# Appendix K:
# Detailed Results of Continuous Turbidity and Temperature Monitoring

# APPENDIX K – DETAILED RESULTS OF CONTINUOUS TURBIDITY AND TEMPERATURE MONITORING

To address Goals 3 and 4 related to improved effectiveness of the entire South 356$^{th}$ Street Regional Detention Facility (RDF), following the retrofit and expansion, the study compared pre- and post-retrofit turbidity and temperature data. Turbidity and temperature were measured continuously at the wetland complex inlet (WCI) and discharge point to the creek (DPC) downstream of the RDF for several years before the retrofit and expansion was complete, and for one year following the expansion (Tables 1 and 2). In addition, pre- and post-retrofit temperature data from the inlet and the North Fork of West Hylebos Creek at S. 359$^{th}$ Street were compared to assess whether any rise in temperature associated with the expanded RDF resulted in a temperature increase in the receiving waters.

**Table 1. Summary of continuous turbidity measurements recorded at inlet (IN) and outlet (OUT) of S. 356$^{th}$ St. RDF, pre- and post-retrofit.**

| Continuous Turbidity Measured at RDF Inlet and Outlet | | Pre-Retrofit | Post-Retrofit |
|---|---|---|---|
| Date Range (excluding all data from Jul, Aug and Sep) | | 5/11/2011 - 3/11/2014 | 5/1/2016 - 4/30/2017 |
| IN (at WCI) | Mean Daily Average Turbidity (NTU) | 5.38 | 4.13 |
| | Standard Deviation of Average Turbidity | 5.96 | 4.17 |
| | Number of days included in analysis of average values | 572 | 272 |
| | Mean Daily Max Turbidity (NTU) | 30.38 | 24.74 |
| | Standard Deviation of Max Turbidity | 41.17 | 45.18 |
| | Number of days included in analysis of max values | 616 | 273 |
| | Percent of days max turbidity exceeded 10 NTU | 52% | 49% |
| OUT (at DPC) | Mean Daily Average Turbidity (NTU) | 3.05 | 2.21 |
| | Standard Deviation of Average Turbidity | 2.94 | 2.62 |
| | Number of days included in analysis of average values | 572 | 272 |
| | Mean Daily Max Turbidity (NTU) | 6.52 | 5.33 |
| | Standard Deviation of Max Turbidity | 7.45 | 6.20 |
| | Number of days included in analysis of max values | 616 | 273 |
| | Percent of days max turbidity exceeded 10 NTU | 18% | 15% |

**Table 2. Summary of continuous temperature monitoring at inlet (IN) and outlet (OUT) of the S. 356th St. RDF, and in the North Fork of West Hylebos Creek at S. 359th St. (Creek).**

| Continuous Temperature Measured at RDF Inlet and Outlet, and in North Fork of West Hylebos Creek | | Pre-Retrofit | Post-Retrofit |
|---|---|---|---|
| Date Range | | 5/12/2011 - 3/11/2014 | 4/19/2016 - 8/16/2017 |
| IN (at WCI) | Mean Daily Average Temperature (°C) | 11.04 | 12.14 |
| | Standard Deviation of Average Temperature | 3.44 | 3.93 |
| | Number of days included in analysis of average values | 836 | 429 |
| | Mean Daily Max Temperature (°C) | 11.50 | 12.62 |
| | Standard Deviation of Max Temperature | 3.42 | 3.95 |
| | Number of days included in analysis of max values | 836 | 429 |
| | Proportion of days max temp exceeded 17.5 °C | 4% | 11% |
| OUT (at DPC) | Mean Daily Average Temperature (°C) | 10.73 | 13.03 |
| | Standard Deviation of Average Temperature | 4.64 | 5.45 |
| | Number of days included in analysis of average values | 836 | 429 |
| | Mean Daily Max Temperature (°C) | 11.33 | 13.74 |
| | Standard Deviation of Max Temperature | 4.72 | 5.62 |
| | Number of days included in analysis of max values | 836 | 429 |
| | Proportion of days max temp exceeded 17.5 °C | 8% | 29% |
| Creek (at NFWHC) | Mean Daily Average Temperature (°C) | 10.02 | 10.74 |
| | Standard Deviation of Average Temperature | 2.98 | 3.10 |
| | Number of days included in analysis of average values | 836 | 429 |
| | Mean Daily Max Temperature (°C) | 10.55 | 11.37 |
| | Standard Deviation of Max Temperature | 3.04 | 3.11 |
| | Number of days included in analysis of max values | 836 | 429 |
| | Proportion of days max temp exceeded 17.5 °C | 0% | 0% |

Turbidity levels were expected to decrease in the RDF outlet due to increased settling in the new CDSTW, as well as bioretention treatment of previously untreated runoff from a basin that drained through the outlet pipe. It was also anticipated that increased residence time of water in the RDF would not result in increased outlet and creek temperatures.

Washington State water quality standards (WQS) specify that turbidity in the West Hylebos Creek basin should not exceed 5 NTU above background (Ecology 2016); the City of Federal Way previously described this threshold as 10 NTU (Smith2006). Although the WQS apply to receiving waters, and not RDF inlets and outlets, this report includes the number of days maximum turbidity levels exceeded 10 NTU in the inlet and outlet because the threshold is environmentally relevant (Table 1).

The WQS standards indicate that the highest 7-day average daily maximum (7-DADMax) stream temperature cannot exceed 17.5°C (Ecology 2016). Due to several data gaps, and because the focus of this analysis was on more subtle temperature shifts, this report includes counts of single days exceeding 17.5°C, and not 7-DADMax (Table 2).

As detailed in the QAPP (2016), continuous turbidity and temperature data were collected with two YSI 6920 Multi-parameter sondes and YSI 6560 probes at the RDF inlet and outlet from October through June, from 2011 to 2014 (Tables 1 and 2). In addition, an Onset® Instruments TidBit temperature logger recorded downstream temperature in the creek (Tables 1 and 2). Following the retrofit, King County staff deployed the same YSI sondes and loggers at the same locations. Daily average and daily maximum values are included in this report.

Summary statistics are used to describe the monitoring results (Tables 1 and 2). In addition, linear regression analyses and model selection were used to assess what factors (location: inlet and outlet; time interval: pre- and post-retrofit; the interaction of location and time interval) best explained the daily average and daily max turbidity and temperature values. Analyses were done in R, version 3.4.3, and the stats package for analysis and ggplot2 for graphics.

The range of turbidity data used for this analysis was limited to values equal to or less than the highest inlet value observed in the post-retrofit interval. This was intended to limit the range of inlet values to those comparable pre- and post-retrofit. Turbidity data used for analysis of daily average turbidity was limited to dates with daily average values between 0 and 25 NTU, while analysis of daily max turbidity was limited to dates with values between 0 and 366 NTU. In addition, because pre-retrofit turbidity data were not available for most days during summer months (July, August and September), data analysis was limited to fall, winter and spring months.

**Turbidity results and discussion**

The differences between inlet and outlet turbidity pre- and post-retrofit indicate the RDF was more effective at reducing turbidity after the retrofit and expansion than before. Results of the linear regression analysis indicate the best models explaining daily average and maximum turbidity values included both location and time, as well as the interaction between location and time. Turbidity in the outlet was reduced significantly compared to inlet turbidity during both time intervals, but was lowest post-retrofit (Figures 1 and 2). The inlet turbidity was not statistically different pre- and post-retrofit (for daily average or daily max values), and yet outlet turbidity pre- and post-retrofit was significantly different. These results, and the significance of the interaction term, indicate that between pre- and post-retrofit, the effectiveness in controlling turbidity improved.

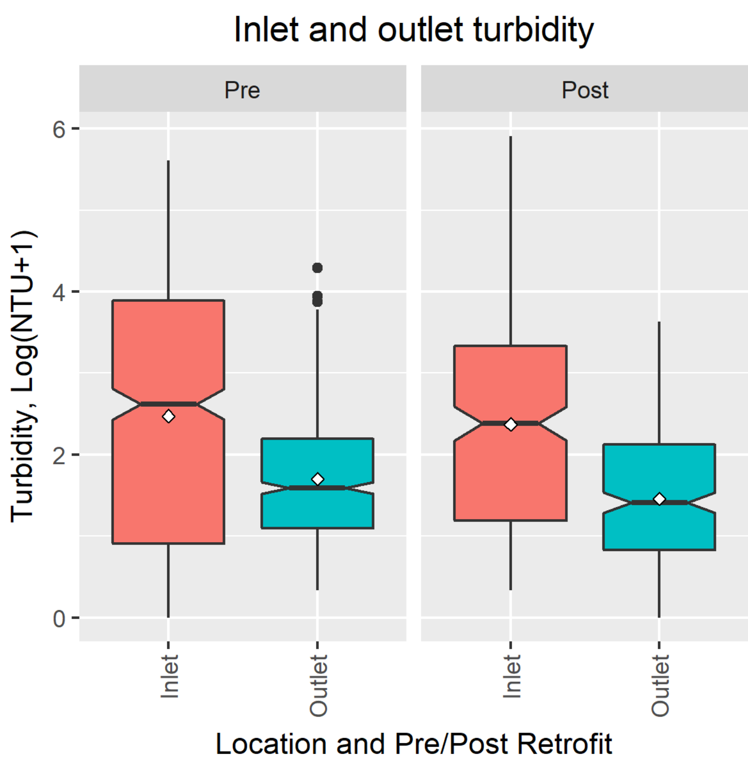


**Figure 1. Box plots of log-transformed daily maximum turbidity (NTU) at the RDF inlet and outlet, pre- and post-retrofit.**

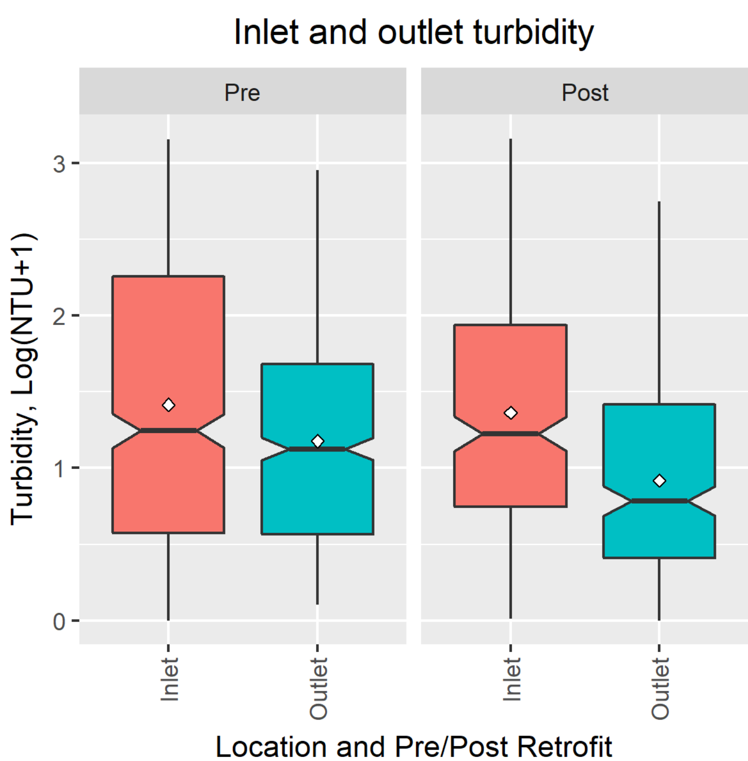


**Figure 2. Box plots of log transformed daily average turbidity (NTU) at the RDF inlet and outlet, pre- and post-retrofit.**

The linear regression analyses of the daily maximum and daily average turbidity (Figures 3 and 4) suggest a somewhat different interpretation of how effective the RDF is at reducing turbidity when inlet values are high. The significance of the interaction term, in the best models for both average and maximum turbidity, suggest the inlet vs outlet slopes change following the retrofit and expansion. Analysis of the daily maximum turbidity data suggests that when turbidity is low (~<10 NTU) the removal efficiency of RDF is similar for both pre- and post-retrofit conditions; however, removal effectiveness improves when inlet turbidity levels are higher (Figure 3).

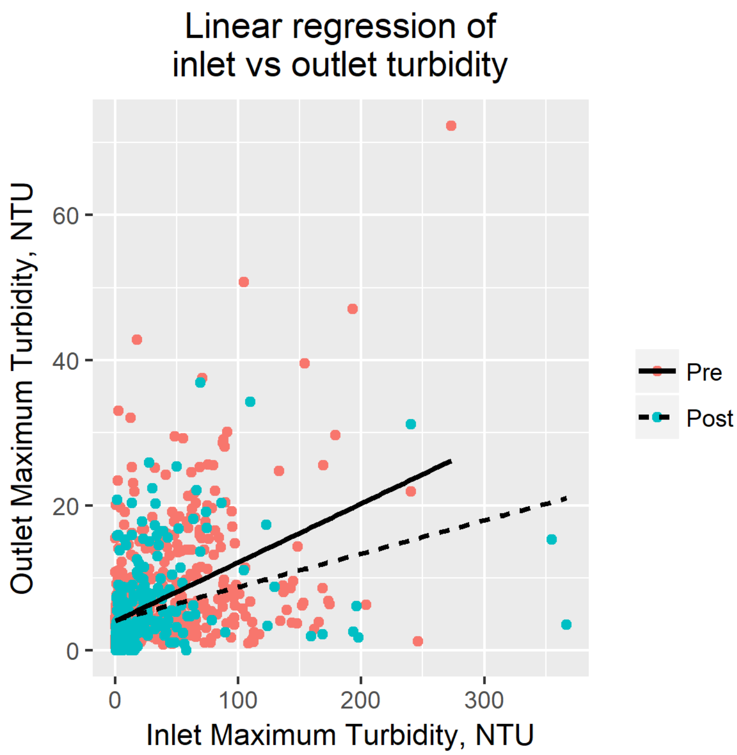


**Figure 3. Linear regression of daily maximum turbidity (NTU) in the RDF inlet vs outlet, pre- and post-retrofit.**

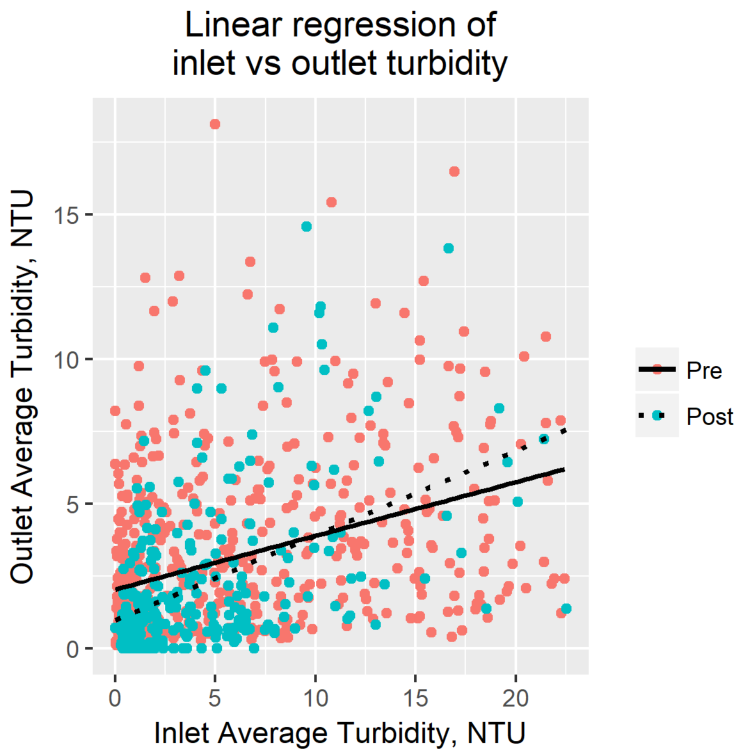


**Figure 4. Linear regression of daily average turbidity (NTU) in the RDF inlet vs outlet, pre- and post-retrofit.**

In contrast, the daily average turbidity data suggest a slightly different result. Analysis of the daily average turbidity data results in a cross of the pre-and post-retrofit lines, suggesting the greatest improvement is observed when inlet turbidity is less than 10 NTU; at higher concentrations the post-retrofit RDF is less effective (Figure 4). This result may be influenced by the shift in the distribution of inlet turbidity values post-retrofit. Additional monitoring would be helpful to determine how well the RDF reduces turbidity in the outlet when daily average inlet turbidity exceeds 10 NTU.

### Water temperature results and discussion

Water temperature in the inlet and outlet was similar during the years immediately preceding the RDF retrofit; however, during the following year post-retrofit, temperature was significantly warmer in the outlet than in the inlet (Figures 5 and 6). The best models describing the RDF average and maximum temperatures include location (inlet and outlet) and time interval (pre- and post-retrofit), but no interaction term. The data distribution (Figures 5 and 6) suggests temperature increased more in the RDF post-retrofit, but the lack of a significant interaction between time and location suggests warmer post-retrofit temperature was likely due to warmer inlet temperature (Figure 7). While this may be the case, the increase in number of days maximum temperature exceeded 17.5°C (the state standard for salmonid spawning, rearing and migration) in the outlet suggests there is increased warming within the RDF post-retrofit and it may be biologically significant (Figures 5-7; Table 2).

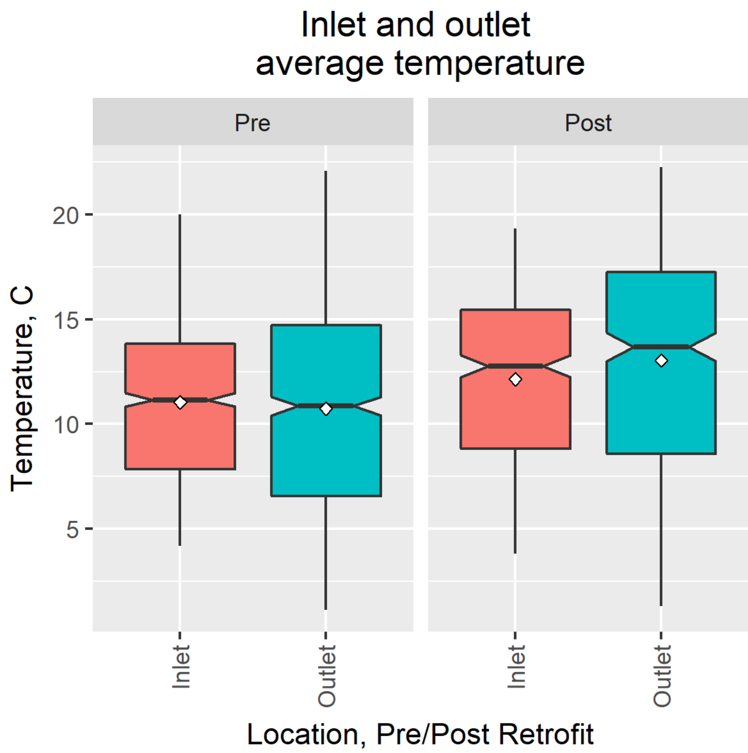


**Figure 5. Box plots of daily average temperatures at the RDF inlet and outlet, pre- and post-retrofit.**

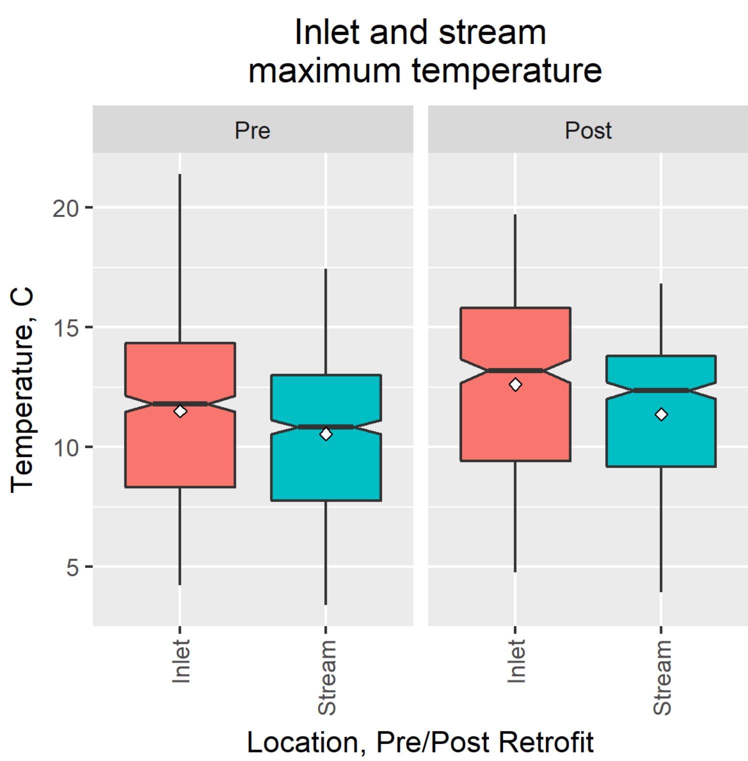


**Figure 6. Box plots of daily maximum temperatures at the RDF inlet and outlet, pre- and post-retrofit.**

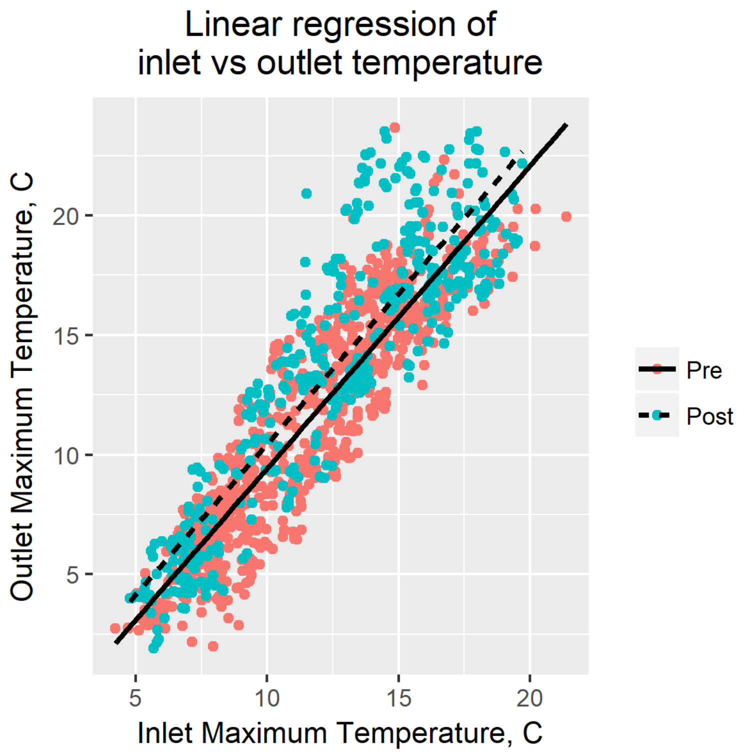


**Figure 7. Linear regression of daily maximum temperatures in S. 356th St. RDF inlet vs outlet, pre- and post-retrofit.**

During both pre- and post-retrofit periods, stream temperature downstream of the RDF was approximately 1°C cooler than inlet water temperatures (Table 2). Although inlet daily max temperatures occasionally exceeded 17.5°C, they never exceeded this threshold (Figure 8). This result is encouraging because it may suggest that cooling from groundwater and shading from riparian vegetation continue to at least partially ameliorate warming that occurs in the basin, and potentially in the RDF.

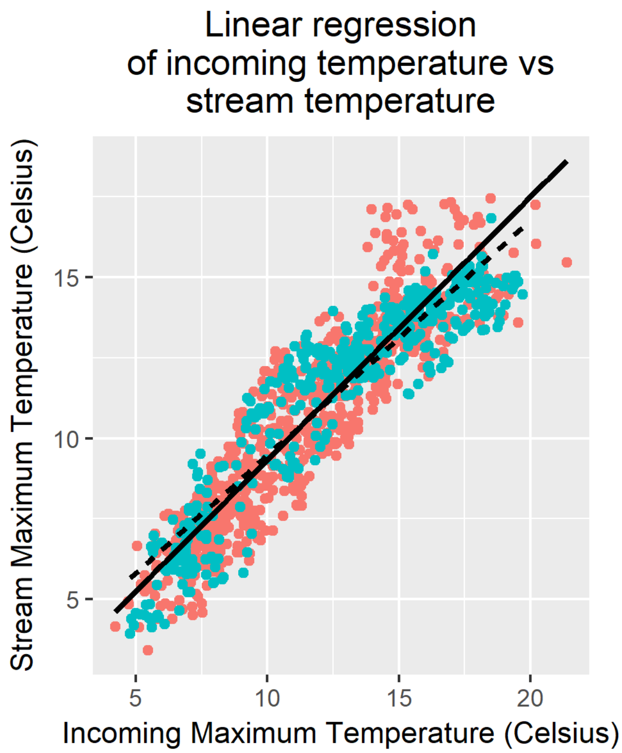


**Figure 8. Linear regression of daily maximum temperatures at the RDF inlet and at North Fork West Hylebos Creek at S. 359th St., pre- and post-retrofit.**

## References

Ecology. 2016. Water Quality Standards for Surface Waters of the State of Washington. Chapter 173-201A. Revised October 2017. Publication no. 06-10-091.

Smith, D. 2006. Stormwater Temperature Monitoring. Project description prepared for the City of Federal Way, WA. 16 pages.