Estimation of Effective Shade, Heat Load, and Stream Temperature Improvements Associated with Mature Revegetation in Newaukum and Soos Creeks

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Washington State Department of Ecology
National Estuary Program

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Department of Natural Resources and Parks

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Citation

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EXECUTIVE SUMMARY

Using funds provided by a National Estuary Program (NEP) Watershed Protection and Restoration Grant administered by the Washington State Department of Ecology (Ecology), King County carried out riparian revegetation along reaches of Newaukum and Soos creeks in 2012-2013. Newaukum Creek, and to a lesser degree Soos Creek, have extensive sections with little riparian vegetation and, as a result, little to no shade for moderating water temperatures along the watercourses. The extent and condition of riparian vegetation plays a critical role in the control of stream temperature, and revegetation of the riparian areas of stream reaches can eventually help reduce elevated summer water temperatures.

The objective of this study was to use the models developed for the Newaukum Creek and Soos Creek Total Maximum Daily Load (TMDL) studies to estimate thermal benefits resulting from the revegetation efforts conducted as part of this grant. The shade and water temperature models were used in sequence to evaluate effective shade, heat load, and maximum water temperature during critical summer conditions in Newaukum and Soos creeks.

Model results indicated increases in effective shade and reductions in the solar heat loads and maximum temperatures in both Newaukum and Soos creeks associated with riparian revegetation. When trees in the new buffers reach maturity, the modeled effective shade within the newly planted areas was predicted to increase by as much as 58 percentage points in Newaukum Creek while the maximum increase in Soos Creek was 18 percentage points. Heat loads were reduced in planted areas along Newaukum Creek by as much as 61 percent. Maximum heat load reduction in Soos Creek reached 23 percent. Modeled water temperature at the end of one project area was reduced by as much as 0.9 °C with an average reduction of 0.3 °C in the reach affected by revegetation of Newaukum Creek. The modeled temperature reductions in Soos Creek were more modest; the average reduction was 0.1 °C over the reach affected by revegetation. The diminished returns on Soos Creek were likely a function of the increased stream width and flow in Soos Creek.

Modeled temperature reductions were relatively small in both catchments. This was likely due to the limited area planted; approximately 1.1 and 1.2 percent of the riparian areas of the modeled reaches in Newaukum and Soos creeks were planted in 2012. A continued planting effort would achieve additional benefits as demonstrated by an Infill Planting scenario where all unvegetated riparian areas in Newaukum Creek were replaced with mature vegetation of similar character to the plantings funded by this grant. This model scenario resulted in an average temperature reduction of 2.5 °C in the reach affected by revegetation and an additional 6.0 km of Newaukum Creek meeting the Washington State temperature standard of 16.0 °C.

There was little change in the modeled effective shade, heat loads, and stream temperatures when vegetation heights were increased or decreased by 20 percent, suggesting that modeled water temperature is not sensitive to relatively small errors or uncertainty in mature vegetation canopy height. While significant uncertainty in absolute
temperature exists due to possible changes to other drivers of stream temperature (such as discharge, climate, and groundwater influence), the critical importance of shade from riparian vegetation in controlling stream temperature on small streams lends credence to this model’s utility as a tool for quantifying the thermal benefits of riparian revegetation.

The study showed that models developed for individual temperature TMDLs have additional utility beyond their initial use in TMDL development. Modeling scenarios can be run that show important localized temperature benefits to support fishery improvement. In addition, other scenarios can be run to examine how planting strategies can provide maximized benefit to fisheries through improved water quality. It is a recommendation of this study that comprehensive riparian restoration plans be developed for both Newaukum and Soos watersheds. Continued monitoring of riparian vegetation, effective shade through hemispherical photography, and water temperature is also recommended to track progress toward goals defined by TMDL allocations and evaluate model and riparian restoration effectiveness.
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1.0. INTRODUCTION

Using funds provided by a National Estuary Program (NEP) Watershed Protection and Restoration Grant administered by the Washington Department of Ecology (Ecology), King County carried out riparian revegetation along reaches of Newaukum and Soos creeks. The revegetation efforts in 2012-2013 were followed by maintenance, monitoring, and replanting where necessary of targeted areas through 2014.

Newaukum Creek, and to a lesser degree Soos Creek, have extensive sections with little riparian vegetation and, as a result, little to no shade for moderating water temperatures along the watercourses. Newaukum and Soos creeks were both identified as exceeding Washington State water temperature criteria and a Total Maximum Daily Load (TMDL) allocation was developed for Newaukum Creek (Lee et al. 2011). A shade and temperature modeling effort is currently underway for Soos Creek with the expectation that a TMDL will be developed (Tetra Tech 2012). Adding importance to these efforts is the presence of Endangered Species Act-listed Chinook and steelhead in both targeted reaches as well as the Green River, to which both streams drain.\(^1\) Water temperature is an important factor in the life cycle and development of salmonids and excess temperatures can result in stress and mortality (e.g., Li et al. 1994, USEPA 1999, USEPA 2001, Richter and Kolmes 2005).

Riparian vegetation is an important link between fluvial and terrestrial ecosystems for a number of important processes. Streamside trees and shrubs can help filter sediment and pollutants in overland runoff and provide terrestrial insects and nutrients for aquatic life. Riparian vegetation can also provide wood for instream habitat and channel formation and, when buffers are adequately wide, can provide a cool microclimate near the stream. Most pertinent to this study, the extent and condition of riparian vegetation plays an important role in the control of stream temperature (Rutherford et al. 2004, DeWalle 2010).

Riparian vegetation can reduce the amount of incoming solar radiation depending on factors such as time of day, stream aspect, stream width, and height and density of streamside vegetation in addition to local topography (Poole and Berman 2001, Cristea and Janish 2007). Solar radiation is the primary source of heat to the stream and plays a central role in the control of temperatures in small streams (Beschta 1997, Johnson 2004). Revegetation of the riparian zones of stream reaches can eventually help control excessive summer water temperature. The TMDLs developed by Ecology for Newaukum Creek specified that reductions in heat load would be achieved through the development and restoration of riparian shade and it is expected that the Soos Creek TMDL will target heat load reductions along the creek achieved through riparian revegetation (Tetra Tech 2012).

This report describes the application of the shade and Qual2kw models developed as part of the Newaukum Creek and Soos Creek TMDLs to estimate the potential reduction in heat load and temperature improvements resulting from revegetation efforts, such as those conducted as part of this grant. A requisite step in the application of these models is the

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\(^1\) A temperature TMDL allocation has also been developed for the Green River (Coffin et al. 2011).
estimation of average mature revegetation canopy height and density to serve as an input to the shade model. Estimates are necessary because the revegetation plantings will not have reached a mature state before the end of this study. The objective of the modeling work described in this report is to quantify the expected long term benefits of the plantings carried out under this grant in reducing heat load to stream channels and maximum water temperature through shading when the plants reach maturity.
2.0. STUDY AREA

The study area includes portions of Soos Creek and Newaukum Creek both subwatersheds of the Green River (Figure 1).

Figure 1. Map of the Green-Duwamish Basin.

Note: This map shows the major drainage basins of King County with the Green-Duwamish basin highlighted. Within the Green-Duwamish basin, the Newaukum and Soos Creek watersheds are highlighted.

2.1 Newaukum Creek

Newaukum Creek drains a 27.4 mi² (80.0 km²) area north of the city of Enumclaw and flows into the Green River at River Mile 40.7 (RKM 65.5). The Newaukum Creek watershed can be subdivided into three sub-basins: the steep, forested upper subbasin in the Cascade foothills (25 percent); the flat farmlands in the Enumclaw plateau (57 percent); and the steep, v-shaped ravine of the lower subbasin (18 percent) (King County 2000, Lee et al. 2011). While Newaukum Creek supports deciduous vegetation in riparian areas in the upper and lower sub-basins, the stream banks in the flat middle subbasin are heavily eroded and devoid of vegetation for substantial stretches (Lee et al. 2011).
All five North American salmon species (Chinook, sockeye, coho, chum, and pink) and steelhead and coastal cutthroat trout have been observed in the waters of Newaukum Creek. Under Washington State’s current water quality standards, Newaukum Creek is considered “core summer rearing habitat for salmonids” with a maximum seven-day average of the maximum temperature (7-DADMAX) of 16.0 °C (Ecology 2011). Additionally, a supplementary water temperature standard of 13.0 °C for spawning and incubation exists on Newaukum Creek from September 15 to July 1 (Ecology 2011).

Planting activity in Newaukum Creek occurred on a combination of public and privately owned property in the flat farmland in the middle subbasin. Over 9,000 plants were planted in 2012, mostly live-stake willow and cottonwoods, on five different properties over a cumulative stream length of approximately 2.2 km. For a complete listing of plant species selection at each of the five properties, please see Tables A-1 through A-5 in Appendix A. For a full description of the plantings that occurred in 2012, please see the report prepared by Sally Abella as part of this grant. The Newaukum Creek model domain extends from its confluence with the Green River to a point on the mainstem approximately 11.6 mi (18.6 km) upstream, near the upstream edge of the middle subbasin (see Figure 2).

Figure 2. Map of the Newaukum Creek Watershed.
Note: The modeled reach of Newaukum Creek is highlighted in red. A larger scale map of the planted areas is shown in the inset map.
2.2 Soos Creek

Soos Creek drains an area approximately 70.0 mi² (181.3 km²) south of Renton and east of Kent, entering the Green River at River Mile 33.7 (RKM 54.2). There are four main tributaries to the mainstem of Soos Creek: Jenkins Creek, Covington Creek, Little Soos Creek, and Soosette Creek. There are a number of large lakes in the Soos Creek watershed that have a total surface area of 1,370 acres. The subbasin has an extensive system of interacting lakes, wetlands, and infiltrating soils collectively capable of attenuating peak stream flows (King County 2000). The tributaries of Soos Creek drain from relatively flat terrain historically characterized by extensive wetlands and a water table that is close to the ground surface (Timm 2009). Land within in this subbasin was converted from old-growth forest to commercial timber production, then to agricultural uses, and has more recently transitioned to urban residential and commercial uses (King County 2000).

The Soos Creek watershed has historically been home to all five North American Pacific Salmon in addition to steelhead and coastal cutthroat trout (King County 2000). Under Washington State’s current water quality standards, Soos Creek is considered “core summer rearing habitat for salmonids” with a 7-DADMAX of 16.0 °C (Ecology 2011). Supplemental protections exist for portions of Big Soos, Jenkins, and Covington creeks that impose a 7-DADMAX of 13.0 °C from September 15 to July 1 (Ecology 2011).

Riparian planting in the Soos Creek watershed occurred on public land owned by King County and the Washington Department of Fish and Wildlife (WDFW) near its confluence with the Green River. The King County property is identified as Hatchery Natural Park, a former agricultural property acquired by the KC Department of Natural Resources that has been a focus for planting efforts in the past decade because it was largely devoid of tall shrubs and trees when purchased. Although planting projects were carried out previously, the presence of completely unshaded stream reaches, resident beavers, and a major infestation of reed canary grass necessitated continued work. In the fall of 2012, over 11,000 live stakes and 1,080 potted plants were planted at Hatchery Natural Park and the adjacent WDFW property near the Soos Creek State Fish Hatchery over approximately 0.5 km of stream reach. For a complete list of the number and species of plants installed, please see Tables A-6 and A-7 in Appendix A. The model domain of Soos Creek extends from its mouth to the headwaters of the mainstem of Soos Creek approximately 15.1 miles (24.3 km) upstream (see Figure 3).
Figure 3. Map of the Soos Creek Watershed.

Note: The modeled reach of Soos Creek is highlighted in red. A larger scale map of the planted areas is shown in the inset map.
3.0. METHODOLOGY

Two sequenced models were used to estimate the Newaukum and Soos creeks effective shade and solar heat loads and to project maximum water temperature during critical summer conditions. These models were developed as part of the temperature TMDLs for Newaukum Creek (Lee et al. 2011) and Soos Creek (in progress). Existing TMDL models were the most appropriate models to use in this study because they formed the basis of the heat load allocation established for each stream, and they provide the appropriate benchmark condition for progress in meeting the TMDL heat load allocations.

The two models worked in sequence. Shade.xls (version 3.1b02), an Excel/Visual Basic for Applications (VBA) program, utilized the geographic information developed in TTools as part of the Newaukum and Soos Creek TMDLs to estimate the effective shade along the stream for a specific day and year at a relatively fine longitudinal resolution. The shade model output averaged over the segment length for the entirety of the temperature model stream reach was then input to Qual2kw (version 5.1b52) (Pelletier et al 2006). Qual2kw was calibrated to continuous stream temperature data collected during critical summer conditions based on observed weather conditions and measured and estimated flow and temperature inputs. The shade and Qual2kw models were then used to evaluate temperature improvement based on the assumption of increased riparian cover by mature trees and System Potential shade.

Vegetation Heights and Model Scenarios

Stand height in the Mature Planting scenario was based on average values derived for revegetated areas taking into account a range of heights for each tree species at maturity, weighted by the relative abundance of each species planted in the replanted areas. Resources for determining tree heights included the National Resource Conservation Service (NRCS) PLANTS Database and height ranges reported in Pojar and McKinnon (1994). The weighted average heights for the planted areas in Newaukum and Soos creeks ranged from 9 to 30 m, with a median of 13 m. To see a full breakdown of the weighted average heights for each property, please see Tables A1-A7 in Appendix A.

It is difficult to estimate the number of years needed to reach mature tree height; species variability, soil conditions, localized light conditions, flooding, beaver damage, disease and parasites, and numerous other factors will affect the growth rate and potential height of the vegetation planted in 2012. Due to the presence of slow-growing, coniferous trees such as

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2 The Soos Creek draft TMDL shade and Qual2kw models were provided to King County by Ben Cope (Region 10 Environmental Protection Agency, Seattle, WA) in June 2014.
3 TTools was developed by the Oregon Department of Environmental Quality (ODEQ, 2009). A King County LiDAR Digital Ground Model was used to develop the inputs in the Newaukum and Soos Creek TMDLs; King County, 20030701, LiDAR Digital Ground Model (DGM) Elevation and Hillshade: King County, WA. Dates specified for models were 7/26/2006 and 8/9/2007 for Newaukum and Soos creeks, respectively. Points were located along the stream centerline every 20 m for Newaukum and Soos creeks.
4 Available from Ecology at www.ecy.wa.gov/programs/eap/models/
5 NRCS Plants Database can be found at http://plants.usda.gov/java/
western red cedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) in Newaukum and Soos plantings, it could take 50 years or more to reach the conditions represented in this model. However, cottonwood and willow live stake plantings (which were used extensively in the revegetation work on Newaukum and Soos creeks) grow at a faster rate and will therefore provide substantial shade benefit benefits well before conditions of the Mature Planting scenario are met.

Two additional model scenarios were run and are discussed in the section that follows (see Table 1). The Pre-planting and System Potential scenarios are reproductions of models developed for the Newaukum Creek and Soos Creek TMDLs. The Pre-planting model represents existing conditions and the System Potential model sets all riparian vegetation heights to 32 m (unless existing vegetation is taller). For additional details, please see the Newaukum Creek TMDL (Lee et al. 2011). The Mature Planting scenario simulated the riparian plantings installed in 2012 reaching maturity.

### Table 1. Vegetation Heights in Model Scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Vegetation heights*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-planting</td>
<td>Existing conditions</td>
<td>From LiDAR DGM</td>
</tr>
<tr>
<td>Mature planting</td>
<td>Areas planted in 2012 reach full maturity, all other riparian areas remain constant</td>
<td>Areas planted in 2012: values based on weighted average of species composition in planted area All other areas: LiDAR DGM</td>
</tr>
<tr>
<td>System potential</td>
<td>All riparian areas vegetated with mature coniferous trees</td>
<td>All areas: 32m</td>
</tr>
</tbody>
</table>

*To see a full breakdown of the weighted average heights for each property, please see Tables A1-A7 in Appendix A.
4.0. RESULTS

4.1 Newaukum Creek

The shade and TMDL Qual2kw models were used to project effective shade, solar heat load, and stream temperature under three different riparian scenarios for Newaukum and Soos Creeks. Modeled effective shade and heat load for Newaukum Creek are shown in Figures 4 and 5, respectively. The modeled 7-DADMAX water temperature in Newaukum Creek is shown in Figure 6.

Mature riparian revegetation was predicted to increase effective shade from 24 percent to 83 percent in the most densely planted area (see Figure 4). Within the planted reaches, the average effective shade increased by 25 percentage points. Meeting System Potential would require a 43 percentage point increase in effective shade throughout the entire length of the modeled reach. Effective shade in the System Potential tree height model averaged 92 percent, with values greater than 90 percent for a majority of the modeled reach.

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6 Planted reach refers exclusively to the reaches of stream where riparian planting occurred in 2012 (see inset map in Figure 2).
7 For Newaukum Creek, the modeled reach extends from where 284th Ave SE crosses the mainstem of Newaukum Creek downstream to the confluence with the Green River (see Figure 2).
Figure 4. Modeled Effective Shade in Newaukum Creek.

Note: The values in the figure above represent a running average of the effective shade in a 200 m reach. Green shading indicates the general reach in which planting project occurred. Anticipated shade at maturity by site is shown by the green dotted lines. All other riparian vegetation in the watershed is assumed to remain at current levels.

Modeled heat load was reduced in planted reaches along Newaukum Creek by as much as 61 percent in the most densely planted area (see Figure 5). The solar heat reduction in the length of the modeled reach averaged just 5 percent, well short of the 84 percent reduction needed to match the predictions of the System Potential tree height model.
The model predicted that the mature riparian plantings would reduce the 7-DADMAX temperatures in Newaukum Creek (see Figure 6). Within the affected reach, the average temperature reduction was 0.3 °C. The greatest temperature reduction of 0.9 °C occurred just downstream of the last planted area. Much of this reduction dissipated by the time the creek reached the confluence with the Green River as the modeled temperature reduction was just 0.1 °C at the creek mouth. In comparison, the System Potential tree height model in the original TMDL estimated an average reduction in maximum modeled temperature of 4.7 °C with temperature at the mouth of Newaukum Creek reduced by 3.5 °C. See Table 2 for a full summary of temperature reductions in Newaukum Creek.

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8 The affected reach refers to the reach of stream from the most upstream planting on Newaukum Creek downstream to the confluence of the Green River. The thermal benefits from riparian shade can extend downstream of planted areas (Rutherford 2004).
Effective shade, heat load, and stream temperature improvements associated with mature revegetation in Newaukum and Soos Creeks

Summary Metrics of Modeled 7-DADMAX Water Temperature in Newaukum Creek.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Maximum temperature (affected reach)*</th>
<th>Average temperature (affected reach)*</th>
<th>Maximum reduction (affected reach)*</th>
<th>Average reduction (affected reach)*</th>
<th>Temperature at outlet</th>
<th>Length in compliance**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-planting</td>
<td>20.9</td>
<td>19.7</td>
<td>--</td>
<td>--</td>
<td>20.9</td>
<td>2.85</td>
</tr>
<tr>
<td>Mature planting</td>
<td>20.8</td>
<td>19.5</td>
<td>0.9</td>
<td>0.3</td>
<td>20.8</td>
<td>2.85</td>
</tr>
<tr>
<td>System potential</td>
<td>17.3</td>
<td>15.0</td>
<td>6.2</td>
<td>4.7</td>
<td>17.3</td>
<td>14.25</td>
</tr>
</tbody>
</table>

* The impacted reach starts at the Hussein property (most upstream planting) and extends downstream to the outlet (approximately 14.25 km).
** Length of stream in compliance with the Washington State temperature standard of 16.0 °C.

4.2 Soos Creek

Modeled effective shade and heat load for Soos Creek are shown in Figures 7 and 8, respectively. The modeled 7-DADMAX water temperature in Soos Creek for the Pre-planting, Mature Planting, and System Potential is shown in Figure 9.

Effective shade in Soos Creek increased in the planted reach, though not as much as in Newaukum Creek. Effective shade increased from 33 percent to 51 percent in the most...
densely planted area, with a 7 percentage point average increase in the planted reach.³⁹ Achieving effective shade equivalent to the System Potential tree height model would require a 32 percent point increase in average effective shade throughout the length of the modeled reach.³⁴ Like Newaukum Creek, effective shade in the System Potential tree height model averaged over 90 percent, though it was generally higher in the upper reaches of the creek and was generally lower in the lowest 8 km of the creek above the mouth, the widest stretch of Soos Creek (see Figure 7).³¹

![Graph](image)

**Figure 7. Modeled Effective Shade in Soos Creek.**

*Note: The values in the figure above represent a running average of the effective shade in a 200 m reach. Green shading indicates the general reach in which planting project occurred. Anticipated shade at maturity by site is shown by the green dotted lines. All other riparian vegetation in the watershed is assumed to remain at current levels.*

³⁹ On Soos Creek, the planted reach refers exclusively to the reach of stream where riparian revegetation occurred in 2012 (see inset map in Figure 3).

³⁴ The modeled reach on Soos Creek extends from the headwaters of Big Soos Creek at 116th Ave SE downstream to the confluence with the Green River (see Figure 3).

³¹ As noted in Section 2.2, much of the headwaters of Soos Creek consist of an extensive network of wetlands. While tree heights of 32 m were used in the System Potential tree height model in the Soos Creek TMDL allocation (which was replicated here), it is unlikely that these vegetative conditions could actually be achieved.
Heat load into Soos Creek was reduced in the planted reach near the catchment outlet; in the most heavily planted areas, heat load was reduced by 23 percent with a 14.5 percent average heat load reduction of the entire planted reach (see Figure 8). The solar heat reduction in the length of the modeled reach averaged 1 percent, well short of the 85 percent reduction needed to reach the System Potential tree height model.

Riparian plantings also reduced maximum modeled temperature in Soos Creek, though the effect was much less pronounced in terms of thermal reductions and stream length impacted when compared to Newaukum Creek (see Table 3 and Figure 9). Within the affected reach, the average temperature reduction was 0.1 °C. Temperature was reduced at the catchment outlet from 17.4 °C to 17.3 °C. Much like Newaukum Creek, temperature reductions in the System Potential model were much larger. The average temperature reduction in the affected reach in the System Potential model was 2.6 °C and the temperature at the mouth of Soos Creek was reduced by over 2.5 °C.

Figure 8. Modeled Heat Load of Soos Creek.

The affected reach of Soos Creek extends from the upstream riparian planting at Hatchery Natural Park downstream to the confluence with the Green River.

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\[^{12}\text{The affected reach of Soos Creek extends from the upstream riparian planting at Hatchery Natural Park downstream to the confluence with the Green River.}\]
Table 3. Summary Metrics of Modeled 7-DADMAX Water Temperature in Soos Creek.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Maximum temperature (affected reach)*</th>
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<th>Maximum reduction (affected reach)*</th>
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<td>14.25</td>
</tr>
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* The impacted reach starts at the Hussein property (most upstream planting) and extends downstream to the outlet (approximately 14.25 km)

** Length of stream in compliance with the Washington State temperature standard of 16.0 °C

Figure 9. Modeled 7-DADMAX Water Temperature of Soos Creek.
5.0. DISCUSSION

5.1 Effective Shade, Heat Load, and Water Temperature Modeling

Modeling of riparian revegetation based on plantings in 2012 in Newaukum and Soos creeks indicated the magnitude of water temperature reductions that would occur once the plantings reached maturity. Though the predicted temperature reductions were relatively small (average temperature reduction 0.3 °C and 0.1 °C in the affected reaches of Newaukum and Soos creeks, respectively), the limited temperature benefit found by the model is primarily due to the small area planted; approximately 1.1 and 1.2 percent of the riparian areas of the modeled reaches in Newaukum and Soos creeks were planted in 2012.

In Soos Creek, all planting activity occurred near the outlet to the Green River, thereby limiting the impact due to the width of the channel, the volume of flow, and the limited downstream reach to receive shade benefits. This reflects the diminished role of riparian shade in controlling stream temperature in higher order streams (Poole and Berman 2001). This can be seen in the results for effective shade in the two catchments; in Soos Creek effective shade only increased an average of 7 percent in planted areas, compared to 25 percent in the narrower Newaukum Creek. Despite these limitations, benefits were achieved in the areas where planting occurred. The greatest temperature reduction in Newaukum Creek was 0.9 °C and heat load was reduced by 61 percent in the most densely planted area.

A continued planting effort would achieve additional benefits. Substantial portions of the riparian areas of both watersheds, particularly Newaukum Creek, are devoid of woody vegetation. This exposure dampens the temperature reductions downstream as the increased solar input quickly raises downstream water temperatures; a significant reduction in the maximum temperature could be achieved by prioritizing planting unvegetated areas. To illustrate the benefits of revegetating bare areas, a fourth model scenario (Infill Planting) was run where areas with no vegetation on Newaukum Creek (a vegetation height of 0-1 feet based on the LiDAR survey) were hypothetically planted with a mix of deciduous live stakes (average mature tree height = 13 meters). See Figure 10 for a map of riparian areas without vegetation in the Newaukum Creek watershed.

---

13 Average wetted width of the modeled reaches equaled 4.50 m and 5.53 m for Newaukum and Soos creeks, respectively. Modeled flow at outlet for Newaukum and Soos creeks equaled 0.34 m$^3$s$^{-1}$ and 0.62 m$^3$s$^{-1}$. 
In Newaukum Creek, the average temperature reduction under Infill Planting conditions approached 2.5 °C in the affected reach while maximum temperature at the outlet was reduced by 1.0 °C (see Figure 11 and Table 4). Additionally, the length of stream in compliance with the Washington state temperature standard for Core Summer Salmonid Habitat (16.0°C) increased by 6.0 km. These results would represent a substantial step towards the modeled System Potential temperatures of Newaukum Creek (see Table A-8 and Figures A-1 and A-2 in the appendix for the equivalent figure and table for Soos Creek).
Table 4. Summary Metrics of 7-DADMAX Water Temperature in Newaukum Creek under an Infill Planting Scenario.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Maximum temperature (affected reach)*</th>
<th>Average temperature (affected reach)*</th>
<th>Maximum reduction (affected reach)*</th>
<th>Average reduction (affected reach)*</th>
<th>Temperature at outlet</th>
<th>Length in compliance**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-planting</td>
<td>20.9</td>
<td>19.7</td>
<td>--</td>
<td>--</td>
<td>20.9</td>
<td>2.85</td>
</tr>
<tr>
<td>Mature planting</td>
<td>20.8</td>
<td>19.5</td>
<td>0.9</td>
<td>0.3</td>
<td>20.8</td>
<td>2.85</td>
</tr>
<tr>
<td>Infill Planting</td>
<td>19.9</td>
<td>17.3</td>
<td>4.0</td>
<td>2.5</td>
<td>19.9</td>
<td>8.85</td>
</tr>
<tr>
<td>System potential</td>
<td>17.3</td>
<td>15.0</td>
<td>6.2</td>
<td>4.7</td>
<td>17.3</td>
<td>14.25</td>
</tr>
</tbody>
</table>

* The affected reach starts at the Hussein property (most upstream planting) and extends downstream to the outlet (approximately 14.25 km)

** Length of stream in compliance with the Washington State temperature standard of 16.0 °C

Note: Under the Infill Planting scenario, all unvegetated riparian areas in the modeled stream of Newaukum Creek are planted with live stakes.

Figure 11. Modeled 7-DADMAX Water Temperature in Newaukum Creek Under an Infill Planting Scenario.

Note: Under the Infill Planting scenario, all unvegetated riparian areas in the modeled stream of Newaukum Creek are planted with live stakes.
5.2 Sensitivity Analysis

To evaluate the sensitivity and uncertainty of the model results, the Newaukum Creek model was run with a lower and upper value for mature stand height. This provided an upper and lower bound of likely reduction in heat load and water temperature resulting when revegetated areas mature. The chosen bounds were 20 percent increases and decreases in the mature tree height value calculated for each stand.

Modifying tree heights had a relatively small overall effect on modeled maximum temperatures (see Figure 13). The largest differential between the upper and lowest bound was 0.13 °C at the most densely planted area. Within the affected reach, the upper and lower bounds varied by an average of 0.03 °C. Interestingly, the effect on temperature was not symmetrical for the upper and lower boundaries. Reducing tree heights had a greater effect on stream temperature than increasing by 20 percent (maximum change of 0.08 °C and 0.05 °C, respectively). These results suggest that the modeled revegetation scenarios are relatively insensitive to small errors/uncertainty in average mature vegetation stand height.

Figure 12. Sensitivity Analysis of the Newakum Creek Model.

Note: In this model, vegetation heights in areas planted in 2012 were increased and decreased by 20% to assess model sensitivity to tree heights.
5.3 Limitations

This modeling study examined changes in solar heat load and associated stream temperature reductions from the installation and growth of riparian vegetation. While this methodology accounts for changes in incoming solar radiation associated with new vegetation, it does not consider other systematic changes that could have major impacts on stream temperature. These include but are not limited to: other changes in vegetation, change in discharge (Poole and Berman 2001), exchange of hyporheic and phreatic groundwater to the stream channel (Findlay 1995, Brunke and Gronser 1997), change to channel geometry and pattern (Hawkins et al. 1997), and change in climate. While it was not a goal of this project to account for changes to these variables, it is important to note that the above factors limit our ability to measure changes in temperature resulting from riparian revegetation. Regardless, the critical importance of shade from riparian vegetation in controlling stream temperature on small streams (Beschta 1997, Johnson 2004) lends credence to this model’s utility as a tool for quantifying the thermal benefits of riparian revegetation.

5.4 Recommendations

It is a recommendation of this study that comprehensive riparian restoration plans be developed for both Newaukum and Soos watersheds. A critical component of any restoration plan will be a primary objective to guide riparian planting activities. It is not within the scope of this study to propose a guiding objective. However, regardless of the chosen objective, this model can be utilized as a planning tool to inform restoration activities.

The Infill Planting scenario described in Section 5.1 describes one possible strategy for future planting activities. If other objectives are deemed more pressing, this model still can serve as a guide for implementation. For example, if maximizing the length of stream in compliance with the Washington State temperature standard is deemed a priority, this model can be used to identify stream reaches where small reductions in incoming solar radiation will result in temperatures in compliance with Washington State temperature standards (see Figure A-3 in Appendix A). Similarly, if reducing the thermal load to the Middle Green River is prioritized, this model can be used to determine the extent and types of vegetation needed to reach a specified temperature reduction in its tributaries (e.g., Rutherford et al. 1997). These examples highlight this model’s utility as tool for estimating the reductions of in-stream temperature from a riparian restoration plan, evaluating the thermal benefits from differing restoration strategies, and projecting the amount of revegetation needed to reach specified in-stream temperatures. Additionally, this model can be used to estimate stream temperature reductions at regular time intervals as trees mature and restoration progresses.

Another key component of a successful restoration plan will be the identification of opportunities and constraints to riparian restoration projects. Potential opportunities might include public lands, cooperative landowners, large parcels of private property, unvegetated areas adjacent to riparian forest, and narrow tributaries where stream
temperatures would be particularly responsive to increased riparian shade. Potential constraints would include landcover incompatible with riparian revegetation (such as the extensive network of wetlands in the headwaters of Soos Creek), utility or transportation right-of-ways that prevent revegetation, uncooperative landowners, stretches with limited buffer width, and areas with an established beaver population. Identifying reaches where revegetation activity will be most effective is critical to developing an effective riparian restoration plan.

This study also highlights the need for continued monitoring of revegetated areas and the stream reaches that they impact. Continued monitoring of in-stream water temperatures is necessary to track progress towards temperature allocations set by TMDLs on each respective creek. Water temperature monitoring should be paired with future modeling efforts to evaluate thermal benefits from riparian restoration and explore model performance.

A continued effort to quantify effective shade is also recommended. The hemispherical photography of stream reaches completed as part of this grant provides a framework for future monitoring efforts. Revegetated reaches should be revisited at repeated regular intervals to measure effective shade and, as plants reach maturity, evaluate effective shade estimations from this model. Monitoring the growth, canopy density, and survival rate of the planted vegetation is also recommended to assess the effectiveness of certain plant species and evaluate the rate at which trees mature.
6.0. REFERENCES


Oregon Department of Environmental Quality (ODEQ). 2009. Tools available for download at http://www.deq.state.or.us/wq/tmdls/tools.htm


APPENDIX A: ADDITIONAL FIGURES AND TABLES

Table A-1  The number and species of potted plants installed at the Lopez property in the Newaukum Creek watershed.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Number</th>
<th>Ratio</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>big leaf maple</td>
<td>Acer macrophyllum</td>
<td>21</td>
<td>0.06</td>
<td>18</td>
</tr>
<tr>
<td>red alder</td>
<td>Alnus rubra</td>
<td>25</td>
<td>0.08</td>
<td>27</td>
</tr>
<tr>
<td>beaked hazelnut</td>
<td>Corylus cornuta</td>
<td>25</td>
<td>0.08</td>
<td>5</td>
</tr>
<tr>
<td>black hawthorn</td>
<td>Crataegus suksdorfi</td>
<td>25</td>
<td>0.08</td>
<td>5</td>
</tr>
<tr>
<td>Oregon ash</td>
<td>Fraximus latifolia</td>
<td>25</td>
<td>0.08</td>
<td>21</td>
</tr>
<tr>
<td>black twinberry</td>
<td>Lonicera involucrata</td>
<td>25</td>
<td>0.08</td>
<td>3</td>
</tr>
<tr>
<td>Pacific crabapple</td>
<td>Malus fusca</td>
<td>25</td>
<td>0.08</td>
<td>5</td>
</tr>
<tr>
<td>Pacific ninebark</td>
<td>Physocarpus capitatus</td>
<td>25</td>
<td>0.08</td>
<td>2</td>
</tr>
<tr>
<td>Douglas fir</td>
<td>Pseudotsuga menziesii</td>
<td>25</td>
<td>0.08</td>
<td>61</td>
</tr>
<tr>
<td>casacara</td>
<td>Rhamnus purshiana</td>
<td>18</td>
<td>0.06</td>
<td>11</td>
</tr>
<tr>
<td>Nootka rose</td>
<td>Rosa nutkana</td>
<td>50</td>
<td>0.15</td>
<td>3</td>
</tr>
<tr>
<td>western red cedar</td>
<td>Thuja plicata</td>
<td>25</td>
<td>0.08</td>
<td>46</td>
</tr>
<tr>
<td>western hemlock</td>
<td>Tsuga heterophylla</td>
<td>10</td>
<td>0.03</td>
<td>52</td>
</tr>
</tbody>
</table>

Ratio weighted mean height (m): 17

Table A-2  The number and species of potted plants installed at the Walker property in the Newaukum Creek watershed.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Number</th>
<th>Ratio</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>black hawthorn</td>
<td>Crataegus suksdorfi</td>
<td>10</td>
<td>0.10</td>
<td>5</td>
</tr>
<tr>
<td>Oregon ash</td>
<td>Fraximus latifolia</td>
<td>10</td>
<td>0.10</td>
<td>21</td>
</tr>
<tr>
<td>black twinberry</td>
<td>Lonicera involucrata</td>
<td>10</td>
<td>0.10</td>
<td>3</td>
</tr>
<tr>
<td>Pacific ninebark</td>
<td>Physocarpus capitatus</td>
<td>20</td>
<td>0.20</td>
<td>2</td>
</tr>
<tr>
<td>Douglas fir</td>
<td>Pseudotsuga menziesii</td>
<td>25</td>
<td>0.25</td>
<td>61</td>
</tr>
<tr>
<td>western red cedar</td>
<td>Thuja plicata</td>
<td>25</td>
<td>0.25</td>
<td>46</td>
</tr>
</tbody>
</table>

Ratio weighted mean height (m): 30
### Table A-3  The number and species of potted plants and live stakes installed at the Zech property in the Newaukum Creek watershed.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Number</th>
<th>Ratio</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>salmonberry</td>
<td>Rubus spectabilis</td>
<td>75</td>
<td>0.02</td>
<td>4</td>
</tr>
<tr>
<td>red alder</td>
<td>Alnus rubra</td>
<td>13</td>
<td>0.00</td>
<td>27</td>
</tr>
<tr>
<td>black hawthorn</td>
<td>Crataegus suksdorfii</td>
<td>12</td>
<td>0.00</td>
<td>5</td>
</tr>
<tr>
<td>Oregon ash</td>
<td>Fraximus latifolia</td>
<td>12</td>
<td>0.00</td>
<td>21</td>
</tr>
<tr>
<td>Pacific crabapple</td>
<td>Malus fusca</td>
<td>13</td>
<td>0.00</td>
<td>5</td>
</tr>
<tr>
<td>Pacific ninebark</td>
<td>Physocarpus capitatus</td>
<td>49</td>
<td>0.01</td>
<td>2</td>
</tr>
<tr>
<td>clustered wild rose</td>
<td>Rosa pisocarpa</td>
<td>51</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>western red cedar</td>
<td>Thuja plicata</td>
<td>89</td>
<td>0.03</td>
<td>46</td>
</tr>
<tr>
<td>Sitka spruce</td>
<td>Picea sitchensis</td>
<td>62</td>
<td>0.02</td>
<td>61</td>
</tr>
<tr>
<td>red-twig dogwood</td>
<td>Cornus sericea</td>
<td>37</td>
<td>0.01</td>
<td>5</td>
</tr>
<tr>
<td>black twinberry</td>
<td>Lonicera involucrata</td>
<td>37</td>
<td>0.01</td>
<td>3</td>
</tr>
<tr>
<td>black cottonwood</td>
<td>Populus trichocarpa</td>
<td>500</td>
<td>0.14</td>
<td>30</td>
</tr>
<tr>
<td>Pacific willow</td>
<td>Salix lucida</td>
<td>500</td>
<td>0.14</td>
<td>16</td>
</tr>
<tr>
<td>Sitka willow</td>
<td>Salix sitchensis</td>
<td>1000</td>
<td>0.29</td>
<td>7</td>
</tr>
<tr>
<td>Scouler's willow</td>
<td>Salix scouleriana</td>
<td>1000</td>
<td>0.29</td>
<td>7</td>
</tr>
</tbody>
</table>

Ratio weighted mean height (m): 13

### Table A-4  The number and species of live stake plants installed at the Big Springs resource property in the Newaukum Creek watershed.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Number</th>
<th>Ratio</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>black cottonwood</td>
<td>Populus trichocarpa</td>
<td>500</td>
<td>0.17</td>
<td>30</td>
</tr>
<tr>
<td>Hooker's willow</td>
<td>Salix hookeriana</td>
<td>500</td>
<td>0.17</td>
<td>8</td>
</tr>
<tr>
<td>Pacific willow</td>
<td>Salix lucida</td>
<td>500</td>
<td>0.17</td>
<td>16</td>
</tr>
<tr>
<td>Sitka willow</td>
<td>Salix sitchensis</td>
<td>1500</td>
<td>0.50</td>
<td>7</td>
</tr>
</tbody>
</table>

Ratio weighted mean height (m): 13

### Table A-5  The number and species of live stake plants installed at the Newaukum Natural Area in the Newaukum Creek watershed.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Number</th>
<th>Ratio</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hooker's willow</td>
<td>Salix hookeriana</td>
<td>500</td>
<td>0.20</td>
<td>8</td>
</tr>
<tr>
<td>Pacific willow</td>
<td>Salix lucida</td>
<td>500</td>
<td>0.20</td>
<td>16</td>
</tr>
<tr>
<td>Sitka willow</td>
<td>Salix sitchensis</td>
<td>1500</td>
<td>0.60</td>
<td>7</td>
</tr>
</tbody>
</table>

Ratio weighted mean height (m): 9
Estimation of Effective Shade, Heat Load, and Stream Temperature Improvements Associated with Mature Revegetation in Newaukum and Soos Creeks

### Table A-6
The number and species of potted plants installed at the Hatchery Natural Park in the Soos Creek watershed.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Number</th>
<th>Ratio</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>big leaf maple</td>
<td>Acer macrophyllum</td>
<td>70</td>
<td>0.12</td>
<td>18</td>
</tr>
<tr>
<td>beaked hazelnut</td>
<td>Corylus cornuta</td>
<td>80</td>
<td>0.14</td>
<td>5</td>
</tr>
<tr>
<td>Douglas fir</td>
<td>Pseudotsuga menziesii ssp. menziesii</td>
<td>50</td>
<td>0.09</td>
<td>61</td>
</tr>
<tr>
<td>western redcedar</td>
<td>Thuja plicata</td>
<td>90</td>
<td>0.15</td>
<td>46</td>
</tr>
<tr>
<td>western hemlock</td>
<td>Tsuga heterophylla</td>
<td>70</td>
<td>0.12</td>
<td>52</td>
</tr>
<tr>
<td>black cottonwood</td>
<td>Populus balsamifera ssp. trichocarpa</td>
<td>90</td>
<td>0.15</td>
<td>30</td>
</tr>
<tr>
<td>Sitka spruce</td>
<td>Picea stichensis</td>
<td>30</td>
<td>0.05</td>
<td>61</td>
</tr>
<tr>
<td>vine maple</td>
<td>Acer circinatum</td>
<td>80</td>
<td>0.14</td>
<td>6</td>
</tr>
<tr>
<td>red-twig dogwood</td>
<td>Cornus sericea</td>
<td>25</td>
<td>0.04</td>
<td>5</td>
</tr>
</tbody>
</table>

Ratio weighted mean height (m): 30

### Table A-7
The number and species of live stake plants installed at the Hatchery Natural Park in the Soos Creek watershed.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Number</th>
<th>Ratio</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hooker's willow</td>
<td>Salix hookeriana</td>
<td>2500</td>
<td>0.23</td>
<td>8</td>
</tr>
<tr>
<td>Sitka willow</td>
<td>Salix stichensis</td>
<td>2900</td>
<td>0.26</td>
<td>7</td>
</tr>
<tr>
<td>black cottonwood</td>
<td>Populus balsamifera ssp. trichocarpa</td>
<td>1200</td>
<td>0.11</td>
<td>30</td>
</tr>
<tr>
<td>Scouler's willow</td>
<td>Salix scouleriana</td>
<td>2500</td>
<td>0.23</td>
<td>15</td>
</tr>
<tr>
<td>Pacific willow</td>
<td>Salix lucida ssp. lasiandra</td>
<td>2000</td>
<td>0.18</td>
<td>16</td>
</tr>
</tbody>
</table>

Ratio weighted mean height (m): 13

### Table A-8
Summary metrics of modeled maximum temperature in Soos Creek. The Infill Planting scenario where all unvegetated riparian areas are planted with live stakes is highlighted in the table.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Maximum temperature (affected reach)*</th>
<th>Average temperature (affected reach)*</th>
<th>Maximum reduction (affected reach)*</th>
<th>Average reduction (affected reach)*</th>
<th>Temperature at mouth</th>
<th>Length in compliance**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
<td>°C</td>
<td>°C</td>
<td>°C</td>
<td>°C</td>
<td>km</td>
</tr>
<tr>
<td>Pre-planting</td>
<td>17.4</td>
<td>17.3</td>
<td>--</td>
<td>--</td>
<td>17.4</td>
<td>0.80</td>
</tr>
<tr>
<td>Mature planting</td>
<td>17.3</td>
<td>17.2</td>
<td>0.1</td>
<td>0.1</td>
<td>17.3</td>
<td>0.80</td>
</tr>
<tr>
<td>Infill planting</td>
<td>16.8</td>
<td>16.3</td>
<td>0.6</td>
<td>0.5</td>
<td>16.8</td>
<td>11.80</td>
</tr>
<tr>
<td>System potential</td>
<td>14.8</td>
<td>14.1</td>
<td>2.7</td>
<td>2.6</td>
<td>14.7</td>
<td>23.95</td>
</tr>
</tbody>
</table>

* The affected reach starts at the most upstream planting at the Soos Creek Hatchery and extends downstream to the outlet (approximately 1.15 km)

** Length of stream in compliance with the Washington State temperature standard of 16.0 °C
Estimation of Effective Shade, Heat Load, and Stream Temperature Improvements Associated with Mature Revegetation in Newaukum and Soos Creeks

Figure A-1. Riparian Areas Lacking Vegetation in Soos Creek.

Note: This figure shows riparian areas with vegetation 1.0 feet or shorter as identified by the LiDAR data. The inset shows an area of Soos Creek at a larger scale to demonstrate the distribution of unvegetated data points.
Figure A-2. Modeled maximum water temperature of Soos Creek including an “infill planting” scenario where all unvegetated riparian areas are planted with live stakes.

Note: As noted in Section 2.2, much of the headwaters of Soos Creek consist of an extensive network of wetlands. While this Infill Planting scenario assumes planting would occur in these areas (like the System Potential tree height model from the Soos Creek TMDL allocation replicated in this report), it is unlikely that these vegetative conditions could actually be achieved.
Figure A-3. Prioritized Planting on Soos Creek.

Note: Stream segments with a maximum water temperature slightly greater than 16.0°C could be targeted for riparian plantings in order to maximize the length of stream in compliance with the Washington state temperature standard for Soos Creek.