2012 In-Stream Temperature Monitoring Report

City of Corvallis
Public Works Department

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Created by Linsey Payne

Introduction

Purpose:

The 2012 In-Stream Temperature Monitoring (ISTM) project continues annual monitoring efforts begun in 2010. The ISTM project was initiated to collect baseline data on in-stream temperature influences that originate within the Corvallis City limits and flow out into the Willamette River. The 2012 data is intended to continue an ongoing data collection effort that can be used to inform future City of Corvallis water quality management decisions. This monitoring effort was conducted for educational purposes only and was not required by the Oregon Department of Environmental Quality (DEQ) or the United States Environmental Protection Agency (EPA).

Background:

According to the DEQ) Willamette Basin Rivers and Streams Assessment (*Mulvey, 2009*), warm water is the single most extensive water quality impairment in the Willamette Basin. Nearly 70% of the streams and rivers within the basin were found to consistently exceed the state temperature criteria for protecting sensitive cold water fish like salmon and trout during summer months. The Upper Willamette Basin, which includes Corvallis, had the second greatest extent of biological impairment and was ranked fourth worst for overall water quality in DEQ's basin assessment. Leading water quality stressors were excessively high water temperatures, low dissolved oxygen levels, and high total suspended solids.

Oregon Water Quality Temperature Standards are established to protect each freshwater phase of the salmon and trout lifecycle. Standards identify where and when each phase of the lifecycle occurs and includes numeric criteria necessary to protect it. Currently Oregon Water Quality Temperature Standards (*DEQ, 2010*) for fish use designations are as follows:

1) salmon /trout rearing and migration, 18.0°C
2) core cold water habitat identification, 16.0°C
3) salmon and steelhead spawning, 13.0°C

The water quality criterion that best applies to the Willamette River during the summer months is 18.0°C (*Ades, 2007*). This is the water quality standard used throughout this report to analyze the 2012 temperature monitoring data. However, in a July 2012 fish survey warmer water native species were found in Dunawi Creek, which indicates that for Dunawi Creek a different temperature standard may be appropriate.

The Oregon Department of Fish and Wildlife (ODFW) performed a fish survey on Dunawi Creek on 7/27 – 7/29/12. Along with nonnative fish, Oregon chub were discovered during the fish survey, which are Endangered Species Act (ESA) species listed as threatened and are found only in the Willamette basin. Spawning occurs from the end of April through early August when water temperatures are between 16.0°C and 28.0°C (*OFW, 2012*). Only males larger than 25 millimeters (1 inch) spawn and males more than 35 millimeters (1.4 inches) defend territories in or near vegetation (*OFW, 2012*). The Oregon chub caught were relatively large (range: 61 mm – 66 mm), which

means that all the fish were likely several years old. The lack of smaller fish indicates that the population is not be breeding at this site. Additionally, given the dominance of nonnative fish in the habitat, the Oregon Chub may not successfully colonize Dunawi Creek in the long run. ODFW has indicated an interest in continuing fish surveys of the habitat over the next couple of years to track the status of the population.

Although it is not currently required by state or federal regulations, the City of Corvallis initiated this in-stream temperature monitoring effort as an anticipatory measure to collect baseline temperature data which will serve to inform future water quality management decisions.

Methods

Previous Monitoring Efforts:

In compliance with federal Endangered Species Act (ESA) protection regulations, the City initiated the Salmon Response Plan (*Dillinger and Jones, 2004*) to identify citizen and city-sponsored activities that negatively impact Chinook salmon habitat in Corvallis, and to develop protocol aimed to prevent further degradation to salmon habitat and restore the health of impaired waters. As part of the ESA initiative, the City of Corvallis collected in-stream temperature data at 14 Corvallis stream sites in 2001, 2003, and 2004. The four streams that were targeted for in-stream temperature monitoring were Dixon, Dunawi, Oak and Sequoia.

The City of Corvallis also voluntarily collects monthly water quality data, including water temperatures, from six downstream sites, to aid in the detection of illicit discharges, and to protect public health and safety.

Project Oversight:

The 2012 In-stream Temperature Monitoring pilot project for the City of Corvallis was designed and implemented by Stormwater Program Intern Linsey Payne, under the guidance of Iris Benson, Public Works Stormwater Program Specialist. Refer to the 'In-stream Temperature Monitoring Protocol' (*Adams, 2010*) for a detailed explanation of the methods used to conduct this project, including data collection procedures and data analysis information.

Monitoring Sites:

Twelve sites were selected for the 2012 monitoring season, closely mirroring the sites previously monitored as part of the City of Corvallis Salmon Response Plan (*Table 1).*

Table 1. 2012 In-Stream Temperature Monitoring Sites

Creek Testing Site	**Logger No.**	**Replacement Logger No./ Notes**
Dixon @ Waste Water Treatment Plant	01	None
Dixon @ Beca Avenue	02, missing on 09/28	18
Dixon @ 29th Street	03	None
Dixon @ Walnut Drive	04	None
Dunawi @ Brooklane Drive	06	None / dried up in July, data logger missing
Dunawi @ West Hills Drive	07	None / dried up in August
Dunawi @ Bruce Starker Arts Park	08	None
Dunawi @ 53rd Street	18	None / dried up in July
Oak @ 30th Street	12	None
Oak @ 53rd Street and Harrison Boulevard	13, missing on 08/31	07
Sequoia @ Sherwood Way	17	None
Sequoia @ Seavy Avenue	16	None

Data Collection:
Water temperature data was collected at 30-minute intervals from May 25 through October 26, 2012. Pre-deployment accuracy checks were performed in the Wastewater Reclamation Plant water quality laboratory on May 24, by Iris Benson. The data loggers were checked against a National Institute of Science and Technology (NIST)-calibrated thermometer.

Field audits were conducted approximately every 30 days. A NIST-calibrated field thermometer was used to ensure data accuracy. Additional information was also collected during field audits, including wetted width of stream, depth of stream, depth of data logger from water surface, and weather conditions. To prevent losing any data, the data was offloaded to a laptop during each field audit.

The data loggers were retrieved from the field on October 26. Some data loggers were retrieved early due to no-flow conditions and some data loggers were stolen or went missing and were then replaced as flow conditions required. Dunawi Creek at Brooklane Drive (Logger 06) went missing on July 27 and had no-flow conditions; Dunawi Creek at 53rd Street (Logger 18) was removed on July 27 due to no-flow conditions; Dunawi Creek at West Hills Drive (Logger 07) was removed on August 31 due to no-flow conditions; Oak Creek at 53rd Street and Harrison Boulevard (Logger 13) went missing on August 31, but was replaced by Logger 07; and Dixon Creek at Beca Avenue (Logger 02) went missing on September 28 and was replaced by Logger 18. Final accuracy checks were performed in the Public Works Department office on October 26, by Linsey Payne. This year the project manager opted not to place duplicate data loggers at any of the 12 sites. Therefore, the equipment was only tested for Level B accuracy, not for precision.

Level B data is approved by the DEQ for use in detecting water quality issues. Level A data is required for permitting and compliance purposes. Level B data is appropriate for this monitoring program, because the purpose of this program is to identify and research water quality issues only. **The City is not required to monitor or submit stormwater quality data for any permit or compliance purposes.** For more information on data precision and accuracy, refer to the 'In-Stream Temperature Monitoring Protocol' (*Adams 2010).*

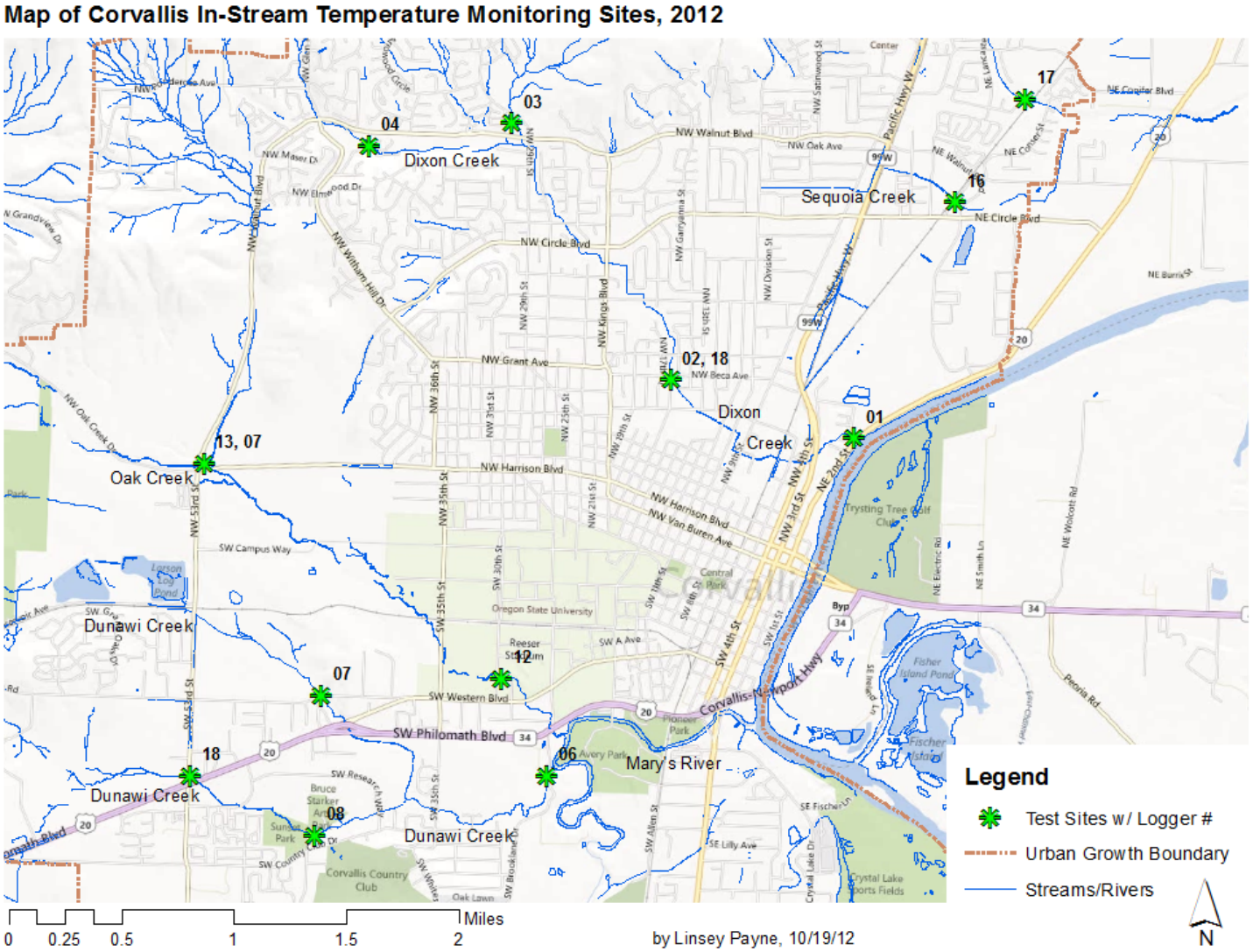

Figure 1. Map of Corvallis with 2012 In-Stream Temperature Monitoring Sites (for sites with two numbers, the first number is from the original data logger and the second number is from the replacement data logger).

Results

Data analysis began in October 2012. The data was organized consistent with data analysis methods conducted in the 2010 and 2011 In-Stream Temperature Monitoring Reports, in the Salmon Response Plan initiative, and according to DEQ's recommendations (*DEQ 1999*). The seven-day moving average of daily maximum temperatures were calculated and graphed for each site on each stream. The downstream-most sites for each creek were then graphed together.

Dixon Creek

There were a total of four monitoring sites on Dixon Creek; one off Walnut Place (Logger 04), one off 29th Street at Timberhill Park Apartments (Logger 03), one at Beca and 16th Street (Logger 02, replaced 9/28 by Logger18), and one located near the confluence with the Willamette River at Waterworks Ave and 2nd Street (Logger 01). *Figure 2* indicates that there is a strong correlation between water temperature and site location for Dixon Creek; sites in the upper region of the watershed had approximately 2˚C cooler temperatures than sites lower in the watershed from late May through to late August. The chart also shows that water temperatures on Dixon Creek began exceeding temperature criteria (18.0˚C) at the downstream-most sites (01 and 02) in early July and continued until late August. The most upstream site on Dixon Creek (04), located off Walnut Pl., only briefly exceeded 18.0˚C for about a week in mid-August. The second upstream-most site (02), located off Beca Street, also briefly exceeded the standard in mid-August, but only for a few days.

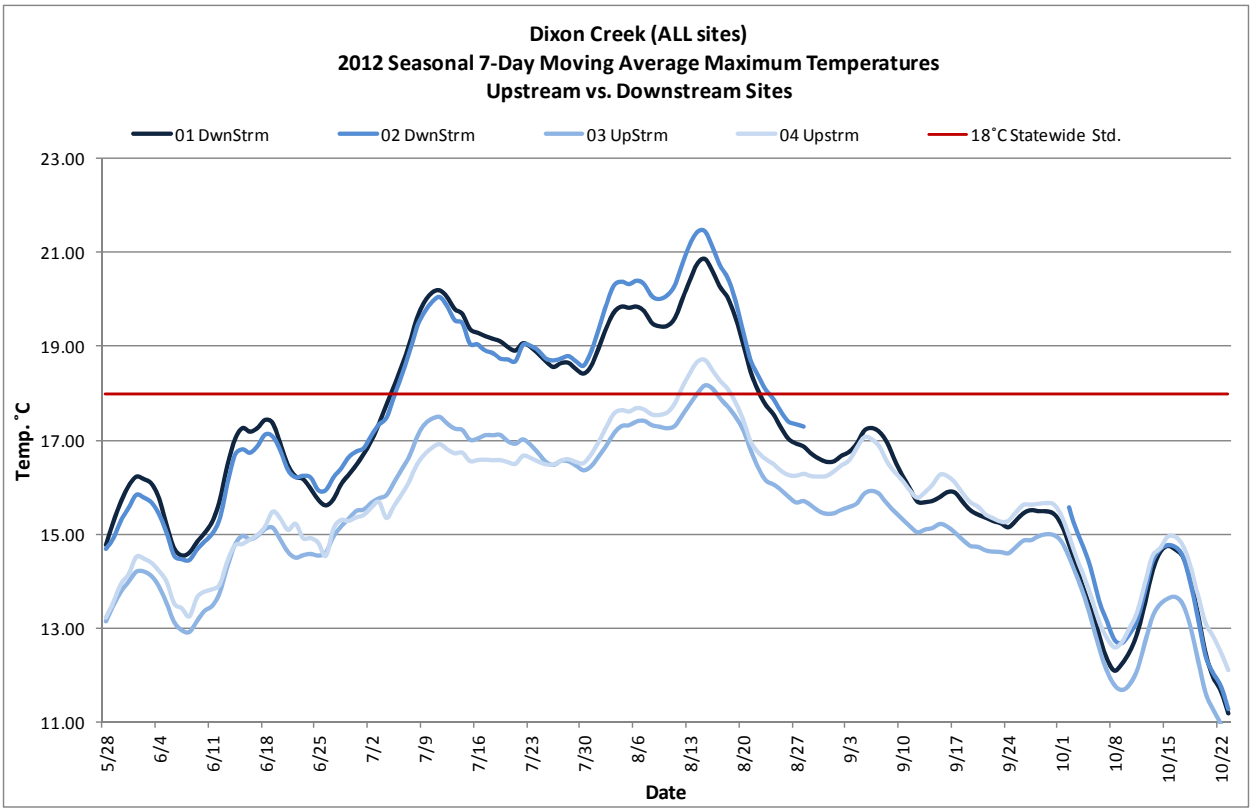

Figure 2. 2012 Seasonal 7-Day Moving Average Maximum Temperatures for Dixon Creek

Based on the raw temperature data, the absolute minimum temperature for Dixon Creek was 8.20˚C, recorded at one of the upstream-most sites (03) on October 25, and the absolute

maximum temperature for Dixon Creek was 22.56˚C, recorded at the second-most downstream site at Beca Street and 16th Ave (3) on August 16.

Dunawi Creek

There were a total of four monitoring sites on Dunawi Creek; Logger 18 on the South Fork off of 53rd Street, Logger 07 on the North Fork off of West Hills Road, Logger 08 on the South Fork near Starker Arts Park, and Logger 06 near the confluence with the Mary's River off of Brooklane Drive. The data from Dunawi Creek did not follow the expected temperature pattern of upstream sites being cooler than downstream sites. As shown in *Figure 3* temperatures on the southern-most fork at Starker Arts Park (08) exceeded the temperature criteria (18.0˚C) for the first 58 days of the monitoring period. In stark contrast to the steady increase in temperatures experienced by the other three locations, the temperatures at this location began to cool down in July before spiking again in August. Temperatures at the other three sites were comparable to one another for the first 30 days until no-flow conditions were experienced at Logger 06 and Logger 18 on July 27 and Logger 07 on August 11. Logger 07 began exceeding 18.0˚C in mid-July for about a week and then again beginning in late July until the creek went dry.

Beaver dams upstream from the West Hills Road (07) site and between the Starker Arts Park (08) and the Brooklane (06) sites may have contributed to the no flow conditions.

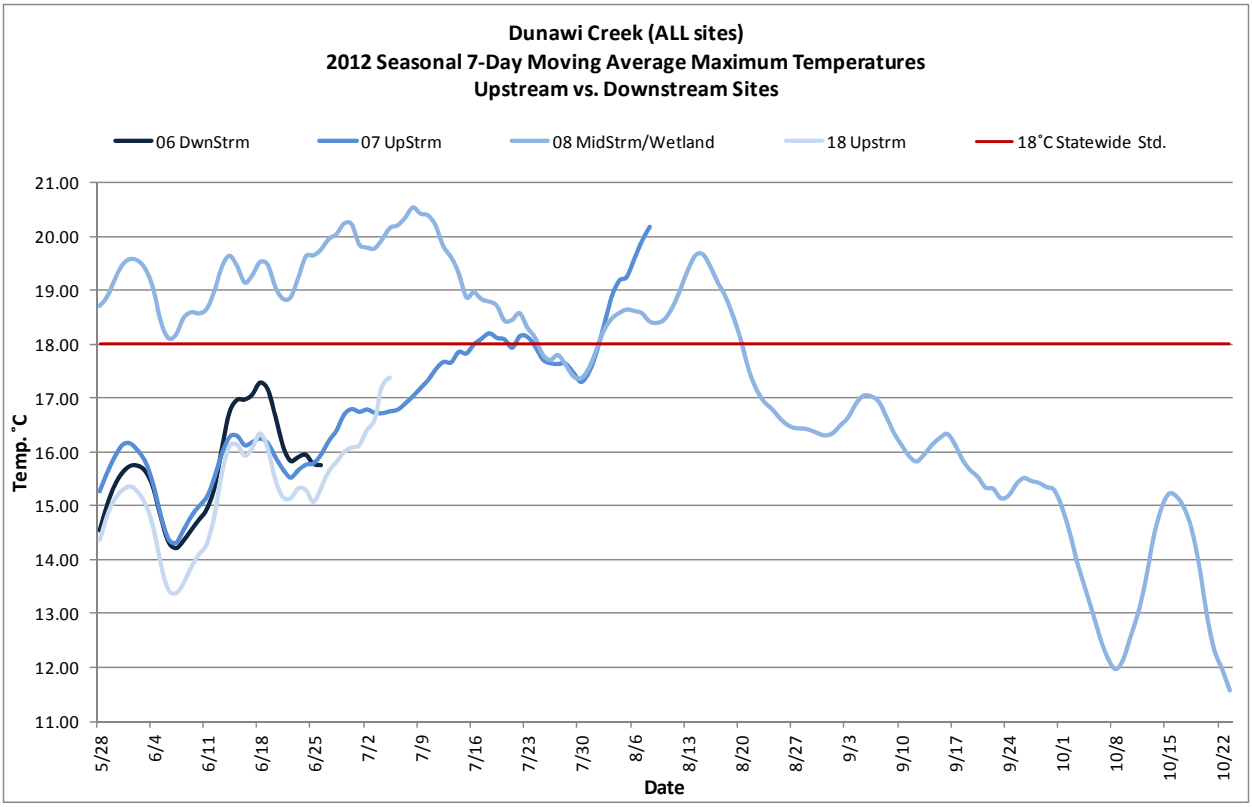

Figure 3. 2012 Seasonal 7-Day Moving Average Maximum Temperatures for Dunawi Creek

Based on the raw temperature data, the absolute minimum temperature for Dunawi Creek was 9.51˚C, recorded at Starker Arts Park (08) on October 25, and the absolute maximum

temperature for Dunawi Creek was 20.96˚C, recorded at the mid-stream site at Starker Arts Park (08) on July 8.

Oak Creek

There were a total of two monitoring sites on Oak Creek; Logger 12 at Western and 30th and Logger 13 at the site near Harrison and 53rd/Walnut Boulevard. The site in the upper region of the watershed was consistently cooler than the site in the lower region of the watershed. As *Figure 4* demonstrates, Oak Creek maintained relatively cool temperatures throughout the monitoring period, compared to the other three streams in this study. Water temperatures did, however, exceed state standards briefly in early July for a week and again for the majority of August at the downstream-most site (13). Logger 12, the upstream site, went missing, or was stolen, sometime during the month of August. A logger from a no-flow site (Logger 07) was used to replace Logger 12. Data for this upstream site was again available beginning in September.

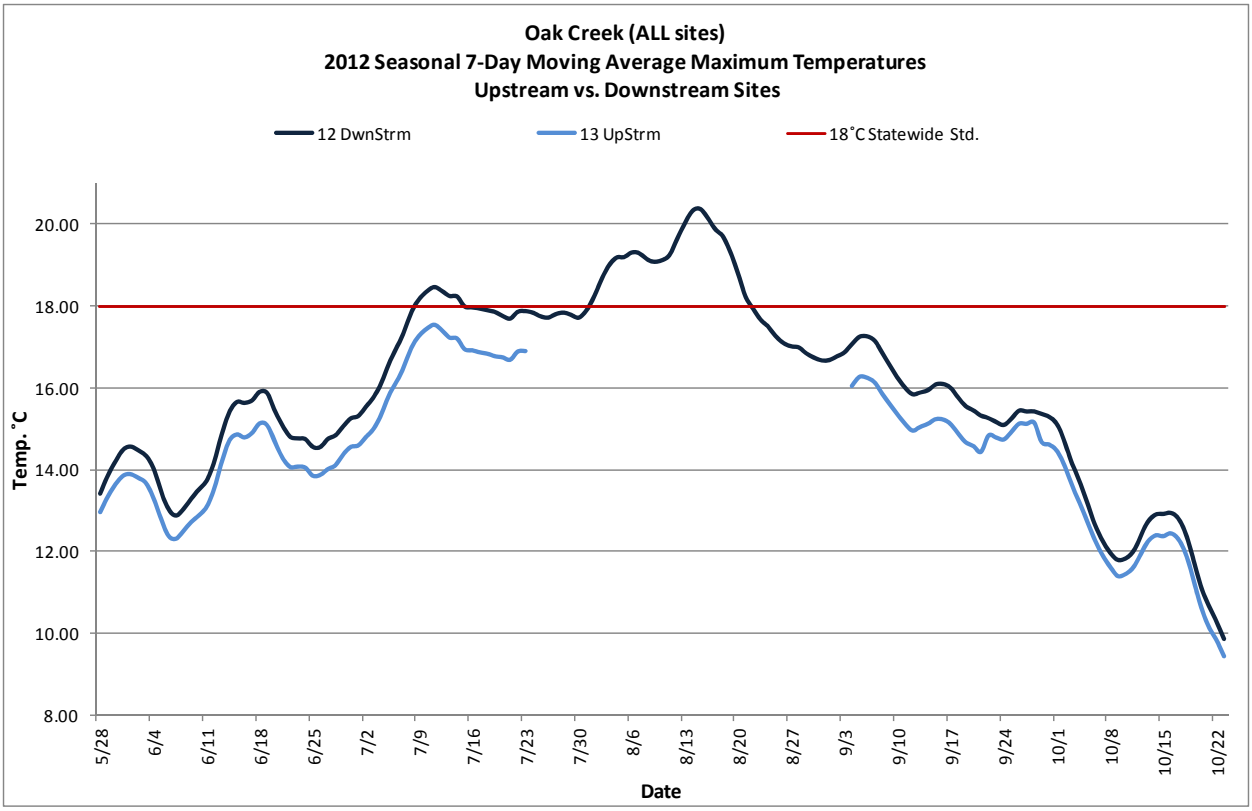

Figure 4. 2012 Seasonal 7-Day Moving Average Maximum Temperatures for Oak Creek

Based on the raw temperature data, the absolute minimum temperature for Oak Creek was 7.52˚C, recorded at the upstream site (13) on October 25, and the absolute maximum temperature for Oak Creek was 21.34˚C, recorded at the downstream site (12) on August 16.

Sequoia Creek

There were a total of two monitoring sites on Sequoia Creek; Logger 17 off of Sherwood Way and Logger 16 off of Seavy Avenue. The downstream-most site (16) started off in May with cooler temperatures than the site upstream (17), but by June 13 recorded temperatures warmer

than the site upstream. Temperatures at Sherwood Way (17) stayed relatively cool, only exceeding the temperature criteria (18.0˚C) in mid July for 13 days and again on August 3 through August 20. Temperatures at Seavy Avenue were consistently higher than the temperature criteria (18.0˚C) during the summer months. Beginning July 3 and continuing through September 9 (except for three days starting on September 1 where they were lower), temperatures at Seavy Avenue exceeded 18.0˚C.

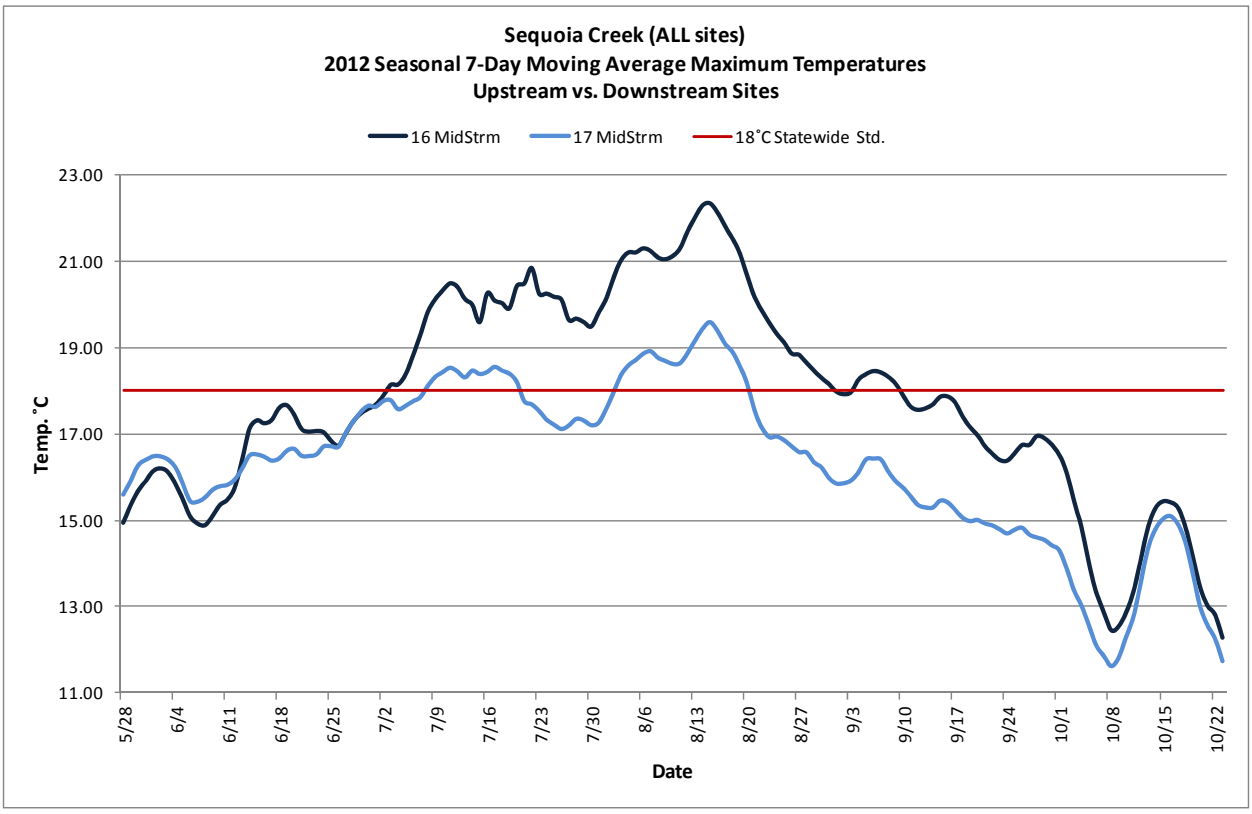

Figure 5. 2010 Seasonal 7-Day Moving Average Maximum Temperatures for Sequoia Creek

Based on the raw temperature data, the absolute minimum temperature for Sequoia Creek was 7.90˚C recorded at the Sherwood site (17) on October 8 and the absolute maximum temperature for Sequoia Creek was 22.94˚C, which was also recorded at the Seavy site (16) on August 16.

Basin Trends:

Figure 6 shows the 7-day moving maximum average temperatures at the downstream-most site for each creek. Dixon, Dunawi and Sequoia Creeks were the three warmest streams. Dunawi became a no-flow site at the end of June. Dixon and Dequoia were consistently above the state temperature standards (18.0˚C) for most of the summer. Temperatures from Oak Creek were consistently cooler than the other three streams for most of the monitoring period, but also exceeded the standard in early June and again for the majority of August. All four creeks generally mirrored the air temperature, shown in dashed purple, except during the hottest part of the summer where the difference between the creek temperatures and the air temperatures increased. For example, while air temperatures reached 34˚C at the peak of summer (August 16), even the warmest creek (Sequoia) only reached 22˚C, a difference of 12 degrees, while earlier in the spring air temperatures reached 25˚C and Sequoia reached 16˚C, a difference of 9 degrees. This shows that while air temperature does affect water temperatures, other factors must be taken into consideration as well. The air temperature data was retrieved from the Oregon State University Hyslop Weather Station website[1], which provided ground level maximum temperatures as a general air temperature reference for the region.

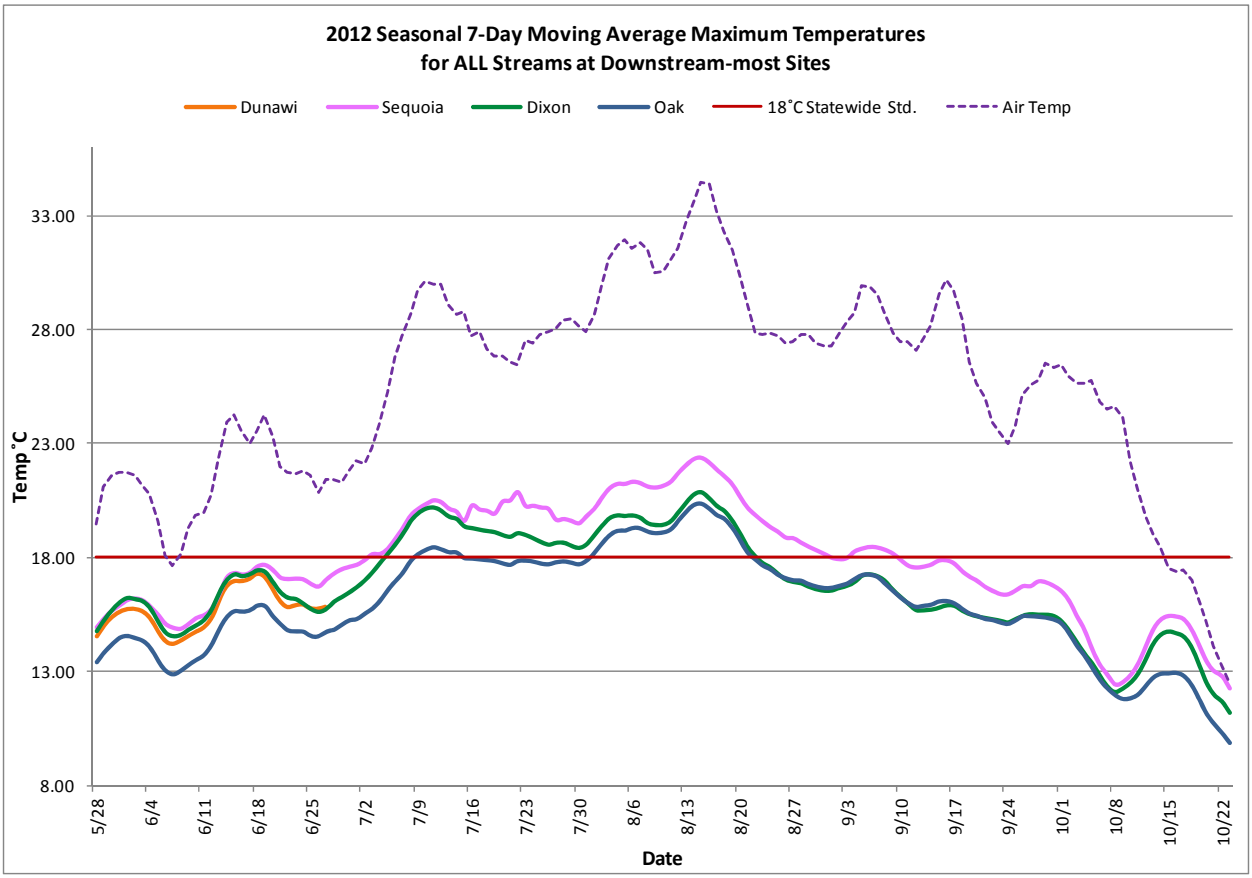

Figure 6. 2012 Seasonal 7-Day Moving Average Maximum Temperatures at the downstream-most site of each stream including air temperature maximums.

[1] Corvallis Farm Unit, Oregon State University College of Agricultural Sciences, retrieved on November 2, 2012: http://agsci.oregonstate.edu/farmunit/weather/archive/month

Using the temperature monitoring period from May 25 to October 26, or 155 days, *Table 2* below illustrates that all four creeks exceeded the statewide standard for fish rearing and migration (18.0˚C) at all but three sites at some time during the 2012 monitoring season. The monitoring period was based on the number of days of data used to calculate the 7-day moving average maximum temperatures, while the percentage of exceedances was calculated based on the 7-day moving average maximum temperatures. Two of the three sites that did not exceed the temperature standard (Loggers 06 and 18) were on Dunawi Creek and dried up early in the summer. The logger at the remaining site sites that did not exceed the temperature standard on Oak Creek (Logger 13) went missing or was stolen during the month of August, the hottest month of the summer, and was then replaced by Logger 07. It is unknown whether the temperatures at the Logger 13 site would have remained below the temperature standard during the month of August. The downstream-most site on Sequoia (16) exceeded the standard 43% of the monitoring period and the wetland-influenced area of Dunawi (08) exceeded the standard 50% of the monitoring period. These two sites exceeded the temperature standard the longest portion of the monitoring period compared to all other sites in this study. The downstream-most site on Oak Creek (12) exceeded the standard for 17% of the monitoring period. The two most downstream sites on Dixon, Loggers 01 and 02, exceeded the standard for 31% and 39% of the monitoring period respectively.

Table 2. Percent of monitoring period that temperatures exceeded state water quality criteria

Stream	Site / Logger ID	# of days monitored	# of days temp. >18.0 (C)	% Exceedances temp. >18.0 (C)
Dixon	01	155	49	31
	02*, 18	127	49	39
	03	155	2	1
	04	155	7	4
Dunawi	06*	36	0	0
	07*	79	15	19
	08	155	77	50
	18*	45	0	0
Oak	12	155	27	17
	13*, 07	119	0	0
Sequoia	16	155	66	43
	17	155	31	20

**indicates creek dried up or logger lost/stolen resulting in fewer monitoring days*

The upstream-most sites on Dixon (03 and 04) Creek exceeded the temperature standard 1% and 4%, respectively, of the time, and the upstream-most site on Sequoia (17) exceeded the standard 20% of the time. The upstream site on Dunawi Creek at West Hills Road (07) exceeded the temperature standard 19% of the time, before the creek dried up.

Comparing Previous Trends:

This section compares the percent of days exceeding the state temperature standards (18.0˚C) for monitoring years 2010, 2011, and 2012. The monitoring periods for each monitoring year has varied slightly: May 15 to September 22 for 2010, May 1 to October 31 for 2011, and May 25 to

October 26 for 2012. Therefore, in order to calculate the percentages using the same monitoring period, a period of 121 days was chosen using the dates of May 25 to September 22, which also coincides with the hottest air temperatures during the summer. The logger IDs have also been adjusted for each monitoring year as shown below in *Table 3* below.

Table 3. Percent of monitoring period that temperatures exceeded state water quality criteria

	Site / Logger ID			**Percent (%) of Days Exceeding >18.0 (C)**			**Average Change in Percent (%) Days of Exceeding >18.0 (C)**
Stream	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**	
Dixon	04/05	04/05	01	48	48	31	11.3
	03	03	02	41	48	39^	6.0
	02	02	03	23	21	1	14.7
	01	01	04	2	8	4	4.0
Dunawi	07	07	06	44	38*	0*	6.0
	08	08	07	15*	37*	19*	14.7
	06	06	08	45	16	50	22.7
			18			0*	N/A
Oak	13	13	12	25	18	17	5.3
	11/12	11/12	13	6	5	0^	4.0
	10			0			N/A
	09			2*			N/A
Sequoia	14	14		7*	10		N/A
	15/16	15/16	16	48	55	43	8.0
			17			20	N/A

**indicates creek dried up resulting in fewer monitoring days*
^indicates logger lost/stolen resulting in fewer monitoring days

Table 3 provides a quick comparison of the percentage of days exceeding the state temperature standard for monitoring years 2010, 2011, and 2012. The average change in percentage ranges from 4.0 to 22.7 percent. There are some sites that appear to be increasing their percentage of days exceeding the standard, while others appear to be decreasing. Additionally, not all sites show a linear progression one way or the other. At this stage in the monitoring progress, there are not enough years of data to determine distinct progressions. For example, the Dixon Creek site at Brooktree Apartments at 29th Street (Loggers 02, 02, and 03) exceeded the temperature standard 23% of the time in 2010, 21% in 2011, and 1% in 2012. This is in contrast to sites such as Dixon Creek at Walnut Drive (Loggers 01, 01, and 04), where the percentage of exceeded temperature standard started at 2% in 2010, increased to 8% in 2011, and then decreased to 4% in 2012. Other complications include missing data loggers and no-flow conditions, which impact the percentage of days exceeding the temperature standard.

Discussion

Summary:

By plotting the data from all of the downstream-most sites (*Figure 6*), we see that the temperature fluctuations at each of the downstream-most sites generally follow the same pattern. The one exception, Logger 06 at Brooklane Drive experienced no-flow conditions early in the monitoring season. *Figure 6* also shows that the Sequoia site has the highest temperature by several degrees compared to the other two. However, in contrast to the other two creeks, the Sequoia Creek flows into the Stewart Slough, which then flows into an oxbow before entering into the Willamette River, which may give it additional time to cool down. Another site could be added along this creek closer to its connection to the Willamette River, possibly behind the Farm Home School along Highway 20.

Figures 2 through 5 show us that, in general, as we travel from the upper part of each stream to the lower part of each stream, water temperatures steadily increase. We can infer from these results that the water temperature fluctuations throughout the watershed are influenced by changes in ambient air temperatures. The one exception, Logger 08 at Starker Arts Park is influenced by a shallow wetland, which resulted in higher temperatures during the beginning of the monitoring period. As shown in *Figure 6*, as air temperatures increase in the summer months, water temperature also increases. Air temperature data used in this monitoring study was taken from the Oregon State University Hyslop Weather Station to provide a general picture of ground level air temperatures for the Corvallis area. In future monitoring years, it may be useful to record air temperature in addition to water temperature at each site, so that this relationship could be examined more closely. This additional monitoring may help us understand how the level of canopy cover at each site impacts the water temperature.

The land use patterns impacting each creek range from significant amounts of open space and little impervious surface to heavy urban, commercial, and industrial development with a majority of impervious surface. Oak Creek appears to be the least impacted by urban development according to aerial photographs and City of Corvallis GIS data. Dunawi Creek is also minimally impacted by urban development with a large portion of the creek designated as wetland and riparian areas by the National Wetland Inventory. For Dixon Creek, the majority of the stream runs through developed single family residential neighborhoods and into the commercial and industrial areas of north Corvallis with extensive impervious surfaces. The southern branch of Sequoia Creek is similarly situated with the creek first daylighting at the intersection of Highland Drive and Sequoia Avenue, a single and multi-family residential neighborhood, and then running through commercial and industrial developments before connecting up with the northern branch of Sequoia Creek and flowing into Stewart Slough. The northern branch of Sequoia Creek is fed by the Jackson-Frazier Wetland and runs through a single and multi-family residential neighborhood before joining the southern branch of Sequoia Creek at Stewart Slough.

Based on the land uses around each creek, it would be assumed that Dixon Creek and Sequoia Creek would have the highest water temperatures at their downstream-most sites. As shown in *Table 6*, the monitoring data confirms that the water temperatures in these two creeks were higher than Oak Creek. However, due to the no-flow conditions at the downstream-most site on Dunawi and the high temperatures experienced at the Starker Arts Park site for the majority of

the first half of the summer, it is unclear whether or not the downstream-most sites on Dixon and Sequoia Creeks would have had higher temperatures than Dunawi's downstream-most site.

Dunawi Creek presented some interesting results, which were not typical of the other three creeks in this study. A midstream site, and the only site that retained water all summer long, was located at Starker Arts Park (06) which exhibited warmer temperatures than the other three sites and was above the temperature standard for the first 61 days of the monitoring season according to the seven day moving average. This may have been due to land uses in that area, as there is a man-made wetland just upstream of this site. This area was flooded during the early spring and was marsh-like into early July. There were also multiple beaver dams between Logger 06 at Starker Arts Park and Logger 18 at 53rd Street. It is unclear what type of influence the beaver dams may have had on creek temperatures, if any. Dunawi Creek is also intriguing due to the extensive number of natural wetlands that exist along the upper branches of the creek and the relatively rural land use pattern surrounding the creek. These combinations of land uses and natural filtration would imply a healthier stream channel, but the no-flow conditions at three of the four sites and the high temperatures at Starker Arts Park suggest otherwise.

Sequoia Creek was the warmest of the four creeks studied in this monitoring program and for the past two monitoring seasons. The southern branch of the creek (Logger 16) reached temperatures of over 21˚C, several degrees over the temperature standard, for two weeks in August. Only one other site, Logger 02 on Dixon Creek, reached above 21˚C and only for a few days. Additionally, when viewing the raw hourly temperature data for Logger 16, the daily highs and lows were inconsistent, occurring at odd times of the day. For example, a peak would occur at 2 am or 10 am instead of the more typical 6 pm or 8 pm. This inconsistency indicated possible illicit discharges. However, the inconsistencies were random and did not lend to an obvious and continued illicit discharge source, if there was one. In contrast, the northern branch of Sequoia Creek (Logger 17) experienced cooler temperatures similar to the downstream-most site on Oak Creek, which was the coolest overall of the four creeks monitored. However, at this Logger 17 site the creek appeared silty, often with a scum layer on the water's surface. Runoff from the neighboring park, streets, and residences could be contributing to higher nutrient levels and pollutants. The canopy cover at this location provided excellent shade, but the banks of the creek were typically steep with stormwater pipes directing runoff directly from the streets into the creek.

Observations made during field visits to each creek revealed other indications of water quality impairment in addition to temperature exceedances, including trash, excessive sedimentation, algal growth, invasive species, and surface films from possible contaminants. For site-specific information gathered during monthly field audits, see system folder L:\PW\Divisions\Utilities\Storm Water\Program_Specialist_Files\LINSEY\In-Stream Temp Mont 2012\Hobo Data 2012\Field_Audit_form2012.xls

Recommendations:
There are several ways the City of Corvallis could begin to address the issues of warm water temperatures and non-point source pollution. These include increased stream bank vegetation, increased rock and gravel in the stream beds to reduce incising and sedimentation, and increased riparian buffers to protect the creeks from the negative impacts of land development. These

efforts should be focused on Dixon, Dunawi, and Sequoia Creeks, because of their high percentage of days exceeding the state temperature standard. The development of spawning habitat should be focused on Dunawi Creek in particular, because of the evidence of Oregon chub found by ODFW this summer and the multiple no-flow conditions at three of the four monitoring sites. A land use impact study should be performed along the southern branch of Sequoia Creek, because of the extremely high temperatures experienced at Logger16 and the inconsistent daily highs and lows. The following questions need to be answered for this section of the creek: Where is the source of this branch of Sequoia Creek? What are the specific businesses and land uses adjacent to the creek? Are illicit discharges occurring along this stretch of the creek? How can negative influences be mitigated?

However, while Dixon, Dunawi, and Sequoia Creek need the most help, Oak Creek should not be overlooked. While it is the healthiest of the four creeks monitored, it also exceeded the temperature standard during the monitoring season. Being the one creek least impacted by land development and having the lowest temperatures, it may make sense to focus the City's limited funding and manpower on keeping the temperatures in this creek below the temperature standard. In a literature review performed by Katie O'Connor in September 2010 on citizen involvement in environmental protection, one of the important factors for continued involvement is "to have a limited scope of activities (*Leach 2001*) and to address issues that have a clear solution (*Stedman 2009*)." Oak Creek provides an excellent opportunity for citizens and particularly the Stream Stewards Program to get involved in restoration and cleanup projects with a clear goal and easily quantifiable results. "If citizens feel that the work they are doing is solving a specific problem in their neighborhood, and they see results from their labor, they are more likely to continue to be involved" (*O'Connor 2010*).

According to DEQ, canopy cover is the single most important factor affecting water temperature that human activities in a watershed contribute to (*Mulvey 2009*). The removal of riparian shading from stream banks results in increased water temperatures due to radiant solar energy. Sedimentation magnifies the effect of solar radiant heating as soil particles absorb more solar energy than water molecules do. Urban streams typically have inadequate riparian buffers due to land development. Rehabilitating riparian areas to restore more natural conditions would help keep water temperatures within the optimal range for fish rearing and migration by providing shade, habitat, decreasing sedimentation to streams and retaining potentially warm run-off waters.

The data collected during the 2012 monitoring season confirms that Corvallis streams are contributing temperature pollution to the Willamette River through non-point source influences. Continued data collection will be needed to assess temperature patterns and influences of these streams over the long term. Reducing erosion and sedimentation into streams and increasing stream shading by planting native trees, shrubs and other ground cover along stream banks is almost certainly the most practical and effective means of reducing water temperatures in these urban streams. Adding logs and rock weirs to the streams may also assist in building up gravel in the stream beds by preventing it from washing downstream. The Coast Fork Willamette Watershed Council has had positive results from adding these types of barriers to Mosby Creek and other streams.

References

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