20	Mod/Severe	0.440	Most
M-MS-80	28	Mod	0.586	Most
M-PH-10	20	Mod/Severe	0.388	Most
M-CE-10A	18	Severe		
Rock Creek Subbasin				
M-RC-10	32	Slight	0.678	Most
M-RC-30	24	Mod	0.677	Most
M-RC-50	34	Slight	1.064	Least
M-TR-10	30	Slight/Mod	0.581	Most
Clackamas River Tributaries				
M-SI-10	22	Mod/Severe	0.484	Most
M-CA-10A	14	Severe	0.242	Most
M-CA-10B	14	Severe	0.097	Most
M-RI-10	32	Slight	0.920	Least

Among the 7 reaches sampled in each assessment year since 2002 (M-MS-10, M-MS-40, M-MS-80, M-RC-10, M-RC-30, M-SI-10, and M-RI-10), multimetric scores suggest variable, yet largely unchanged or potentially improving biological conditions (Figure 7). MWCF O/E scores similarly suggest variable but unchanged and perhaps improving conditions for these 7 reaches (Figure 7). Considering all reaches monitored in each year, both MM scores and MWCF O/E scores suggest potentially improved biological conditions in all streams sampled since 2002 (Figure 8). Importantly, neither the MM scores nor MWCF O/E scores indicate downward trending at any of these reaches over the 15-year monitoring period. Considering the mean values of the 7 reaches sampled each assessment year since 2002, the same subtle, yet positive trend of potentially improving biological conditions is evident with the both the MM and O/E scores (Figure 8).

When multimetric scores of riffle-sampled reaches were averaged by subbasin, the Mt. Scott Creek (n = 4) and Kellogg Creek (n = 2) subbasins had the lowest multimetric score of 22 (same as in 2014), while the mean multimetric score for the Rock Creek subbasin was 30.0 (SD: 4.3, n= 4). Tributaries to the Clackamas River, including Sieben and Carli creeks had a mean multimetric score of 16.7 (SD = 4.6, n = 2). For comparison, the Richardson Creek reach (M-RI-10) received a multimetric score of 32 in 2017 (Figure 9).

MWCF O/E scores, when summarized in the same manner, followed a similar pattern (Table 14). The mean O/E score for the Mt. Scott Creek subbasin was 0.46 (SD: 0.08 n= 4), followed by the Kellogg Creek subbasin (mean: 0.49; SD: 0.14, n= 2), and the Rock Creek subbasin (mean: 0.75; SD: 0.21, n= 4; Figure 9). Tributaries to the Clackamas River, including Sieben and Carli creeks had a mean O/E score of 0.27 (SD: 0.20; these summary statistics include the lower Carli Creek project area sample at M-CA-10B). For comparison, the Richardson Creek reach (M-RI-10) received a multimetric score of 0.92 in 2017.

Table 13. Multimetric scores calculated for riffle samples collected from stream reaches in Clackamas County (CCSD #1), Oregon, in the fall of 2002, 2007, 2009, 2011, 2014, and 2017.

	Year Sampled					
Reach Code	**2002**	**2007**	**2009**	**2011**	**2014**	**2017**
Kellogg Creek Subbasin						
M-KL-10	-	-	16	22	22	22
M-KL-20	-	-	-	18	22	22
Mt. Scott Creek Subbasin						
M-MS-10	16	14	16	18	22	22
M-MS-40	16	18	18	14	20	20
M-MS-80	16	16	24	20	24	28
M-PH-10	-	-	-	16	22	20
M-CE-10	16	10	12	16	-	
M-CE-10A						
Rock Creek Subbasin						
M-RC-10	22	32	34	30	32	32
M-RC-30	22	28	26	28	34	24
M-RC-50	-	-	26	20	26	34
M-TR-10	-	-	24	20	18	30
Tributaries to the Clackamas River						
M-SI-10	24	18	20	22	20	22
M-CA-10	-	10	12	12	18	
M-CA-10A						14
M-CA-10B						14
M-RI-10	30	34	38	32	38	32

Condition classes: Severely disturbed: 10-18; Moderately disturbed: 20-28; 30-38: Slightly disturbed; 40-50: No disturbance.

Table 14. MWCF O/E scores calculated for riffle samples collected from stream reaches in Clackamas County (CCSD #1), Oregon, in the fall of 2002, 2007, 2009, 2011, 2014, and 2017.

	Year Sampled					
Reach Code	**2002**	**2007**	**2009**	**2011**	**2014**	**2017**
Kellogg Creek Subbasin						
M-KL-10			0.242	0.630	0.436	0.388
M-KL-20				0.533	0.581	0.582
Mt. Scott Creek Subbasin						
M-MS-10	0.291	0.338	0.388	0.436	0.339	0.388
M-MS-40	0.291	0.483	0.533	0.484	0.581	0.440
M-MS-80	0.387	0.532	0.533	0.580	0.484	0.586
M-PH-10				0.387	0.436	0.388
M-CE-10	0.387	0.483	0.533	0.387		
M-CE-10A						0.484
Rock Creek Subbasin						
M-RC-10	0.532	0.918	0.775	0.774	0.871	0.678
M-RC-30	0.629	0.870	0.678	0.822	0.967	0.677
M-RC-50			0.823	0.822	0.774	1.064
M-TR-10			0.581	0.629	0.581	0.581
Tributaries to the Clackamas River						
M-SI-10	0.194	0.338	0.387	0.436	0.484	0.484
M-CA-10		0.097	0.242	0.290	0.387	
M-CA-10A						0.242
M-CA-10B						0.097
M-RI-10	0.774	0.773	0.823	0.919	0.871	0.920

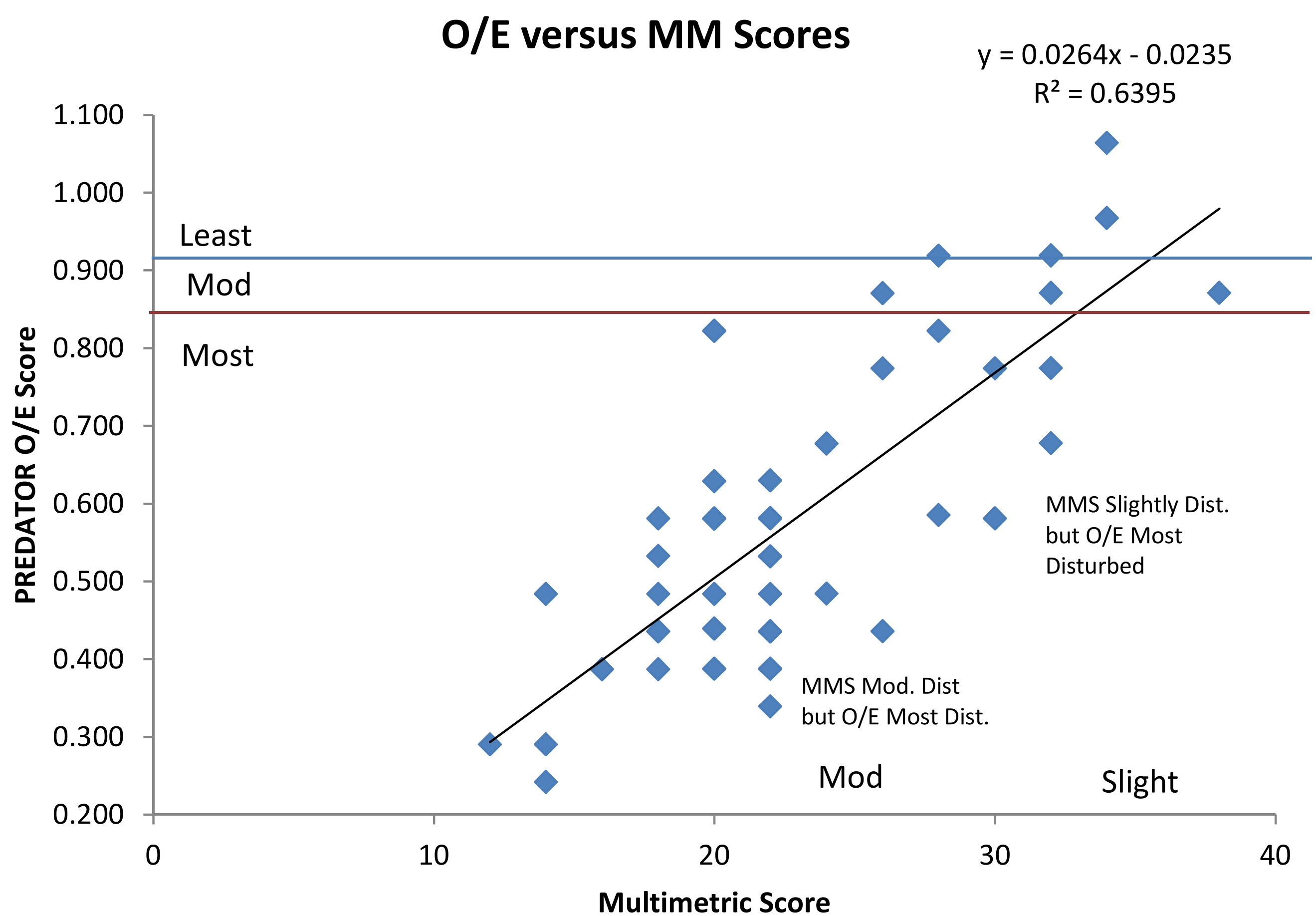

FIGURE 6

Relationships between multimetric scores and PREDATOR O/E model scores of macroinvertebrate communities sampled from riffles in stream reaches in Clackamas County (CCSD#1), Oregon in the fall of 2017.

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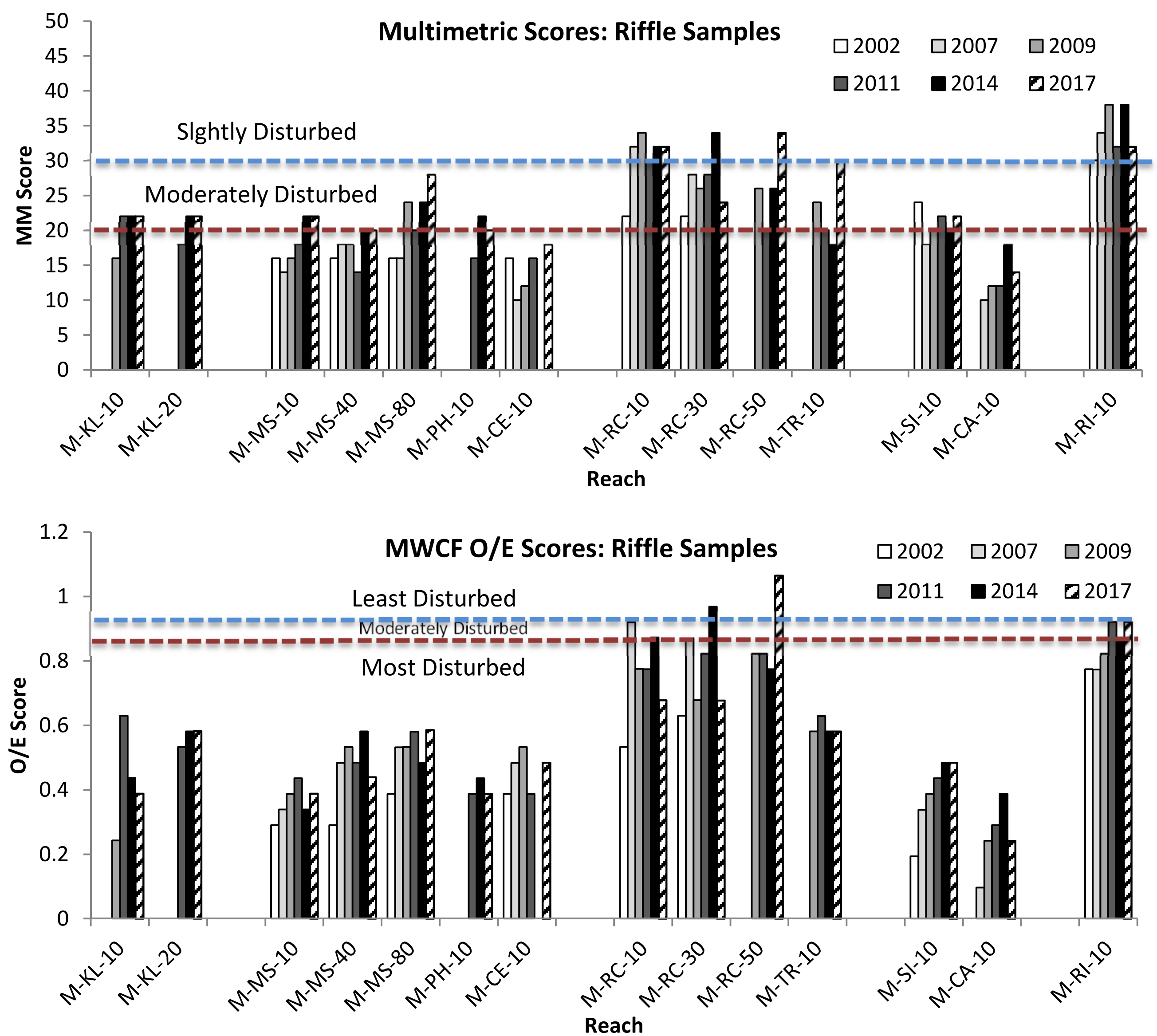

FIGURE 7	Multimetric scores (top panel) and PREDATOR MWCF O/E scores (bottom panel) of macroinvertebrate communities sampled from riffles in Clackamas County (CCSD#1), Oregon in the fall of 2002, 2007, 2009, 2011, 2014, and 2017.	WES MONITORING SD1 FINAL REPORT JUNE 2018	COLE ECOLOGICAL, Inc.

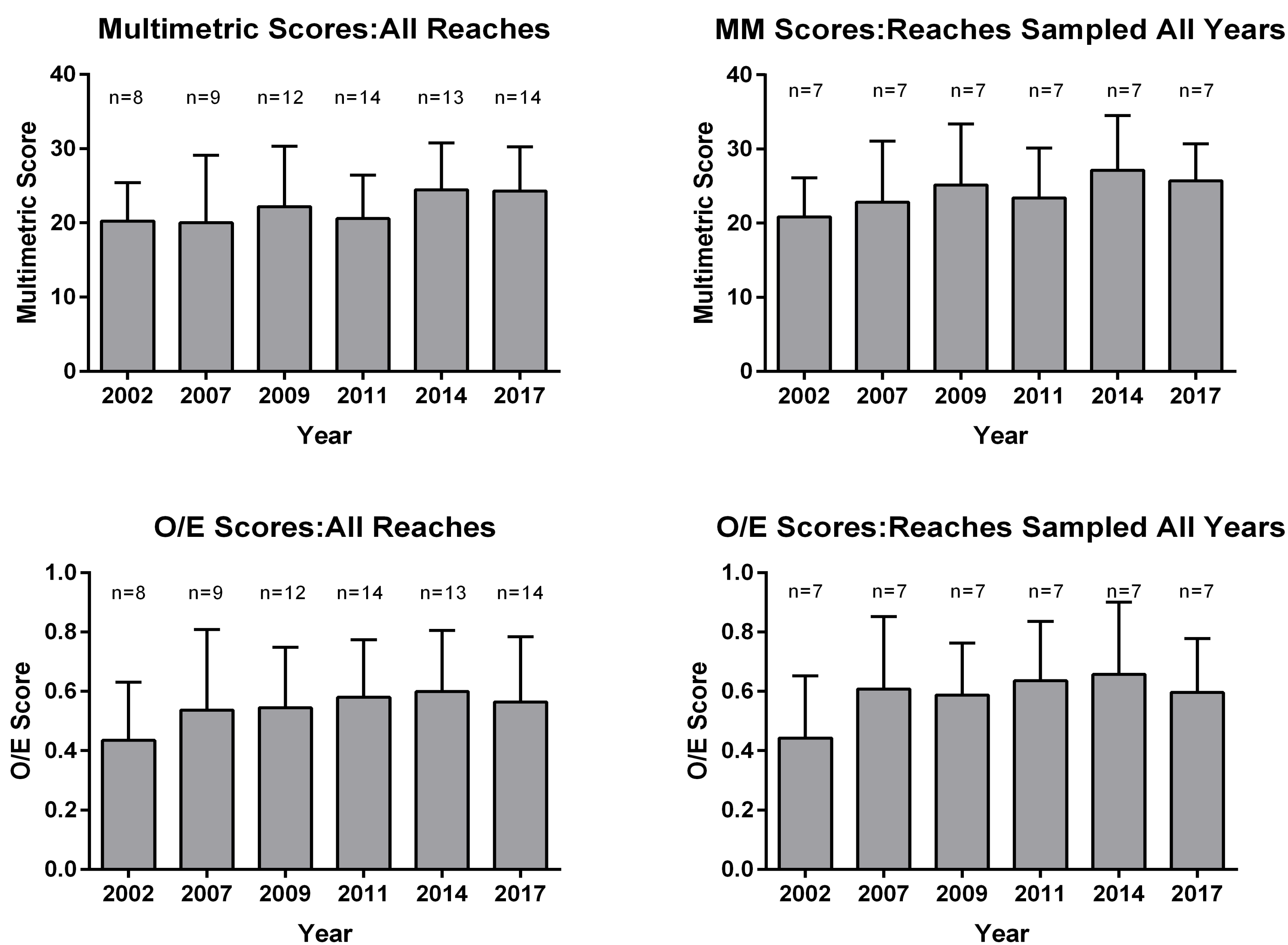

FIGURE 8

Mean multimetric (upper panels) and mean MWCF O/E (bottom panels) scores of macroinvertebrate communities sampled from riffles in Clackamas County (CCSD#1), Oregon in the fall of 2002, 2007, 2009, 2011, 2014, and 2017. Left panels include data from all reaches where riffles were sampled, while the right panels include data from a subset of reaches where riffles were sampled in each of the five survey years (n=7).

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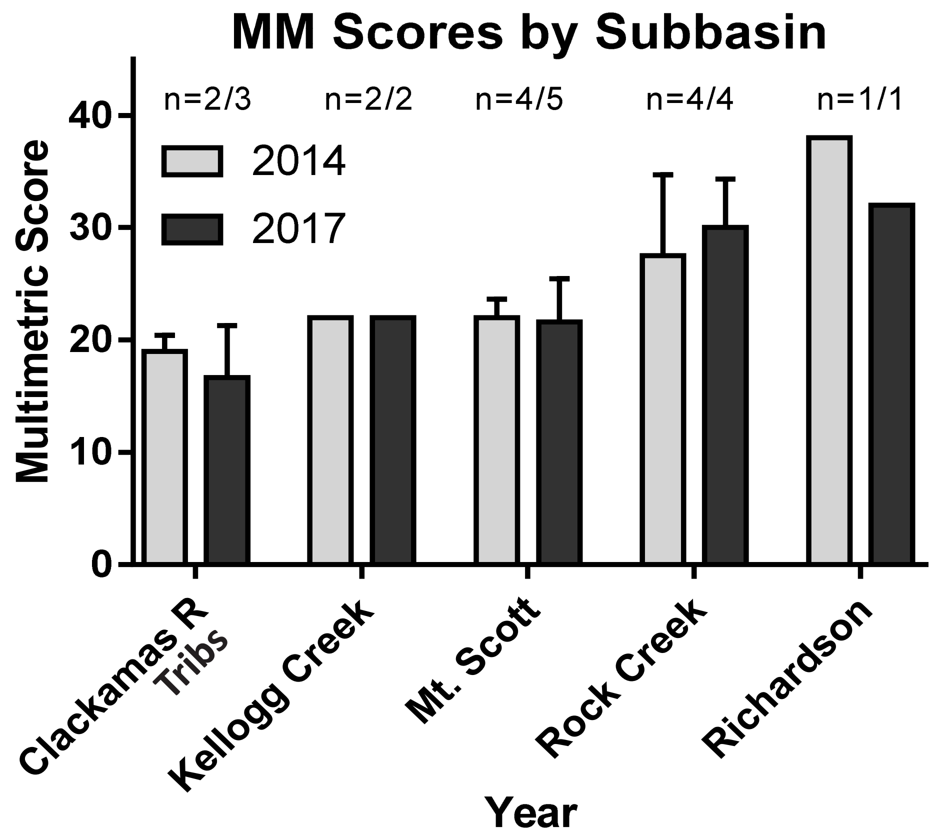
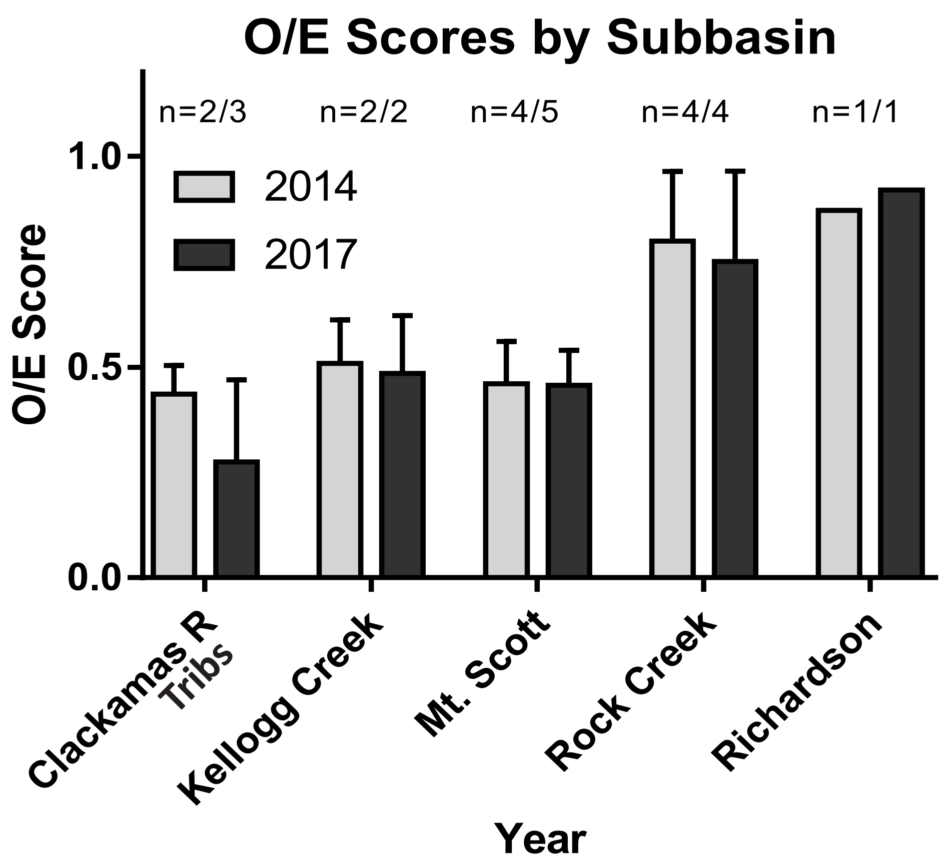




Mean multimetric scores of riffles sampled from reaches within three Clackamas County (CCSD # 1) subbasins (Kellogg Creek, n= 2; Mt. Scott Creek, n= 4; and Rock Creek, n= 4), Clackamas River tributaries (n= 2), and the Richardson Creek reach. Samples were collected in the fall of 2017.	WES MONITORING SD1 FINAL REPORT JUNE 2018	COLE ECOLOGICAL, Inc.	FIGURE 9

Furthermore, future assessments of macroinvertebrate communities should include the use of yet a third assessment tool that is presently in its last stages of development (Jen Stamp, Tetra Tech, personal communication). This new tool, known as the Biological Condition Gradient (BCG), is a scientific framework that can be used by practitioners of water quality monitoring to better interpret biological responses from the cumulative effects of stressors than allowed by present tools. In some respects, the BCG is much like the western Oregon multimetric index used in the present and other studies. However, much larger data sets were used and numerous experts (including Dr. Cole) were convened to inform the development of this tool, which is intended to more precisely define and measure biological condition in Willamette Valley Ecoregion streams. The BCG was first proposed in 2006 as a conceptual framework developed by EPA in partnership with scientists from states, USGS and the academic community; the BCG framework and process have been implemented in a number of states and regions across the country with the oversight of EPA and their consultants. Much like the western Oregon multimetric index, the Willamette Valley/Puget Sound Lowlands BCG utilizes a series of metrics – or community attributes – that are known to be responsive to the degradation of freshwater resources. However, the scoring criteria are developed to align assignment of condition classes by the tool with expert opinion of what constitutes various levels of disturbance by the panel of experts involved in model development. Furthermore, the BCG includes six classes of biological condition,which provdes greater resolution in classification of condition that allowed by the current tools (MMI has 4 classes and the MWCF model has only 3 classes.. While the application of the new regional BCG tool to WES macroinvertebrate communities won't occur until the next round of monitoring, it is sure to provide excellent additional context for assessing biological conditions in Clackamas County streams.

Individual measures of community condition (using individual metrics) varied widely among reaches (Table 15). Total taxa richness ranged from 6 taxa in the Carli Creek (M-CA-10) active restoration reach to 37 taxa in the upper Rock Creek (M-RC-30) and Richardson Creek (M-RI-10) reaches and averaged 26.6 taxa across all reaches from which riffles were sampled. Mayfly (Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) richness again varied among riffle samples. These orders, collectively referred to as "EPT taxa," are generally regarded as sensitive to water pollution and habitat degradation. The upper Rock Creek reach supported the highest number of EPT taxa in 2017 (20), while the Richardson Creek reach (M-RI-10) supported 19 EPT taxa. Richardson Creek had supported the highest number of EPT taxa in 2002 (17 taxa), 2007 (18 taxa), 2009 (19 taxa), 2011 (18 taxa), and 2014 (20 taxa). The number of taxa represented by each of these orders varied widely among study reaches (Table 15); only one EPT taxon was sampled from each Carli Creek reach (M-CA-10A and M-CA-10B), while only 5 EPT taxa were sampled from the Sieben Creek (M-SI-10) and lower Mt. Kellogg Creek (M-KL-10) reaches. The Richardson Creek reach supported the highest number of sensitive taxa, including the stoneflies (Order: Plecoptera) *Despaxia augusta*, *Capniidae*, and *Zapada frigida*. *Zapada frigida* was present only in the Richardson Creek sample (and has been sampled here in past years), while *Despaxia augusta* was also present in the Rock Creek subbasin (M-RC-10 and M-RC-30), and immature stoneflies belonging to the family Capniidae were also sampled from Mt. Scott Creek (M-MS-80), Rock Creek (M-RC-10 and M-RC-30)and from the duplicate sample collected on Carli Creek (M-CA-10A-dup).The percentage of tolerant organisms, percentage of sediment-tolerant organisms, and percent dominance by one taxon also varied widely among reaches, further reflecting the range in macroinvertebrate community conditions in riffles among sampled reaches (Table 15).

Fine-sediment stressor model results suggested that macroinvertebrate communities in the Kellogg Creek and Mt. Scott Creek subbasins were likely showing fine-sediment-induced stress across all reaches sampled (Table 16).

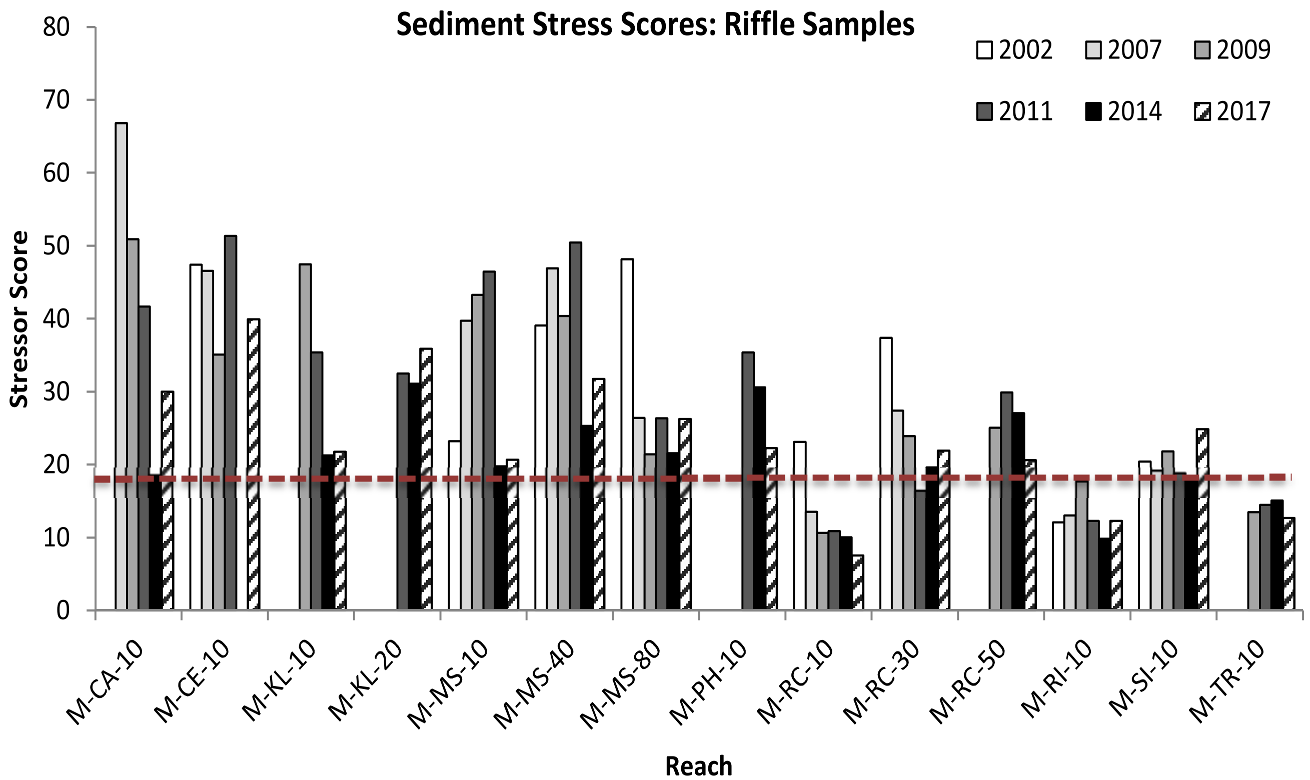
Table 15. Macroinvertebrate community metrics calculated for riffle samples collected from stream reaches in Clackamas County (CCSD #1), Oregon, in the fall of 2017 (n= 7).

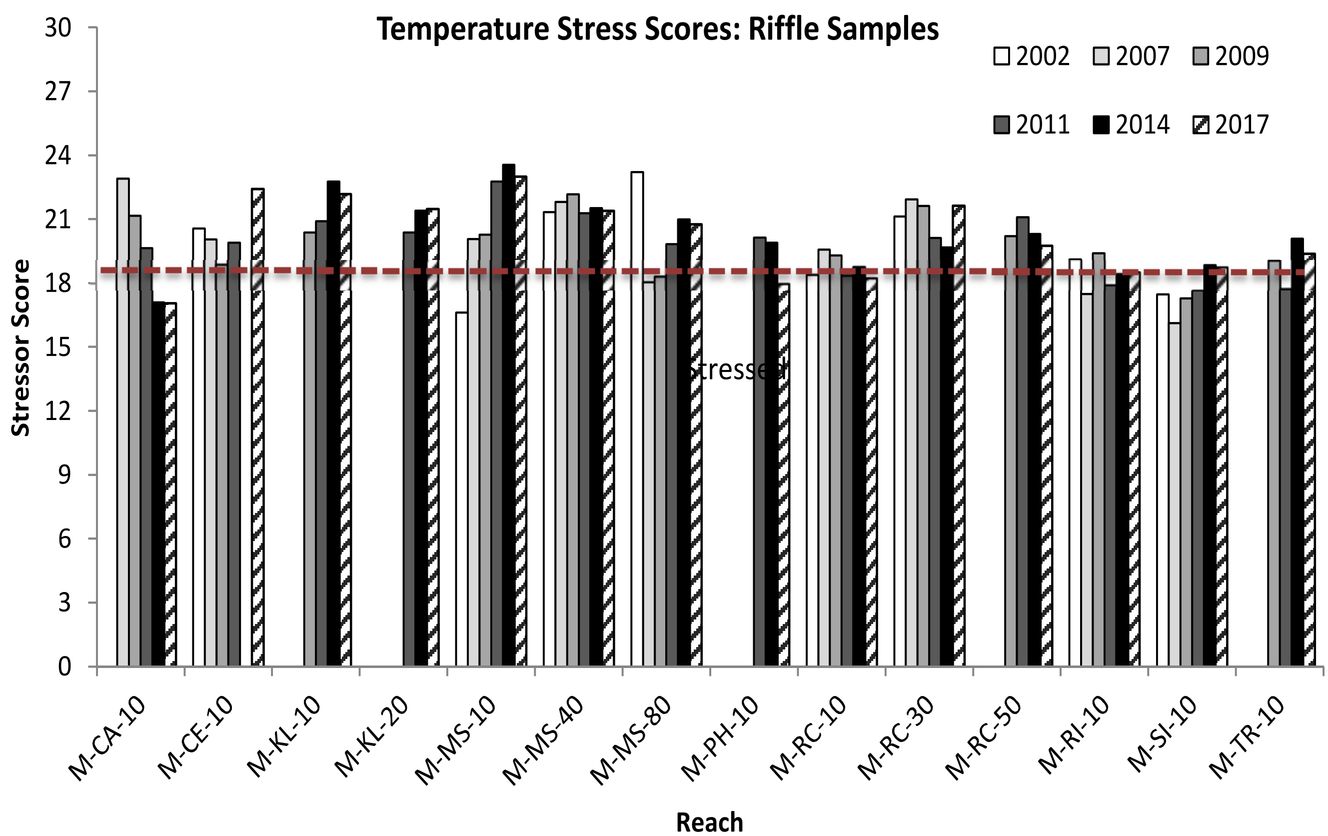
Metric	Mean	SD	Min	Max
Taxa richness	32.6	6.8	23	40
Mayfly richness	4.3	1.8	1	6
Stonefly richness	4.7	2.6	2	8
Caddisfly richness	4.4	1.4	3	7
Number sensitive taxa	2.4	1.0	1	4
Number sediment sensitive taxa	1.4	1.0	0	3
Modified HBI	4.1	0.6	3.6	5.3
Tolerant taxa (percent)	21.2	7.1	7.8	28.2
Sediment tolerant taxa (percent)	10.0	4.2	2.3	15.6
Dominant (percent)	24.5	10.7	14.4	45.3
Total MM Score	32.3	6.7	22	40

Fine-sediment stressor (FSS) model results indicated that macroinvertebrate communities from 11 of the 13 higher-gradient reaches exceeded the DEQ fine sediment stress threshold of 19 percent for the Willamette Valley (Figure 10). Fine sediment was once again determined to be a likely stressor in both Kellogg Creek reaches and all 4 of the Mt. Scott Creek reaches sampled in 2017 (Table 16). Two of three Rock Creek reaches exceeded the FSS 19 percent threshold, but these exceedances were generally again considerably lower in 2017 than in years prior to 2014 (Figure 10). As a second year of results suggest that Rock Creek appears to be showing a trend of improved FSS scores, fine sediment was determined to be a likely stressor in only one of the four Rock Creek subbasin reaches, M-RC-50. This reach received an FSS score of 20.6 percent which was higher than the Willamette Valley threshold of 19 percent (Huff et al. 2006; Figure 10). Because FSS scores appear to be potentially decreasing in the middle Rock Creek reach (M-RC-30), this reach is presently listed as potentially being stressed by fine sediment (Figure 10, Table 16). Sieben Creek's fine sediment stress scores have consistently scored only marginally higher than the 19 percent Willamette Valley threshold, warranting a potentially sediment stressed classification for this study (Figure 10). Lower Rock Creek (M-RC-10), Richardson Creek (M-RI-10) and Trillium Creek (M-TR-10) have consistently received FSS scores below the 19 percent threshold, suggesting no indication of FSS-induced stress in the macroinvertebrate community (Figure 10, Table 16).

Table 16. Summary of stressor identification results for macroinvertebrate communities sampled from 13 higher-gradient and instream reach in Clackamas County (CCSD #1), Oregon, fall 2017. Stressors include elevated levels of fine sediment, elevated water temperature (Temp), and low dissolved oxygen (DO).

Reach ID	Likely Stressors	Potential Stressors	Not Likely Stressors
Kellogg Creek Subbasin			
M-KL-10	Fine sediment, Temp	-	DO
M-KL-20	Fine sediment, Temp	DO	-
Mt. Scott Creek Subbasin			
M-MS-10	Fine sediment, Temp	DO	-
M-MS-40	Fine sediment, Temp	DO	-
M-MS-80	Fine Sediment, Temp	-	DO
M-PH-10	Fine Sediment, Temp	DO	-
M-CE-10A	Fine Sediment, Temp, DO	-	-
Rock Creek Subbasin			
M-RC-10	-	Temp	Fine sediment, DO
M-RC-30	Temp	Fine Sediment	DO
M-RC-50	Fine sediment, Temp	-	DO
M-TR-10	-	Temp	Fine sediment, DO
Tributaries to the Clackamas River			
M-SI-10	-	Fine sediment, Temp	DO
M-CA-10A	Fine Sediment	Temp	DO
M-RI-10	-	-	Fine sediment, Temp, DO





Fine sediment stressor model scores (top panel) and temperature stressor scores (bottom panel) of macroinvertebrate communities sampled from riffles in Clackamas County (CCSD#1), Oregon in the fall of 2002, 2007, 2009, 2011, 2014, and 2017. Red lines indicate thresholds above which values indicate a stressed

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FIGURE
10

Temperature stressor model results from 2017 suggested that macroinvertebrate communities in the Kellogg Creek and Mt. Scott Creek subbasins are likely continuing to show elevated temperature stress (Figure 11, Table 16), as macroinvertebrate assemblages from all 6 of the reaches in the two subbasins received inferred temperature stressor scores higher than the Willamette Valley threshold of 18.2 °C (Huff et al. 2006). Continuous temperature monitoring data collected from lower Kellogg Creek and lower Mt. Scott Creek by WEST Consultants for WES corroborate this general finding of high likelihood of thermal stress in the lower sections of these streams. Lower Kellogg Creek's Summer 2017 continuous temperature data (June through September) indicated that daily maximum water temperatures exceeded 68ºF (20ºC) on 47 and 62 days in lower Kellogg Creek and lower Mt. Scott Creek, respectively.

Elevated stream temperature is also likely a stressor in two of the four reaches in the Rock Creek subbasin (M-RC-30 and M-RC-50). These reaches are located in the middle and upper portions of Rock Creek. Interestingly, the farthest downstream reach on Rock Creek (M-RC-10) has always received the lowest TS scores among the three Rock Creek reaches, including in 2017. These results once again suggest a cooler thermal regime in this lower reach than upstream. Instantaneous water temperature measurements made during each macroinvertebrate sampling event over the years have consistently shown the lowest Rock Creek water temperatures occur in this lowest reach; however, these data are often not collected on the same day or same time of day, resulting in tentative comparisons. Continuous temperature monitoring data collected from lower Rock Creek by WEST Consultants for WES corroborate this general finding of a low likelihood of thermal stress in lower Rock Creek. Lower Rock Creek's summer 2017 continuous temperature data indicated that daily maximum water temperatures never exceeded 68ºF (20ºC). Longitudinal patterns in Rock Creek water temperatures could be better investigated with continuous temperature monitoring in each of the three monitoring reaches, rather than in only lower Rock Creek.

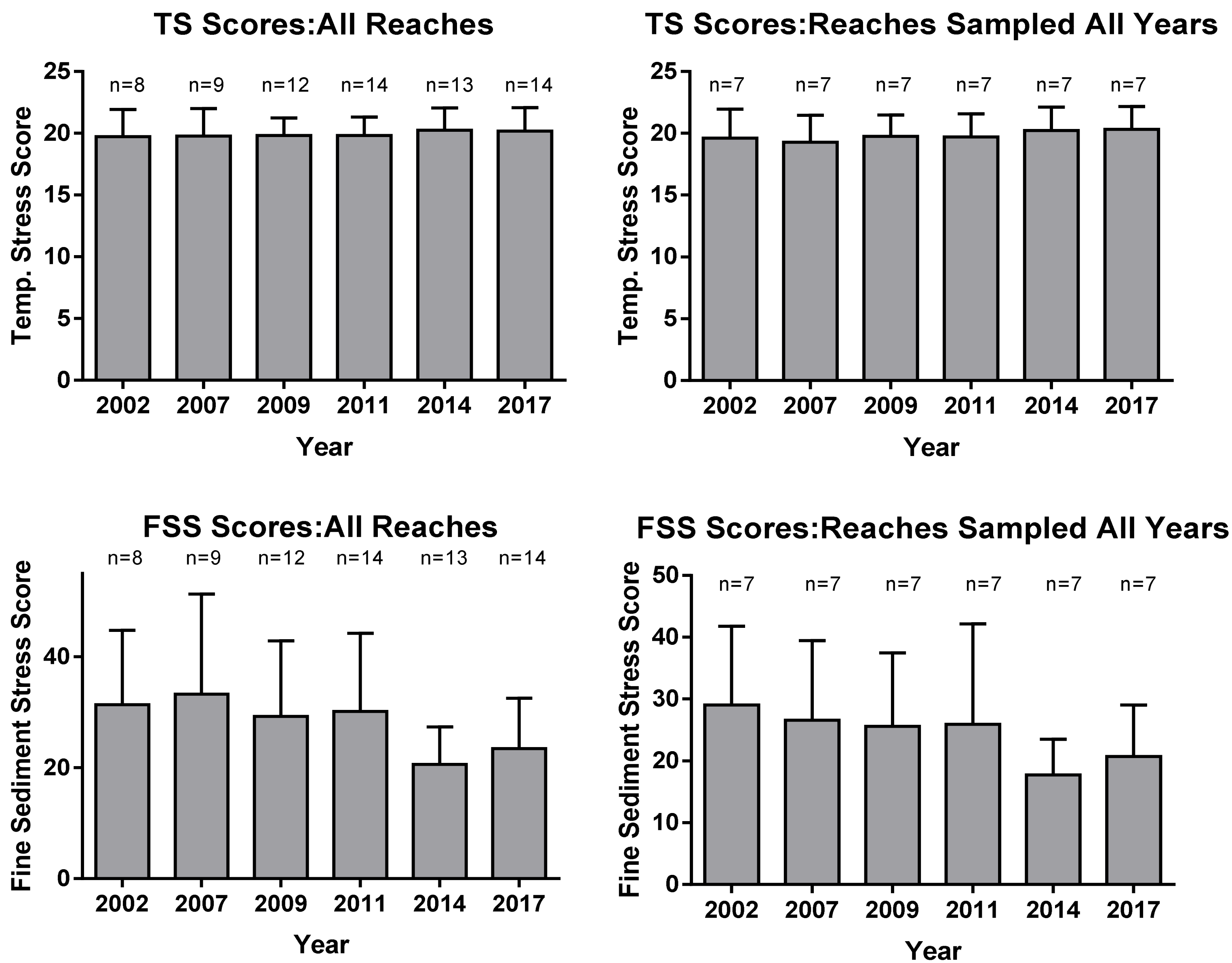

FIGURE 11

Mean temperature stressor scores (upper panels) and mean fine sediment stressor scores (bottom panels) of macroinvertebrate communities sampled from riffles in Clackamas County (CCSD#1), Oregon in the fall of 2002, 2007, 2009, 2011, 2014, and 2017. Left panels include data from all reaches where riffles were sampled, while the right panels include data from a subset of reaches where riffles were sampled in each of the five survey years (n=7).

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Macroinvertebrate Community Conditions –Glide Samples

A single glide sample was collected from the Cow Creek reach (M-CO-10) in 2014. The Cow Creek reach (M-CO-10) received a MWCF O/E score of 0.435 in 2014 relative to 0.29 in 2011, the first year of sampling Cow Creek in this reach. Macroinvertebrate communities sampled from this reach were characterized as having a low total richness (19 total taxa), few EPT taxa (1 mayfly and 1 caddisfly taxon in 2014), and a high HBI score (HBI = 5.8). While only two EPT taxa – *Baetis tricaudatus* and *Hydropsyche* sp. – were sampled from this reach in 2014, the presence of these two taxa in the subsample is encouraging when compared to the absence of EPT taxa from the subsample in 2011.

Correlation of Community Conditions with Environmental Conditions

Correlation analyses of macroinvertebrate community scores with environmental conditions were performed on the combined 2017 SWMACC and CCSD #1 data sets to increase sample sizes and statistical power of the analyses. As in previous years, both riffle sample multimetric scores and MWCF O/E scores were significantly correlated with land use composition in the upstream drainage area, including percent urban (MM score: Spearman rho = -0.8191, $p < 0.0001$; O/E score: Spearman rho = -0.7749, $p < 0.0001$), percent agriculture (MM score: Spearman rho = 0.8059, $p = <0.0001$; O/E score: Spearman rho = 0.7276, $p < 0.0001$), percent urban and agriculture land uses combined (MM Score: Spearman rho = -0.6369, $p = 0.0004$; O/E score: Spearman rho = -0.7615, $p = <0.0001$), and percent forest (MM Score: Spearman rho = 0.6383, $p = 0.0004$; O/E score: Spearman rho = 0.7635, $p = <0.0001$; Figure 12 and Figure 13).

Among measured physical habitat attributes, only wetted width was significantly correlated with both MM and O/E scores (MM Score: Spearman rho = -0.3936, $p = 0.0258$, O/E Score: Spearman rho = -0.5082, $p = 0.0047$). This apparent relationship between stream size and community condition potentially results from smaller streams generally being less disturbed than larger streams within the study area, at least among those included in the study. Furthermore, smaller streams will generally support cooler water temperatares during peak-stress times than larger streams. Bankfull width was also significantly correlated with O/E scores (Spearman rho = -0.4096, $p = 0.021$; Figure 12 and Figure 13) while the percentage of the reach comprised of riffle habitat (MM Score: Spearman rho = 0.3505, $p = 0.0429$) and the mean stream gradient (MM Score: Spearman rho = 0.3748, $p = 0.0325$) were each significantly correlated with only MM scores (Figure 12 and Figure 13).

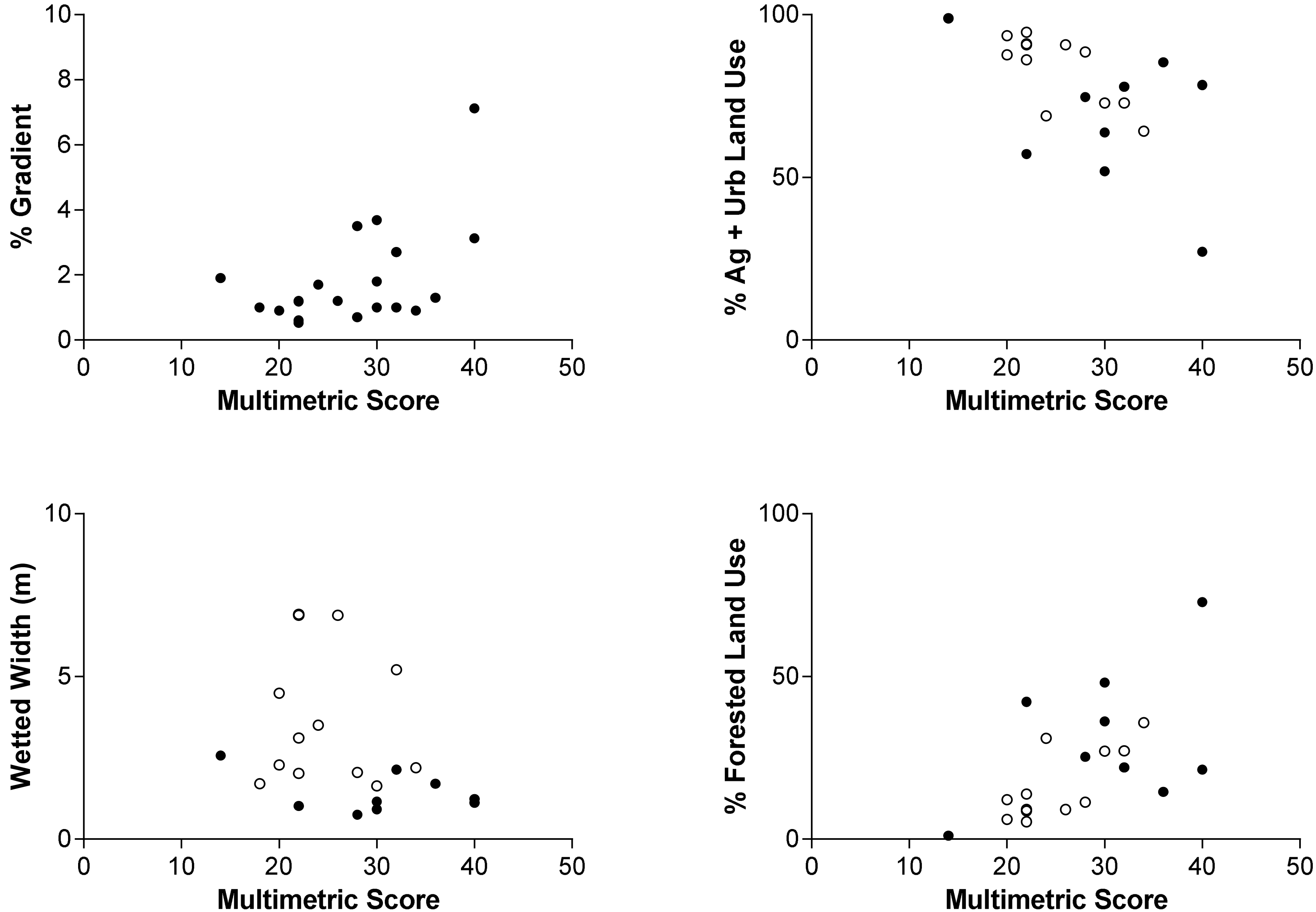

FIGURE 12

Relationships between multimetric scores of macroinvertebrate communities sampled from riffles and select environmental variables in Clackamas County (SWMACC: Solid circles and CCSD # 1: Open circles), Oregon in the fall of 2017.

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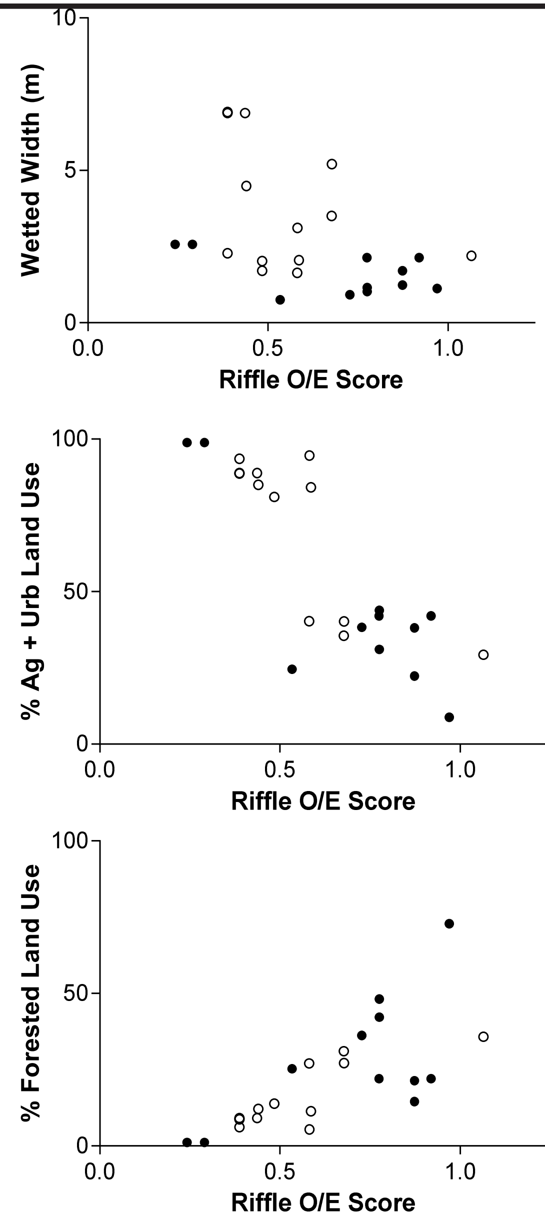

FIGURE

13

Relationships between MWCF O/E scores of macroinvertebrate communities sampled from riffles and select environmental variables in Clackamas County (SWMACC: Solid circles and CCSD # 1: Open circles), Oregon in the fall of 2017.

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4.0 DISCUSSION

4.1 DISCUSSION OF GEOMORPHIC SURVEY

The results from the geomorphic monitoring may be best viewed within the context of a "sediment budget" of each study reach. Geomorphic changes seen in the monitoring data reflect changes in the timing and magnitude of water and sediment supply from the watershed. Slow growth and urbanization have increased the size and frequency of floods available to transport sediment, leading to erosion in stream channels throughout the region. These impacts have already affected most, if not all, of the channels within the CCSD #1 service area, and all of the channels that were surveyed in CCSD #1 are impaired to some extent due to lack of large wood supply, channel straightening, modified hydrology, and channel incision. The discussion focuses on two aspects of the geomorphic data: identifying areas of instability within the CCSD #1 monitoring area; and examining the impact of geomorphology on the macroinvertebrate communities.

Areas of Geomorphic Instability in CCSD #1 Monitoring Reaches

The geomorphic survey identified both stable and unstable reaches. Geomorphically stable reaches are those in which the sediment balance is about neutral over time. Stable reaches may be dynamic, moving laterally but maintaining the same approximate channel shape and elevation over time. Unstable reaches are those in which either erosion or deposition predominate. The geomorphic survey identified three main types of instability in the channels: aggrading reaches, degrading (incising) reaches, and active headcuts.

The unstable reaches in the CCSD #1 area are identified in Table 17, based on the geomorphic data in Appendix A and the site descriptions in Section 3.1.

The watershed-scale causes, impacts, and options for dealing with the three types of channel instability are summarized below:

1. ***Aggradation***. One type of geomorphic instability is a reach-scale change in the elevation in the streambed, either an increase (aggradation) or decrease (incision). Reach-scale channel aggradation is caused by a positive imbalance between the supply of sediment and the reach's transport capacity of sediment (oversupply of sediment). Under these conditions sediment will deposit in the channel bed, building gravel or sand bars. Aggradation in channels is typically accompanied by channel widening, because more of the flow energy is deflected towards the banks. Aggrading channels typically have more topographic complexity, and therefore better habitat. Also, since an aggrading bed is approaching the elevation of the floodplain, aggrading channels also flood more frequently (a condition that is considered beneficial for habitat and for protecting downstream properties from flooding, not considering effects on structures and infrastructure in the flooding zone). Although the causes of channel aggradation are complex and site-specific, in general it is caused by an increase in the sediment supply, a reduction in the sizes of floods, or an increase in the base level of the stream. Unless there is a risk to infrastructure, aggrading channels are considered to be beneficial to ecosystems.

2. ***Degradation (incision).*** When the sediment balance is negative (transport capacity exceeds supply), streams and rivers incise. Incising, or degrading, streams are commonly encountered in urbanizing environments, because more rainfall runs off of impervious surfaces and enters streams quickly, leading to higher peak flows and a resulting increase in the sediment transport capacity. Due to the increase in transport capacity, streams incise, usually becoming narrower and deeper. In this situation, much of the topographic complexity in the channel bed is removed by erosion. Also, incised streams often become "disconnected" from the adjacent floodplain, flooding infrequently or never. The steep, high banks caused by incision become unstable and collapse, increasing the supply of fine sediment to the stream. In some areas the incision may also cause groundwater levels in the floodplain to drop, impacting groundwater wells. In contrast to headcuts, which can be stabilized relatively easily, reversing or preventing reach-scale incision over the long term could potentially require changes at the scale of the entire watershed.
3. ***Active Headcut.*** A third type of geomorphic instability seen in many of these reaches is a headcut, which is a sharp geomorphic transition from a stable reach upstream to a degrading reach downstream. Headcuts commonly migrate upstream, increasing the size of the instability. Headcuts are initiated by a variety of causes – both watershed-scale and local-scale factors – but most often are caused by local events, such as the removal of a grade control feature. Downstream of headcuts, erosion predominates, starting with incision of the channel, which may in turn destabilize banks, often leading to an increase in the supply of fine sediment to the stream, causing detrimental impacts to downstream areas. One common method of treating headcuts uses natural channel design methods, such as wood or boulder installations to halt the continued upstream migration. To do this at the scale of the CCSD #1 service area, areas of active headcutting must be identified. Although headcuts have been be identified at some of the monitoring sites through observations in the field or analysis of the longitudinal profile (Table 18 and Section 3.1), we have not mapped headcuts outside the surveyed reaches.

Geomorphic Impact on Macroinvertebrates

The geomorphic data were also used to try to explain some of the variability in macroinvertebrate communities in tributaries of the lower Clackamas River basin. The highest O/E score in the 2017 data set for the CCSD #1 service area is in the upper Rock Creek drainage basin, at Troge Road site (M-RC-50) (0.87), and the lowest is at Carli Creek (M-CA-10) (0.24). The high score at the Troge Road site is unexpected, as the geomorphic quality of that reach is not particularly high, having few pools and riffles, a high content of fines in riffle gravel. The low score at Carli Creek is not surprising, but probably is unrelated to geomorphic factors – the site has impaired water quality due to the presence of pollutants, including metals (copper, lead and zinc) that would inhibit the growth of certain macroinvertebrates.

Unlike in the SWMACC district (Waterways, 2018b), the O/E scores in the CCSD #1 service area do not have a strong correlation with geomorphic variables (Figure 14). The only significant correlation is with the percent fines in the bulk sample (R^2=0.36); however, this is a positive correlation, not a negative correlation as would be expected (less fines is considered more favorable). Therefore based on the correlation presented here, it appears that factors other than local geomorphic ones, such as water quality, are the most important controls on the macroinvertebrate communities in the CCSD #1 service area, such as tolerant taxa and high HBI scores from the presence of nutrient-tolerant taxa (i.e. nutrient pollution).

Table 17. Summary of Geomorphic Condition of CCSD1 Monitoring Reaches[1]

	Measured Parameters			Interpretation			
Reach	**Bank Stability** (% bankline actively eroding)	**Substrate** (% sand+ fines in pool tail)	**Channel Cross Section** (W/D ratio)	**Incising** Yes (Y), No (N), or Maybe (?)	**Aggrading** Y, N, ?	**Active Headcut(s)** Y, N, ?	**Key Features of Reach**
KL-10	2.4	15	13.6	N	N	N	Bed armored with angular cobble and boulders.
KL-20	14.3	48	5.9	N	N	N	Armored banks in residential backyard area with manicured grass floodplain.
KL-30	0.0		6	N	N	N	Channel in a low-gradient straightened ditch in backwater of culvert.
MS-10	4.0	12	15.3	N	N	N	Stable and functioning channel and floodplain at downstream end of and below a recent stream restoration reach.
MS-40	1.7		6.8	?	N	N	Stable and slightly incised reach with mature riparian forest corridor; in Three Creeks Natural Area.
MS-70	1.7	28	11.5	N	N	N	Bed changes such as filling and deepening of pools and exposed bedrock but stable overall; in Mt. Talbert Nature Park.
MS-80	3.1		14.9	?	?	?	Restored area upstream of dam removed in 2009; apparent aggradation in middle section of reach and incision at upstream end.
MS-90			5.2	N	N	N	Small tributary to Mt. Scott Creek created during construction of housing development; stream stabilization in 2014.
MS-100	0.0		10.4	N	N	?	Mostly bedrock reach with some angular rock and fine sediment; thick blackberry and ivy on floodplain. Headcut downstream may advance through this reach.

MS-110	0.0		5.4				Low energy reach with small channel and debris jams. Little geomorphic change.
PH-10		24	7.6	N	Y	N	Confined reach with narrow functional floodplain and relatively complex channel adjacent to Costco parking lot. Continue to monitor gravel deposition upstream of culvert.
RC-10	0.0	25	8.4	Y	N	N	Steep walled canyon reach incised to bedrock.
RC-30	0.0		9.6	Y			Reach eroded to bedrock but contains a reasonably healthy riparian forest.
RC-40							Not accessed in 2017; monitoring reach may be re-established in next survey year.
RC-50	0.0	36	10.1	N	?	N	Confined channel on private property with narrow riparian floodplain. Presence of beaver dam causing aggradation in the lowermost section of the reach
RC-60	0.0		6.5	N	N	Y	Low gradient reach on private property appears to be depositing fine sediment among reed canary grass and debris obstructions. Continue to monitor headcut.
CA-10	0.0	11	9.6	N	N	N	Functional channel and floodplain immediately upstream of 2017 restoration reach.
CO-20				?	?	?	Beaver dams and fine sediment dominate reach. No survey or sampling performed due to site conditions, access, and safety.
SI-10	14.0	35	2.3	Y	N	N	Narrow confined channel deeply incised to bedrock with little geomorphic process and limited habitat value.

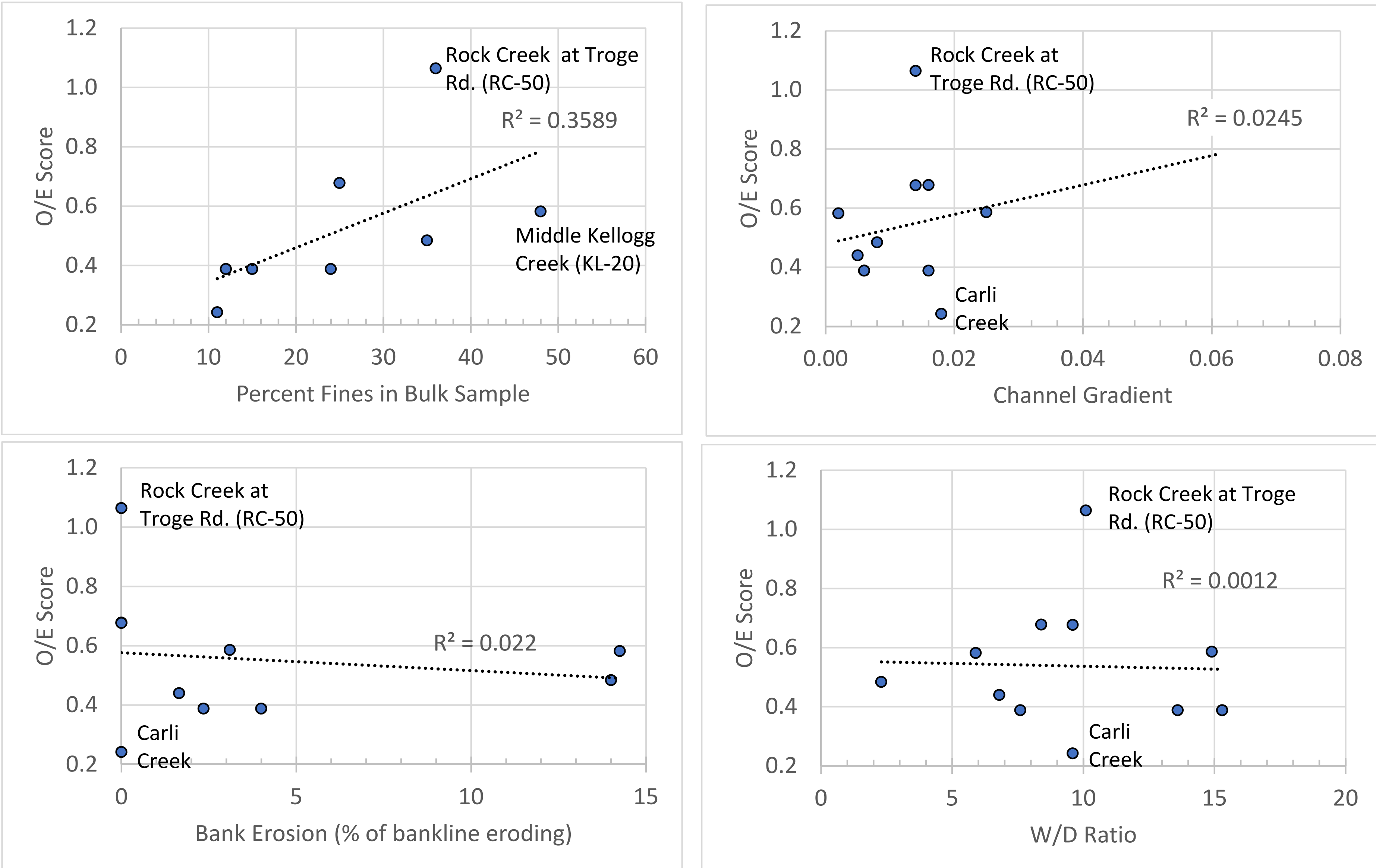

FIGURE **14**

Correlation between geomorphic parameters and O/E scores sampled from reaches in Clackamas County (CCSD#1), Oregon in the fall of 2017

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4.2 DISCUSSION OF MACROINVERTEBRATE SURVEY

These geomorphic instabilities often lead to degraded habitat for macroinvertebrates. As in previous assessments of macroinvertebrate communities of the CCSD #1 service area, macroinvertebrate community conditions varied among stream reaches sampled in fall 2017. All streams in the survey showed evidence of current or past instabilities and varying degrees of elevated sediment loading, likely resulting from hydromodification. Among the 13 higher-gradient reaches included in this assessment, fine sediment was identified as a "likely stressor" in 8 reaches based on the high inferred fine sediment values produced by the FSS model and as supported by geomorphic and physical habitat data. Stress induced by fine sediment inputs appears to be affecting the macroinvertebrate communities in the Kellogg Creek and Mt. Scott Creek subbasins in particular, 2017 marked the sixth year of macroinvertebrate sampling in the CCSD #1 service area by WES since monitoring was initiated in 2002. In fifteen years of monitoring these area streams, it is significant that none have exhibited further degradation in a period during which Clackamas County has seen robust population growth (2002: 350,850; 2017: 412,672, source: US Census Bureau). Seven stream reaches have been sampled in all six assessment years (some reaches have been re-located by short distances but biological results are combined for trending purposes). Collectively, their results suggest that macroinvertebrate community conditions in these streams have largely remained unchanged, if not slightly improved, in some cases, a message first conveyed after the 2014 round of sampling and supported again by the 2017 results. The average multimetric score from these 7 reaches increased from 20.9 in 2002 to 27.1 in 2014 and 25.7 in 2017, with variation only within these extremes between 2007 and 2011. Potential biological improvements in Mt. Scott Creek at M-MS-80 and in Rock Creek at M-RC-50 during this time period are of particular noteworthiness. In 2014, Rock Creek at M-RC-30 was noted as potentially improving in 2014, yet the 2017 MM score was closer to its average over earlier years. The next few monitoring rounds will be of particular interest to see if the data continue to support these potential trends at these and other reaches such as lower Mt. Scott Creek (M-MS-10) and Trillium Creek (M-TR-10).

There was general agreement between potential trends in macroinvertebrate community conditions and geomorphic condition ratings in this study. Specifically, most reaches included in the study received an overall geomorphic condition rating of "stable – at risk", and conditions of macroinvertebrate communities in most reaches were deemed to be stable or even slightly improving. Only two reaches included in both the geomorphic and macroinvertebrate studies received geomorphic condition ratings of "At Risk" or "At Risk – Unstable". G-MS-40/MS-40 received the only geomorphic condition rating of "At Risk", and this site has consistently received among the poorest FSS model scores, indicative of a community that is chronically stressed by excessive sediment loading. The Seiben Creek reach G-SI-10/M-SI-10 received the only geomorphic condition rating of "At Risk – Unstable", and also received among the lowest MMI and MWCF O/E scores. Future monitoring should continue to examine overall geomorphic condition ratings in relation to apparent trends macroinvertebrate community conditions to determine whether increasing or decreasing conditions in one corresponds with the other. Of course, other factors such as water quality, water temperature, and streamflow conditions all affect macroinvertebrate community conditions, so the lack of correspondence between these two aspects of the work may indicate that other factors are at play in affecting biological conditions.

As in previous years, disturbance classes derived from multimetric scores did not correspond well with those derived from MWCF O/E scores. In 2017, 11 of 13 higher-gradient reaches received O/E classification of most disturbed. Among those, only two received a corresponding multimetric classification of severely disturbed, while 9 received an MM classification of moderately disturbed. These results generally suggest that the MWCF O/E classification of "most disturbed" corresponds to both the "moderately" and "severely" disturbed classifications of the multimetric index. The apparent disparity in the condition class assignments between the models appears to be partially related to the almost complete absence of some taxa that were predicted to occur at more than half of the reaches under least-disturbed conditions. This across-the-board absence of specific taxa from all or nearly all CCSD #1 samples results in lower O/E scores than corresponding multimetric scores. The O/E scores are more sensitive to the absence of certain taxa because the O/E models are based on the predicted presence of particular taxa, while the multimetric model results are based on broader metrics related to general taxonomic richness and ecological attributes of the taxa that are sampled. In some other regional studies, O/E scores and multimetric scores have shown better correspondence, but when they don't correspond, the O/E scores tend to be lower than the multimetric scores. Because correspondence in conditions classes does not always occur, we suggest continuing to assess macroinvertebrate community conditions using both approaches and focusing primarily on the scores and the trends in those scores themselves rather than on the resultant condition classes. Longer-term trends in these scores will be most useful for examining and quantifying changes and trends in biological conditions of CCSD #1 streams over time. Furthermore, future analyses of biological conditions in CCSD #1 streams will include the use of the Biological Conditions Gradient (BCG) tool for Willamette Valley and Puget Sound Lowlands ecoregions streams. As this tool is nearing completion and is not yet available in final form for use, the next round of CCSD #1 macroinvertebrate sampling will certainly include its use, at which time the output from the BCG can be tested against both the multimetric scores and the MWCF O/E scores. Such a three-way evaluation may help ascertain which of the tools are best suited for longer term use and which may no longer be necessary.

Macroinvertebrate community condition in higher-gradient reaches (i.e., from which riffle samples were collected) was once again correlated with land use types and several physical habitat characteristics. Pooling sample data across both service areas (CCSD #1 and SWMACC) provided a larger sample size and a wider range of environmental conditions, allowing for stronger correlations to be made. Although only correlative (i.e. one cannot infer cause and effect), the relationships allow for the identification of environmental stressors that are potentially responsible for producing the observed biological community conditions. Multimetric and O/E scores calculated from riffle samples were once again highly correlated with percent urban, agriculture, urban/agriculture, and forest land use types. Scores were negatively correlated with percent urban land use and the combination of percent urban and agriculture and uses, while scores were positively correlated with percent agriculture and percent forest land use types. Urban land use is relatively high in the Kellogg Creek (91.7 percent), and Mt. Scott Creek (88.3 percent) subbasins when compared to the Rock Creek subbasin (36.3 percent). percent). When multimetric scores of riffle-sampled reaches were averaged, the Mt. Scott Creek and Kellogg Creek subbasins each had the lowest multimetric score of 22, while the Rock Creek subbasin MM scores averaged 30.0. MWCF O/E scores, when summarized in the same manner, followed a similar pattern with lower mean scores observed in the more urbanized Kellogg Creek and Mt. Scott Creek subbasins (O/E Scores of 0.49 and 0.57 respectively) and a higher mean score observed in the less urbanized Rock Creek subbasin (0.75).

The Carli Creek reach (M-CA-10; CCSD #1), which once again received the lowest multimetric and MWCF O/E scores among all higher-gradient reaches in both service districts, had the highest percentage of urban land use in the drainage basin upstream of the reach (98.9 percent). Conversely, the upper Rock Creek reach (M-RC-50), lower Rock Creek reach (M-RC-10), and the Richardson Creek reach (M-RI-10), which received the highest multimetric scores of 34, 32, and 32 respectively, have a relatively low percentage of urban land use in the drainage basin upstream of the reaches (M-RC-10: 40.2 percent, M-RC-50: 29.3 percent, and M-RI-10: 42.0 percent).

As in previous years of sampling CCSD #1 stream reaches for macroinvertebrates, no freshwater mussels were sampled in 2017. This does not indicate that they are absent from CCSD #1 streams. The methods used in these studies are not intended to detect mussels when they are present. As several Pacific Northwest mussel species are state or federally listed, and as a group, freshwater mussels are generally sensitive to water pollution and habitat alteration, interest in determining their status in northwest Oregon waters is increasing. Protocols specific to detecting their presence and estimating their abundance have been established (e.g., Strayer and Smith 2003) and would need to be used in order to understand the current status of mussels in CCSD #1 streams.

Urban development results in large impervious surface areas that modify hydrologic patterns, resulting in destabilized streamflows, altered seasonal high and low flows, increased sediment inputs, and modified channel morphology and habitat. Urban stormwater also carries numerous pollutants, some of which can attain toxic concentrations during first-flush storm events. This phenomenon, known as “urban stream syndrome” or “multiple stress syndrome” is well documented among urban streams (Walsh et al. 2005). Mechanisms driving the syndrome are complex and interacting, yet rapid and unabated stormwater delivery into highly physically altered (often channelized) receiving waters is largely the source of the various perturbations observed and measured in this and other regional studies of stream condition. These highly modified hydrologic patterns destabilize streamflows and alter seasonal high and low flows, pollutant concentrations, temperature and dissolved oxygen extremes, sediment inputs, and channel morphology, all which cumulatively degrade biological communities.

Among pollutants entering streams through stormwater, pesticides are only starting to receive their deserved attention with respect to understanding effects on the ecology of surface waters. Recent work in Clackamas County, Oregon found that several indicators of macroinvertebrate community condition were strongly negatively correlated with streambed sediment concentrations of the pyrethroid insecticide bifenthrin, now widely used in urban areas (Carpenter et al. 2016). Carpenter et al.’s work suggests that pesticides carried by stormwater may play an important role in the degradation of aquatic communities in some areas, but much more work is necessary on this front. Continued and expanded pesticides monitoring in Clackamas County and elsewhere could assist with further understanding this emerging issue as it relates to stormwater management and consequences to the biology in receiving waters. Four CCSD #1 streams were included in the Carpenter et al. (2016) study: Carli Creek, Rock Creek, Seiben Creek, and Kellogg Creek. None of these streams were implicated by the Carpenter study as having bifenthrin concentrations in streambed sediments that would potentially be deleterious to macroinvertebrates (Kurt Carpenter, unpublished data).

While many proximate factors may contribute to the biological disturbances measured in this study, ultimately, causation in most cases can likely be attributed to stormwater. Protection of area streams should focus on minimizing total effective impervious areas and improving stormwater retention and drainage patterns to minimize the hydrologic effects of storm events on stream channel conditions. Certain stormwater mitigation strategies such as artificial wetlands and retention facilities also serve to remove pollutants through physical, chemical, or biological processes. Further development within the CCSD #1 service area will necessitate careful attention to these and other measures intended to preserve and enhance stream conditions and functions. As such measures and other restoration activities are undertaken these data will assist with determining the success of these actions relative to their intended benefits to aquatic life.

5.0 RECOMMENDATIONS AND CONCLUSIONS

The primary objective of this project was to re-assess geomorphic and biological conditions at stream monitoring stations throughout Clackamas County's CCSD #1 Service Area, and provide some general and specific recommendations based on the observations. In 2017 we revisited geomorphic and macroinvertebrate monitoring stations on tributary streams to the lower Clackamas and Willamette Rivers that had been previously surveyed in 2002, 2007, 2009, 2011, and 2014. Changes in channel morphology influence instream physical habitat; for example, geomorphic patterns determine the distribution of slow- and fast-water habitat units, as well as substrate composition associated with the various types of habitats.

Summary Observations

All of the stream channels evaluated in this assessment have been impacted in some way by land use changes and hydromodification. In most study reaches, hydromodification has resulted in moderately incised stream channels that are inset into wider valley bottoms. This incision restricts access to historic floodplain areas, which in turn confines higher flows to the primary channel, resulting in more energy being concentrated on the bed and banks of the channel. Because floodplain deposits are typically composed primarily of fine grained sediment, streambanks comprised of these materials are particularly vulnerable to erosion.

Bank erosion is not a widespread issue among the CCSD #1 monitoring reaches: of the 19 geomorphic monitoring sites, only two [Middle Kellogg Creek (KL-20) and Sieben Creek (SI-10)] have severe bank erosion exceeding 10 percent of the total bank length. Fine sediment intrusion into the gravel substrate is more prevalent: 5 of the 9 sites where bulk samples were collected have riffles composed of more than 25 percent sand. This may be a reflection of the local geology and topography, but may also reflect accelerated rates of erosion, and(or) the locations of some of the monitoring reaches in areas backwatered by culverts.

Table 17, which summarizes the geomorphic condition of CCSD #1 Monitoring reaches, identified three incising or clearly incised reaches:. Lower Rock Creek (G-RC-10), Rock Creek below Sunnyside Road (G-RC-30)[4], and Sieben Creek (G-SI-10); several additional reaches may also be incised, incising, or partially incised. Only one of the reaches has clear evidence of aggradation, and that is due to local deposition upstream of an undersized culvert (Phillips Creek, G-PH-10). Active headcuts were only observed in one of the reaches (Upper Rock Creek, G-RC-60).

Table 18 summarizes categorical stream "conditions" for several geomorphic measures of stability published in the literature, and the corresponding scores for the CCSD #1 geomorphic monitoring reaches from the 2014 survey. Use of the standard thresholds to define overall channel condition is presented in Table 19. The conclusions of summary have not changed much in 2017. Among the 16 reaches with geomorphic monitoring components, 3 were rated with low floodplain connectivity, 3

[4] Site G-RC-10 had incised to bedrock throughout its entire length resulting in abandonment of its narrow floodplain prior to any geomorphic surveys. As mentioned in Section 3.1 and apparent in Figure A23 (Appendix A), the 2017 survey data show that some discontinuous aggradation has occurred in the reach since 2014. However, the amount of aggradation since 2014 is small compared with the total amount of incision prior to 2014, bedrock is exposed over much of the reach, and the floodplain is still far too high to be flooded even during large floods; therefore this reach is still considered to be incised.

were rated 'At Risk' for bank stability, and 5 had high sediment intrusion ratings. Qualitative assessment and best professional judgement led to an overall rating of 'At Risk' or 'At Risk – Unstable' geomorphic rating for three of the sites. The most at risk or geomorphically unstable sites are listed below with some recommendations on how they may be addressed or monitored.

Table 18. Channel condition thresholds for key geomorphic and bed substrate parameters.

Parameter	Indicator	Threshold Values	Reference
Floodplain Connectivity	Entrenchment	Low: Entrenchment Ratio < 1.4 Moderate: Entrenchment Ratio from 1.4 to 2.2 High: Entrenchment Ratio > 2.2	Rosgen, 1996
Bed Morphology	Pool Depths	Qualitative based on pool depth, channel size and field observations	
Streambank Conditions	Percent Bank Erosion	Stable: < 5 percent on both banks Stable - At-Risk: from 5-10 percent on either bank At-Risk: > 10 percent on either bank	
Degree of Fine Sediment Intrusion	Bulk Sample Results	Low: 6.3mm < 15 percent; 0.85mm < 10 percent Moderate: 6.3mm from 15-30 percent; 0.85mm from 10-20 percent High: 6.3mm > 30 percent; 0.85mm > 20 percent	Kondolf, 2000

Table 19. Qualitative assessment of 2017 channel conditions for each study reach -Clackamas County Service District #1 (CCSD #1), Oregon.

Site ID	Floodplain Connectivity	Bed Morphology	Stream Bank Conditions	Degree of Fine Sediment Intrusion (6.3mm: 0.85mm)	Overall Channel Condition
Kellogg Creek Subbasin					
G-KL-10	Moderate	Pool-Riffle	At Risk	High	Stable – At Risk
G-KL-30	Moderate	Plane Bed	Stable	NA	Stable – At Risk
Mt. Scott Creek Subbasin					
G-MS-40	Low	Pool-Riffle	Stable – At Risk	Moderate	**At Risk**
G-MS-70	Moderate	Pool-Riffle	At Risk	High	Stable – At Risk
G-MS-80	High	Pool-Riffle	Stable	Moderate	Stable
G-MS-90	High	Plane Bed	Stable – At Risk	High	Stable
G-MS-100	Moderate	Plane Bed	Stable	NA	Stable – At Risk
G-MS-110	High	Plane Bed	Stable	NA	**At Risk**
G-PH-10	Moderate	Pool-Riffle	Stable	Moderate: Low	Stable – At Risk
Rock Creek Subbasin					
G-RC-10	Moderate	Pool-Riffle	Stable	Moderate	Stable – At Risk
G-RC-20	High	Plane Bed	Stable	NA	Stable
G-RC-30	Low	Plane Bed	Stable – At Risk	NA	Stable - At Risk
G-RC-40	Moderate	Pool-Riffle	Stable – At Risk	High	Stable – At Risk
G-RC-50	Moderate	Pool-Riffle	Stable – At Risk	High	Stable – At Risk
G-RC-60	High	Backwatered	Stable	NA	Stable – At Risk
Tributaries to the Clackamas River					
G-SI-10	Low	Plane Bed	At Risk	Moderate: Low	**At Risk-Unstable**

Monitoring Recommendations

To continue to advance this dataset's value for understanding long-term changes in channel morphology and ecological conditions, we make the following recommendations:

- The monitoring effort described in this report should be repeated every three years and the geomorphic component following storm events that exceed a 10 year recurrence. Geomorphic data collected in the future should be compared to the baseline data collected in the first few years of this monitoring effort to assess long term trends. Macroinvertebrate data should continue to be analyzed using both the Western Oregon multimetric index and the Marine Western Coastal Forest predictive model. The next survey round will also allow the new Willamette Valley Biological Condition Gradient tool (currently in development by EPA) to be used, providing yet another tool that will likely even more precisely evaluate biological condition.

- Consider adding potential "reference sites," if any can be found, that have not been significantly impacted, and where additional impacts associated with hydromodification are not expected to occur.

- The databases developed as part of the Kellogg/Mt. Scott and Rock Creek Watershed Action Plans should be updated to reflect these data. The current database relied solely on fish habitat assessment data that was more general and not necessarily focused on characterizing geomorphic conditions. Updates to the database using these data will only be possible in the reaches where surveys were conducted.

- As the biological data collected ultimately reveals the overall ecological conditions of WES district streams (as affected by both the physical and chemical environment), macroinvertebrate monitoring should continue at the same interval (every three years) as the geomorphic monitoring. To the extent possible, geomorphic and macroinvertebrate monitoring reaches should continue to be co-located.
- Long-term monitoring of geomorphic, biological, physical, and chemical conditions in WES districts will allow further elucidation of relationships between environmental stressors and biological responses. The stressor models and the CADDIS stressor identification framework should continue to prove useful in identifying causes of measured degradation to biological conditions. This approach could be further strengthened with the inclusion of continuous monitoring data—such as temperature and dissolved oxygen—at or near biological monitoring reaches. Such data would allow for more reliable identification of environmental conditions that induce biological stress and therefore development of stronger relationships between environmental extremes and biological condition. Such data would significantly improve the ability to make inferences regarding elevated temperature effects on measured invertebrate community conditions in these area streams.
- Detection of longer-term trends in biological conditions in the CCSD #1 service area will benefit from maintaining consistent sample stations across years. Beginning in 2011, a concerted effort was made to cluster monitoring activities within specific reaches, resulting of co-location of 8 geomorphic and biological monitoring reaches in 2014. Monitoring activities currently being conducted within the CCSD #1 service area include the biological (macroinvertebrates) and geomorphic monitoring detailed here, as well as water chemistry and stream flow monitoring. WES administers a creek water quality and flow monitoring program within the CCSD #1 service area. The program's services include water quality sample collection and flow measurement; laboratory and field analysis of water samples; and water quality data management and reporting. The macroinvertebrate survey reaches within Kellogg Creek (M-KL-20), Mt. Scott Creek (M-MS-10), Phillips Creek (M-PH-10), and Sieben Creek (M-SI-10) are clustered respectively with the WES#14, WES#15, WES#11, and WES#7 monitoring locations. The former three macroinvertebrate reaches were shifted upstream of the previously sampled reaches to align with these monitoring stations. These creek water quality monitoring sites are each visited nine times per year. Future macroinvertebrate and geomorphic assessments should incorporate data collected during these visits when possible.

Site-Specific Recommendations

Based on our evaluation of site conditions and the geomorphic monitoring data, the stream reaches thought to be the most at-risk are as follows (not necessarily in order of priority):

G-MS-40: This reach runs through the Three Creeks Natural Area. This low gradient reach runs adjacent to a remediation site at the upper extent and near walking paths in the lower extent.

The reach has incised to bedrock over much of its length. From 2011 to 2014, this reach experienced an increase in the width and width to depth ratio. The banks of the channel were identified as steep and unstable in 2014, although the 2017 survey only mapped 2 percent of the bankline as actively eroding. In addition to unstable banks and incised condition, the particle size in depositional features, from the pebble counts, appears to have increased since 2009, while the percent of sand infiltration into the gravel may have also increased. These apparently contradictory changes in the trajectory of bed substrate may indicate armoring of the bed due to increased high flows due to urbanization, and also an increase in the supply of fine grained sediment from the watershed. At least one deep pool also filled with sediment since the 2014 survey. While the reach is not necessarily heavily impaired, it does appear to be degrading by multiple measures. Since the reach runs through a natural area, there is minimal adjacent infrastructure, so there may be an opportunity to restore floodplain connectivity. This could be done by adding large wood to aggrade the channel and by laying back the banks to increase bank stability.

- G-MS-100 and G-MS-110: These reaches are located in upper Mt. Scott Creek in the Happy Valley Area. The G-MS-100 study site is located just downstream of a large headcut. Downstream of the headcut, the channel is incised down to bedrock and lateral erosion has been occurring since 2009. It is likely that the rapid development that has occurred in Happy Valley will result in continued upstream migration of the observed headcut, which could result in several feet of channel incision upstream of G-MS-100, through Happy Valley Park and into Reach G-MS-110. Incision into these reaches would not only degrade channel and aquatic habitat conditions in these two reaches but would also result in delivery of large amounts of fine sediment to downstream reaches. The channel has widened slightly between 2009 and 2014 and some deposition occurred at the downstream cross sections, which is possibly a result of sediment movement from the headcut (Appendix A, Figure A19). Stabilization measures for site G-MS-100 were implemented in 2015. The work included addition of large wood to stabilize the existing headcuts and replacement of a culvert with a bridge to increase connectivity, both laterally and longitudinally, with the floodplain. However, landowner permission was not received at G-MS-110, so measures were only implemented within the boundary of Happy Valley Park.
- G-SI-10: Sieben Creek is a small tributary that flows directly into the Clackamas River and flows between Shadowbrook Mobile Home Park and a neighborhood, and is the most impaired of the CCSD #1 monitoring reaches from a geomorphic perspective. The channel is severely incised with steep banks more than 10 feet high, and exposed bedrock over most of the channel. The banks are actively eroding; all the cross sections have widened since the initiation of the geomorphic monitoring program, and this trend continued in the 2017 data set (Figure A33). The top of bank contains a narrow vegetative buffer dominated by invasive Himalayan blackberry which is directly adjacent to the mobile home park on the right and to housing on the right bank. These changes may be due to drainage reconfiguration upstream, which may have introduced more stormflow into the reach than naturally occurred; straightening of the stream may also have played a role in the incision. Given the proximity to infrastructure, stabilizing banks at this site may be considered high priority: if the channel continues to widen and erode, it could threaten the adjacent

properties. In addition, the geomorphic impairment may also be an impairment to habitat, although the macroinvertebrate scores in this reach have not been particularly impaired relative to the other CCSD #1 sites. Although there is some infrastructure risk and clear geomorphic impairments, given the amount of aggradation that would need to occur to recover to a more natural morphology, combined with the narrow confinement from residential uses, trapping sediment and reversing incision in this reach may be impractical.

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APPENDIX A

Geomorphic Summary Figures

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APPENDIX B

Macroinvertebrate Summary Figures

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APPENDIX C

Completed Geomorphic Field Data Sheets

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APPENDIX D

PSI, Inc. Laboratory Report

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APPENDIX E

Response to Comments (RTC) Table