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A tool for assisting municipalities in developing riparian shade inventories

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ABSTRACT

Streams in many urbanized watersheds have elevated water temperature, and stream temperature is a regulated aspect of water quality in many parts of the western U.S. Some municipal point source polluters develop temperature mitigation plans that involve compensatory measures linked to stream temperature, principally increasing riparian shade. In this paper we describe a tool designed to help municipalities and other riparian property managers develop inventories of current and potential stream shade. The tool is based on the insolation module of the published model Heat Source to which we made the following modifications: (1) developed user interfaces and regional supporting geospatial data that minimize data acquisition and user expertise requirements; (2) incorporated LiDAR data to produce direct high spatial resolution estimates of riparian vegetation architecture; (3) created a new method to estimate site specific potential vegetation, with concomitant changes in the shading algorithm involving finer discretization and fewer parameter requirements. The new tool produces estimates of existing shade conditions comparable to those derived from on the ground field measurements for small to medium sized streams. We used the tool to develop a riparian shade inventory and a map of potential shade restoration for the City of Albany, Oregon, U.S.A. Results of this case study demonstrate that the tool can help municipalities meet shade reporting and monitoring goals at a minimum cost, including identifying specific areas with highest potential gains in shade. However, the case study identified limitations in some regional GIS framework data that potentially limit broad applicability or increase costs.

Introduction

In the U.S. Pacific Northwest salmonid populations have drastically declined since the late 18th century, and several stocks throughout the region are threatened with extinction (Rand et al., 2012). An important component of stream habitat for salmonids is water temperature, which directly affects many aspects of salmonid physiology particularly during juvenile life stages (McCullough, 1999). The thermal regime of streams across the region has been altered by a number of stressors associated with urban development. One of the most significant drivers has been a decline in riparian tree cover that has increased incident solar radiation to streams. This has resulted in many streams being too warm for juvenile salmon particularly during the summer (Paul and Meyer, 2001).

Partly because of its importance for salmon, stream temperature is a regulated aspect of water quality under the Clean Water Act of 1972 (Bauer and Ralph, 2001). Total maximum daily loads (TMDL) for water temperature based on biologically critical high temperature thresholds for juvenile salmonids have been defined for watersheds throughout the region (Boyd and Sturdevant, 1997). One of the most common point source contributors of thermal load is municipal wastewater treatment plants (Rounds, 2007). These point source polluters can directly mitigate their temperature impact in a number of ways including refrigeration, dilution with cooler water sources, and groundwater recharge. However, these techniques are costly either in terms of direct capital costs or in terms of tradeoffs such as reduced water for municipal or commercial use. In addition, strategies such as water refrigeration may not create marked improvements to salmonid habit since they occur at ecologically inappropriate points in space or time (Martin, 2006; Battin et al., 2007; Niemi et al., 2007). An alternative approach to reducing overall thermal loads involves offsetting

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the loads from point sources with compensating reductions deriving from restoration of riparian vegetation that provides shade and reduces direct solar loading of the stream. Restoration can be more cost effective than other approaches, and it can be more strategically applied at locations that have the greatest impact on salmonid habitat improvement, such as the upper reaches of watersheds. Restoration also can provide ancillary environmental benefits and ecosystem services such as habitat for terrestrial species (Kauffman et al., 1997; Cochran and Logue, 2011).

A number of natural resource management agencies in the U.S. Pacific Northwest have pioneered strategies for linking regulated water quality obligations to broader riparian habitat restoration. For example, the State of Oregon requires all agencies that are known to measurably affect stream temperature to develop TMDL implementation plans that describe activities to reduce pollutant load, include an evaluation plan for determining success, and set out a timeline for achieving reduction goals (Shine, 2007). The Oregon Department of Water Quality (ODEQ) has identified biophysical measures that influence stream temperature and allows agencies to use these surrogate measures of temperature in their TMDL implementation plans. The primary surrogate measure that has been adopted in Oregon and elsewhere in the region is shade provided by riparian vegetation. A number of municipalities have developed TMDL implementation plans based on monitoring and improving riparian shade conditions (e.g. Majidi, 2007; Pacific Habitat Services, 2009; City of Springfield, 2009). In addition, a broad-based consortium of stakeholders in the region have been developing an ecosystem services marketplace that includes the creation and trading of shade credits (Deal et al., 2012; Mass-Hebner and Dunham, 2014).

These frameworks depend on the ability to accurately quantify and track riparian shade conditions. Several approaches are in current use. Shade conditions have been directly estimated using field techniques such as hemispherical photography and light sensors (Quigley, 1981; Davies-Colley and Rutherford, 2005). In addition, a number of modeling approaches have also been used. These typically involve mechanistic heat budget models that have the end goal of predicting stream temperature, but which include components that model the influence of topography and riparian vegetation architecture on blocking incident solar radiation (Allen et al., 2007; Rutherford et al., 1997; Chen et al., 1998; Boyd and Kasper, 2003; Cox and Bolte, 2007). These models require estimates of parameter values that describe vegetation architecture in relationship to local solar insolation conditions. Vegetation parameters are typically estimated from a combination of direct field estimates, remote sensing, and geographic database framework data. Heat Source (Boyd and Kasper, 2003) is a vetted model commonly used in regional regulatory and market-based frameworks. Heat Source and its derivative models have been the basis for developing TMDL's, defining tradable temperature credits, and prioritizing stream restoration efforts (Independent Multidisciplinary Science Team, 2004; Shaub, 2007). In these contexts modeled shade estimates are made for both current vegetation conditions and estimated site potential vegetation conditions. Site potential vegetation characteristics are typically modeled using correlative relationships between plant community composition or vegetation structure and physical site conditions such as site hydrology, elevation, climate, and soil (Whiley, 2003; Cristea and Burges, 2010). A similar approach uses early land survey records to establish the potential non-disturbed land cover type for a site (e.g. grassland, shrubland, forest), and then estimates potential structural characteristics such as maximum height and density based on site physical conditions (Oregon Department of Environmental Quality, 2006b).

Both direct field measures of shade and shade modeling are usually time consuming and costly. Logistic and time constraints typically limit the spatial scope of field approaches. While modeling approaches can produce basin and even regional scale shade estimates, running these models currently requires a high degree of technical expertise to develop project-specific parameter sets, run and calibrate models with opaque and non-intuitive user interfaces, and validate model results. These cost and technical capacity constraints could be a significant burden for smaller sized municipalities that are required to develop temperature TMDL implementation plans. In addition, these constraints likely discourage private landowners from participating in market-based shade credit trading schemes. The difficulty and expense of calculating ecosystem service values such as shade are significant roadblocks to the development of ecosystem service markets (Kroeger and Casey, 2007).

In this paper, we describe a new tool, the Stream Shade Calculator (SSC) that is designed to make riparian shade estimation more accessible to municipalities. The tool is based on Heat Source v. 8.0.8 (Boyd and Kasper, 2003; Oregon Department of Environmental Quality, 2012), but includes three significant additions: (1) an user interface that minimizes the training and expertise required to implement the model; (2) the use of LiDAR framework data to produce direct high spatial resolution estimates of riparian vegetation architecture; (3) the use of LiDAR-based estimates of current vegetation topographies to inform estimates of site specific potential vegetation. We compared the performance of our tool against field estimates of riparian shade and compared our tool estimates versus estimates of insolation generated using the ESRI Solar Analyst model (Fu and Rich, 1999, 2002). We also describe a case study of using the tool to develop a stream shade inventory and restoration potential map for the City of Albany, OR, U.S.A. for use in their TMDL implementation plan.

Methods

Study area

The Willamette River Valley, Oregon, U.S.A. lies between the Cascade and Coast Ranges. Although it is now dominated by urban development and agriculture, this landscape has been dramatically altered since the arrival of European settlers in the mid-19th century. Initial U.S. government land surveys conducted in 1851 indicate that the upper margins of the basin were dominated by coniferous forest while the valley floor contained a complex mix of coniferous forest, riparian forest, oak savanna, and prairie (Hulse and Gregory, 2002). The most common geomorphic surfaces in the Valley are fine- and course-grained Missoula Flood deposits and recent alluvium of the Willamette River and its tributaries (O'Connor et al., 2001). The City of Albany (44°37′49″ N 123°5′46″ W) is located adjacent to the Willamette River 118.4 miles upstream of the confluence with the Columbia River. The Willamette and Calapooia Rivers converge at Albany, and several tributaries flow through the city. Urban storm water is directed to these tributaries. Both the Willamette and Calapooia Rivers are listed as temperature impaired streams under the Clean Water Act Section 303(d) (Oregon Department of Environmental Quality, 2006a).

Software Overview

Our software includes the following components (Fig. 1). We developed two user interfaces, one on the web and one on the desktop. Our software uses the core shade algorithms from Heat Source v 8.0.8 (Oregon Department of Environmental Quality, 2012). Typically users of Heat Source use TTools (Oregon Department of Environmental Quality, 2009) to generate riparian landscape parameters needed by the shade algorithms. TTools is hosted in an external GIS and requires a labor-intensive workflow. We developed software to automate the generation of the parameters