The Shade Credit Incentive Landscapes of the McKenzie/Willamette Confluence

by

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ABSTRACT

Increasing population and land use decisions have had a negative effect on the aquatic ecosystems in the Willamette River Basin. One result is elevated temperatures in many of the Basin's streams, which adversely affect the fish that live in these streams. There are several regulatory mechanisms in place to improve water quality; however, recent attention has been focused on market-based pollution credit trading systems as an alternative approach. Clean Water Services, the public water utility in the Tualatin Watershed near Portland recently began the first program in the country to trade temperature pollution credits for creating shade. This project explores the distribution of high and low shade credit potential in the landscape around the confluence of the Willamette and McKenzie Rivers using the peer reviewed WET_Temp stream temperature model. The intent of this project is to provide a tool for land use planners to explore the geographic characteristics of high incentive areas (high shade potential) and target these areas with shade credit programs. Also, this project explores the effects of management decisions on the changing shade credit incentive landscape.

Keywords: water quality trading, stream temperature, Clean Water Services, Willamette Basin TMDL

1. INTRODUCTION

Since 1973, decisions to convert land from one use to another in Oregon have been vetted through one of the "most highly structured statewide land planning and growth management programs" in the country (Jackson and Kuhlken 2006). These land use plans were developed by each county in accordance with nineteen state planning goals that attempted to balance conservation and development. The result of this progressive planning effort is a landscape where urban sprawl has been minimized by containing development within strict boundaries. Nevertheless, even with these regulatory mechanisms in place, steadily increasing population has created development pressures and fueled land use decisions that have taken their toll on Oregon's terrestrial and aquatic ecosystems.

Declines in water quality have been most pronounced in the region of greatest population growth: the Willamette River Basin nestled between the Coast and Cascade Mountain Ranges in western Oregon. A central feature of the Willamette River Basin is the Willamette River itself, the 13th largest river in the United States which drains an area of approximately 11,500 square miles (29,785 square kilometers). Under the federal Clean Water Act of 1972, the Oregon Department of Environmental Quality (ODEQ) has had the task of identifying streams and rivers that violate established water quality standards and including them on a list of such streams known as the 303(d). The latest version of the 303(d) list, updated in 2006, identifies many of the rivers and streams in the Willamette River Basin as "water quality limited", with the most common offenses being high bacteria levels, high mercury levels and high stream temperatures (*Willamette TMDL: Chap. 1* 2006).

Though elevated stream temperature may not register immediately in one's mind as a "pollutant", it is included as a water quality standard due to its negative effects on the cold-water fish that live and spawn in Oregon's streams. The Willamette River and its tributaries are home to a wide range of aquatic fauna which play a large economic, cultural and recreational role in the region. Many of these fish are dependent on cool water to maintain their metabolic processes. Elevated stream temperatures have been linked to high mortality rates in coho salmon (Tang, Bryant, and Brannon 1987), and cause a reduction in dissolved oxygen, which has been tied to embryo abnormalities in Chinook salmon (Geist et al. 2006). Desirable stream temperatures in the region vary based on the species and life stage of the fish that use the stream, but they range from 12°C for bull trout habitat to 18°C for salmonid rearing (*Willamette TMDL: Chap. 1* 2006). However, temperatures as high as 23°C are frequently observed in the streams of the Willamette River Basin between the months of June and August (*Willamette TMDL: Chap. 4* 2006).

In 2004, Oregon governor Ted Kulongoski reacted to reports of poor water quality in the region by making his plan to "repair, restore and recreate" the rivers in the Willamette Basin one of his high priorities (*Gov. Kulongoski: Willamette River Legacy* (no date)). To go about this task, the governor defined actions that, under the management of ODEQ, would attempt to reach water quality standards over the next several years. One of these actions was the accelerated creation of Total Maximum Daily Load (TMDL) documents for the Willamette River and its tributaries, and another action was the endorsement of pollution credit trading systems to supplement the regulatory mechanisms currently in place.

Total Maximum Daily Load documents, another mandate of the Clean Water Act, are created for 303(d) streams and define the maximum level of various pollutants that the stream can maintain without violating water quality standards. This maximum level is computed by determining the amount of the pollutant that would likely exist in the absence of anthropogenic influences (described further for temperature in section 2.2). Though TMDL's have been required since the Clean Water Act's creation, very few states have actually developed them (*Total Maximum Daily Loads* 2007). However, bacteria, mercury and temperature TMDL documents for the entire Willamette River Basin were submitted and approved by the Environmental Protection Agency (EPA) in 2006 and have become an important component of water quality improvement strategies in the region.

Pollution credit trading systems are based on the understanding that the mitigation cost for regulatory compliance can vary significantly among polluters (*Water Quality Trading Policy* 2003). Credits equivalent to some unit of a pollutant are distributed among polluters in a region, with the number of credits totaling the maximum amount of a pollutant allowed, defined by the TMDL. Those who can economically mitigate within their operation can then sell their credits to those for whom mitigation may be prohibitively expensive. Ideally this approach leads to competition and innovation in reaching environmental standards. Market-based mechanisms have been very efficient conservation tools in the past when the right circumstances have existed, as seen in the sulfur dioxide trading program during the 1990's (Stavins 2005). Because 96% of the Willamette Valley is privately owned (*OR Conservation Strategy* 2006), voluntary, market-based approaches may be more successful at achieving conservation goals than the more conventional, regulatory approaches.

An initial foray into the arena of water quality credit trading has already begun in the Willamette River Basin. In 2004, Clean Water Services (CWS), the public utility in charge of water resources in the Tualatin River watershed near Portland, became the first organization in the country to trade credits for temperature. Through an EPA grant intended to foster water quality credit trading, CWS began a prototype endeavor to generate riparian shade along the

Tualatin so as to offset the excess thermal energy (the amount above the TMDL) introduced to the river by effluent from their wastewater plants (*CWS Temp. Mgmnt. Plan* 2004). Riparian vegetation plays a very strong part in attenuating solar radiation, and solar radiation has been shown to be a driving influence on stream temperatures (Johnson and Jones 2000).

To restore vegetation in areas that have been cleared, CWS "buys" shade credits that are "sold" by owners of land along the Tualatin who are willing to plant and maintain riparian shade. Shade credits are calculated based on the predicted amount of solar radiation that will be attenuated once planted vegetation reaches its twenty-year height (see section 2.3). Currently there is only one credit buyer, so the CWS program is not yet a well-developed trading system; however, the intention is that kinks in the prototype program will be ironed out and more credit buyers and sellers will be introduced over time. Since 80% of the streams on ODEQ's 303(d) list are there because of temperature excesses (*Oregon DEQ: Water Quality Credit Trading*), the shade credit trading approach being tested by CWS is being watched carefully by ODEQ and could prove to be an effective tool to lower stream temperatures throughout the state.

As mentioned above, a TMDL defines the maximum amount of a pollutant that would likely be present in a potential landscape without anthropogenic influence. With a temperature TMDL, the maximum potential stream temperature is governed largely by the vegetation that is predicted to grow along an affected stream. Appendix C of the Willamette Basin TMDL documents describes ODEQ's guiding principle in regards to temperature:

> "In general, areas where the greatest difference is observed between historic/potential land cover and current land cover are the areas that provide the greatest opportunity for establishing near-stream vegetation. These areas are ODEQ's highest priority for improving stream temperature for aquatic life." (*Willamette TMDL: Appx. C* 2006)

With a shade credit program in place, the difference between the current amount of radiation attenuated by vegetation and the amount of radiation that could potentially be attenuated roughly translates to two forms of incentive. For land where this difference is large, there is a monetary incentive for the owners to plant in the form of shade credits, and there is a management incentive for agencies to facilitate planting so that they meet TMDL requirements. Where are these areas of high shade incentive? How is this incentive distributed in the landscape? How could shade credit programs like (or unlike) those used by Clean Water Services target high incentive areas? How does incentive change as management decisions are made upon the landscape? This research project will explore these questions using the WET_Temp stream temperature model.

2. BACKGROUND

2.1. The study area

The study area for this project is located in the southern portion of the Willamette River Basin and includes the McKenzie River and the Willamette River from their confluence to approximately 6 miles (9.6 km) over land upstream and 3.5 miles (5.6 km) over land downstream (Figure 2.1). The southwest corner of the study area contains a portion of Eugene, the third largest city in Oregon after Portland and Salem, with an estimated population of approximately 148,600. The remainder of the study area has a diverse land cover that includes agricultural fields (row crops, grass seed, grains), hardwood forests, orchards, vineyards and a few small towns. The area was chosen because of this diversity of land uses as well as for the ready availability of quality data.

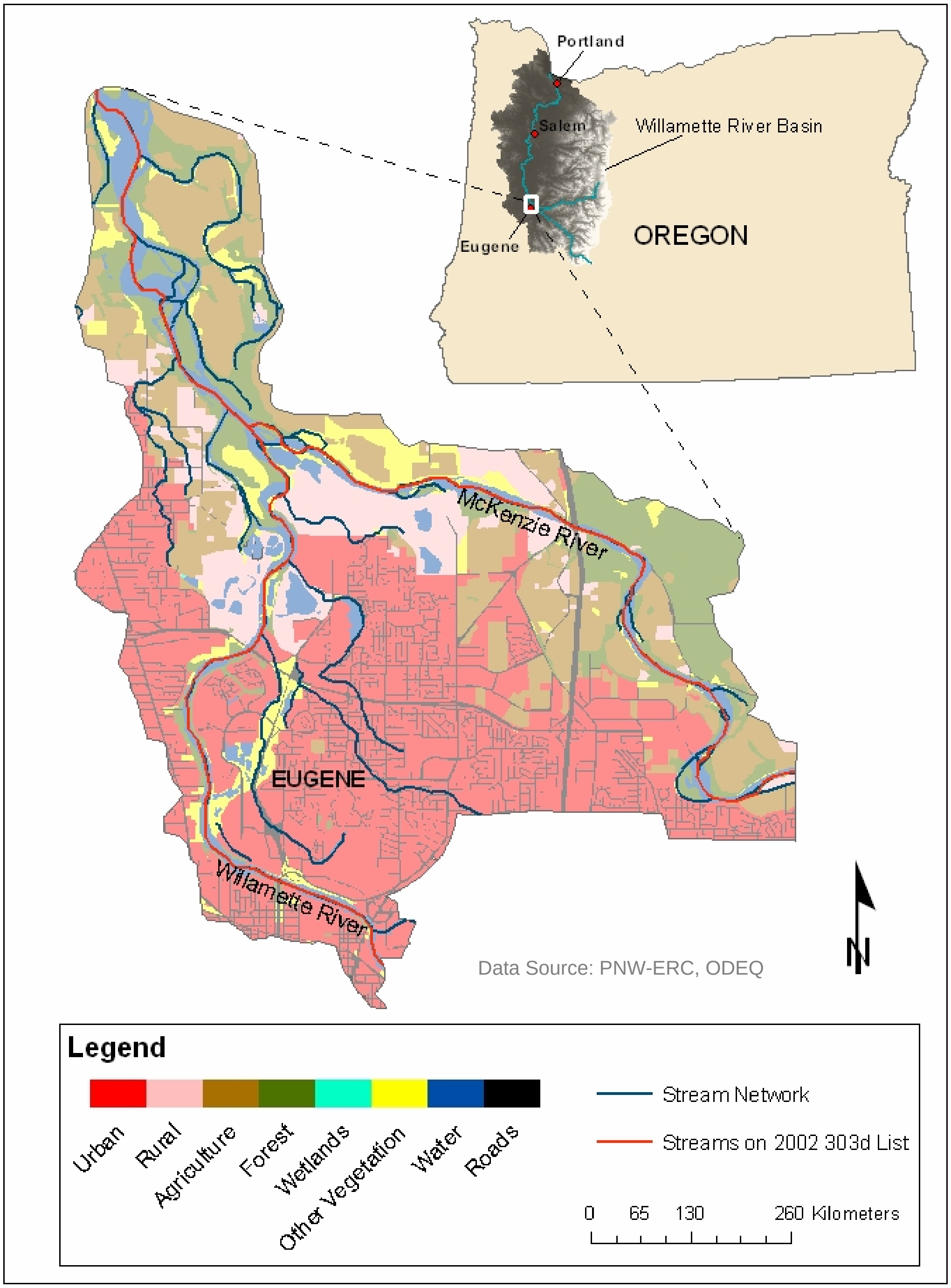

Figure 2.1: Map of the study region

Figure 2.2 below illustrates the coarse articulation land use/land cover (LULC) percent breakdown for the entire study region as well as for land within 100 meters of a stream that could be planted with riparian vegetation. Since roads and water can not be planted, they were not included in this near stream acreage. The term “coarse articulation” refers to the level of abstraction of the LULC. For example, the coarse articulation LULC (called LULC_A in this project following existing standards, see Appendix 2) for a particular piece of land might be “Agriculture”, the medium articulation LULC (called LULC_B) might be “Wood & Nursery Products” and the fine articulation LULC (called LULC_C) might be “Christmas Trees”.

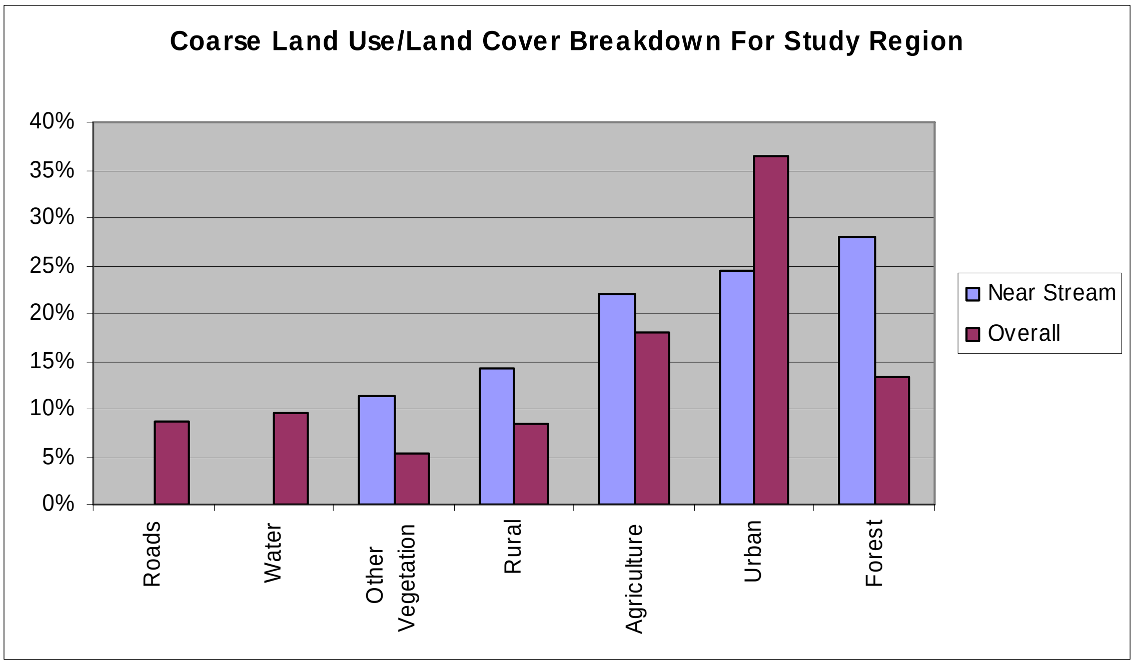

Figure 2.2: Land use/land cover breakdown

The medium articulation LULC_B breakdown for the study region can be found in Appendix 1, and a list of all LULC values found in the study region (at their three articulation levels) can be found in Appendix 2.

The climate in the study region is maritime temperate, with cool rainy winters and warm, dry summers. The hottest summer temperatures on average occur in July and August and are in the low 80’s (°F). Spring and summer stream flow of the Willamette and McKenzie is largely dependent on snow melt from the glaciers of the Cascade Mountains to the east, but is also affected by the operation of the Cougar Reservoir approximately 60 miles (96.5 km) upstream from Eugene. The reaches of the Willamette and McKenzie Rivers included in this project are designated as both core habitat for cold-water fish and as salmon/trout rearing and migration areas. Maximum temperatures for these uses are 16°C and 18°C respectively; however, water temperatures have been shown to consistently exceed these critical levels between late June and mid August (*Willamette TMDL: Chap. 4* 2006). Due to these excesses, the study area reaches of both rivers are on the 303(d) list as water quality limited for temperature.

2.2. Willamette Basin temperature TMDL generation

In order to determine the total maximum daily temperature load of a particular stream, ODEQ researchers needed to estimate the likely temperature of the stream if anthropogenic influences were removed. This estimation required some knowledge of the likely vegetation that would be found along these streams, called "system potential vegetation" (SPV), to determine the amount of solar radiation that would reach the stream surface. To accomplish this goal, the researchers analyzed the geomorphology, geology, ecoregions, soils, existing vegetation and historic vegetation (from 1850) of several streams in the basin to gain some understanding of the height and density of vegetation that would naturally occur along these streams. This digital analysis was subjected to expert review, and resulted in a set of rules which translate geomorphic class to a predicted near-stream vegetation breakdown (*Willamette TMDL: Appx. C* 2006). For example, the geomorphic class Qalc (see section 3.3) has a predicted breakdown of 80% forest, 17% savanna and 3% prairie. The numbers for forest and savanna are broken down even further into percent of conifer, hardwood or mixed conifer/hardwood. Finally, for each category, the height and density of the vegetation at maturity was estimated, since these values are imperative when calculating solar radiation attenuation.

Once system potential vegetation height and density was defined for an area, ODEQ used a stream temperature model called Heat Source to estimate the maximum daily stream temperatures that would occur if this riparian vegetation existed. Heat Source consists of a set of Microsoft Excel worksheets that contain various sets of stream data and Visual Basic modules used to simulate temperature flux in a stream. The Heat Source temperature calculations are performed at virtual points spaced every thirty meters along the center of the stream, and involve algorithms that determine the amount of solar radiation reaching the stream surface at these points based on the point location (i.e. the relationship between the point and the sun, described more in section 2.4) and the radiation attenuation by nearby riparian vegetation.

On the Heat Source vegetation worksheet, each row represents one of these virtual simulation points; however, aside from specifying the distance in river miles from the mouth of the river, these points are not spatially defined (i.e. latitude/longitude). Also, the river is treated as a set of linear reaches, and tributaries are handled in separate Heat Source files. Heat Source was one of two models used by ODEQ to create temperature TMDL's and is the primary model used by Clean Water Services to calculate shade credits, as discussed in the next section.

2.3. Clean Water Services shade credits and the Willamette Partnership

As mentioned earlier, Clean Water Services received a grant from the EPA to start a water quality trading program and became the first organization in the country to trade temperature credits (in actuality, the grant was given to ODEQ to fund a prototype trading program in Oregon). Since agriculture occupies approximately one third of the Tualatin watershed where CWS operates, and since much of the floodplain land in this watershed has been cleared for crops, the CWS credit programs focus on shade generation on agricultural land (*CWS Temp. Mgmnt. Plan* 2004). When a land owner shows interest in one of the marketed shade credit programs, CWS first uses Heat Source to determine how much solar radiation the parcel of land should be capable of attenuating once newly planted vegetation reaches its twenty-year height. CWS uses estimates of twenty-year vegetation height and density from various sources depending on the type of vegetation that is to be planted. The amount of radiation blocked is expressed in average kilocalories per foot squared per day (kcal ft^{-2} day^{-1}).

Once the amount of radiation attenuated is determined, CWS multiples this value by the surface area of the stream bordering the parcel of land to get the average kilocalories of radiation blocked per day. This value is then multiplied by a "safety factor" of 0.5, which is meant to account for the delay until actual shading occurs as well as the risk that the planted vegetation will not survive. The resultant value is the number of shade credits. Though there is also a discussion in the CWS plan of an "incentive factor", that weights streams with high restoration priority (identified by a stream restoration prioritization model called RESTORE (Lamy et al. 2002)) by multiplying shade credits by four (*CWS Temp. Mgmnt. Plan* 2004), a member of the CWS team noted at a recent meeting with the Long Tom Watershed Council that this weighting has not actually been implemented.

After shade credits have been calculated, an agreement is entered into between CWS and the land owner. The land owner agrees to plant and maintain riparian vegetation in exchange for payments based on the number of shade credits their land will generate and the current market price of shade credits. CWS in turn uses the shade credits generated as an offset to their thermal input above TMDL. To plant vegetation and to monitor its growth, CWS contracts with other local agencies, such as the Soil and Conservation District. If it is determined that the conditions of the shade credit contract are not being met (i.e. dead vegetation, vegetation cleared), the agreement goes through a review process, and payments (as well as the shade credit offset) are potentially reduced.

The EPA awarded another grant, called a Targeted Watershed Grant, to a different organization in Oregon with the same goal of addressing watershed pollution concerns through market-based conservation programs. The recipient of this grant, the Willamette Partnership, is working to create what they refer to as an Ecosystem Marketplace. This marketplace is envisioned to be an online trading forum where information about conservation credit trading can be obtained, and actual trades can be initiated. The Willamette Partnership's initial focus is to use credit trading to address temperature concerns, so they are naturally quite interested in the CWS program.

The Willamette Partnership is also staying very close to and even funding research on various alternate hypotheses for reducing stream temperatures other than the use of riparian shade. One such hypothesis suggests the cooling effects of hyporheic flow (the flow of stream water through permeable gravel in the stream's flood plain) to reduce stream temperature (Lancaster, Haggerty, and Gregory 2005). The theory is that the creation of levees and revetments has blocked the river's access to hyporheic zones and has thus participated in elevating stream temperatures. Another alternate hypothesis is the notion that stream restoration should focus on "cold water refugia" (pockets of cool water that are large enough and spaced appropriately to form a "ladder" for fish) rather than attempting to cool entire stream reaches. As the literature on such hypotheses expands, the Ecosystem Marketplace will ideally expand their methods and strategies for conservation credit trading to incorporate this new knowledge.

2.4. The WET_Temp stream temperature model

WET_Temp (Watershed Evaluation Tool – Temperature) is a peer reviewed, spatially explicit, network-based stream temperature model developed at Oregon State University (OSU) in 2002. The model was created following the logic used in Heat Source (the version in use in 2002), but was designed to a) make use of easily accessible spatial datasets and b) facilitate watershed-level analysis rather than the more commonly encountered reach-level analyses. The application itself is an object-oriented C++ program in contrast to the Excel spreadsheet and Visual Basic code used by Heat Source. The object-oriented design of WET_Temp has recently drawn the interest of ODEQ, since they have been discussing the upgrade of Heat Source to a more efficient, user-friendly format, which could lead to collaboration between OSU and ODEQ in the near future.

There are four spatial datasets required as input to run a WET_Temp simulation. These datasets are:

- a stream layer where stream reaches are represented as individual polylines connecting nodes in a tree network configuration (that is, braided channels must be broken),
- a cell layer which divides the surrounding landscape into smaller units, typically by land ownership and LULC – each cell in this layer must be tied to a specific down-slope stream reach (via a *HydroID* field) and have both an *Area* and *LULC* attribute,
- a digital elevation model (DEM) of the area, and
- a flow layer consisting of points along the stream network where measured flow data (in cubic feet per second) are available.

A user also has the option of providing a layer that indicates water withdrawal points along the stream network (irrigation), a layer of observed temperatures for calibrating the model, a layer describing channel widths and depths, and/or a comma-separated value (CSV) file with climatological data to be used in calculating heat gain/loss due to condensation/evaporation at the stream surface.

As with Heat Source, WET_Temp has a robust near-stream shade algorithm which estimates the amount of solar radiation reaching the stream surface at each simulation time step as the angle of the sun relative to the stream changes throughout the day. WET_Temp was chosen for this project because of this shade algorithm as well as for its object-oriented design, simple input data requirements and landscape-level view of the stream network. An additional motivation for using WET_Temp in this project and expanding its shade component was to prepare the model for incorporation into a multi-agent policy analysis tool called EvoLand, where it could be used to explore the effect of shade credit policies on the landscape. The incorporation of WET_Temp into EvoLand, however, is outside the scope of the current project. Since this project focuses on shade and incentives to create shade, the following sections cover the elements of WET_Temp from the sun to the surface of the stream and do not delve into WET_Temp's treatment of temperature below the stream surface.

2.4.1 Pre-processing shade parameters

When a WET_Temp file is opened, the model first checks for the existence of the required and optional spatial datasets mentioned above, then begins an operation called pre-processing. The notion of pre-processing is to handle all one-time calculations prior to running the model in order to reduce the amount of time required to finish a simulation. Once pre-processing has been completed, WET_Temp writes a file called *stream.wt* to the input file directory. This file can be several megabytes in size and contains a binary copy of the data structures created in pre-processing as well as the results of the functions run during the operation. Once a *stream.wt* file has been generated, the contents of this file will be used in lieu of running through the pre-processing steps outlined below.

One prominent operation that takes place in WET_Temp pre-processing is the division of the input stream network layer into reaches, nodes, sub-nodes and sub-reaches (Figure 2.3) and the creation of structures to maintain data at each of these levels. The model assumes that a) each stream polyline is a reach and b) the last vertex in each polyline (in the order of vertex creation) is the furthest downstream point of the reach. Though these assumptions may seem presumptuous, the output of the *Stream Definition* function found in the ArcHydro extension of ESRI's ArcGIS geographic information system (GIS) is in just this format. By matching the x and y coordinates of upstream and downstream vertices, WET_Temp creates an object-based stream network in memory where each reach is aware of its upstream and downstream reach neighbors.

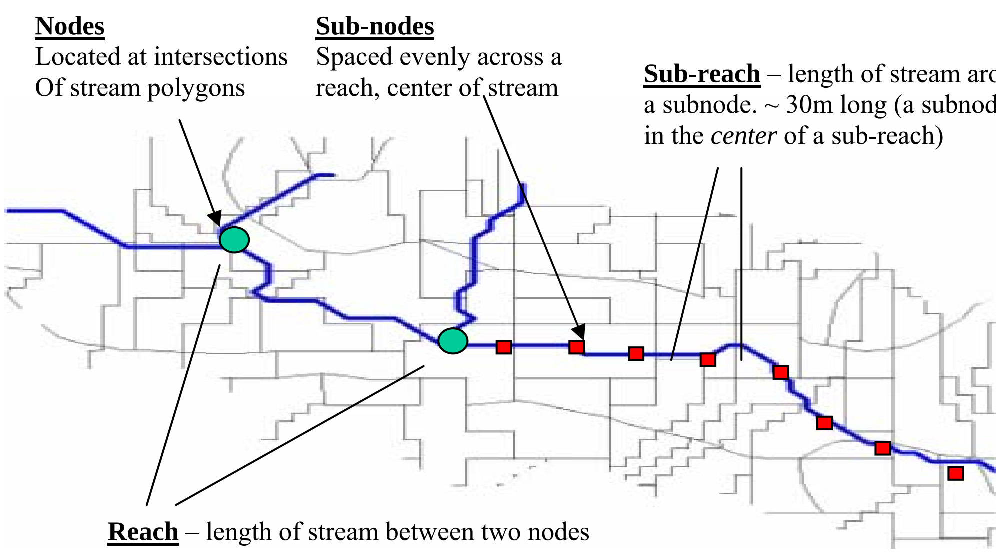

Figure 2.3: WET_Temp stream network (adapted from Cox and Bolte 2007)

In the WET_Temp simulation, all shade and stream temperature calculations are done at the sub-node level and are then aggregated to the reach level. Sub-nodes are equally spaced, virtual data points located at stream center along the length of each reach. A model parameter governs the maximum distance in meters between each sub-node, which is used to divide a reach into sub-reaches; therefore, the distance between sub-nodes can vary from reach to reach.

Radiating out from each sub-node in the four cardinal and four ordinal directions (called the eight "major" directions from here on) are eight sets of information that are referenced in shade calculations at various times throughout the simulation day as the solar azimuth changes (Figure 2.4).

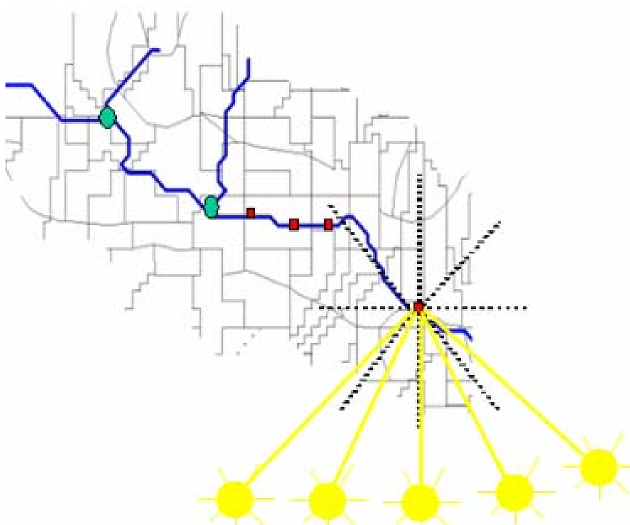

Figure 2.4: Eight major directions around a sub-node (adapted from Cox and Bolte 2007)

This directional information is determined during pre-processing and includes the following:

- The maximum topographic shading angle in the current direction (Figure 2.5). This value is calculated by stepping from grid cell to grid cell along the digital elevation model for two kilometers in the current direction.

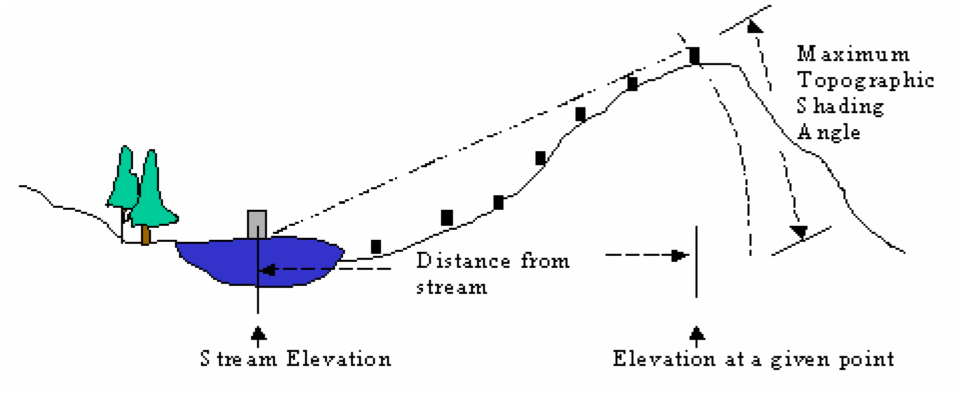

Figure 2.5: Maximum topographic shading angle (adapted from Cox and Bolte 2007)

- The distance to vegetation in the current direction (DistToVeg, Figure 2.6). This value is estimated using the aspect of the sub-reach (degrees from north) coupled with the width of the reach's near-stream disturbance zone (NSDZ). The NSDZ is in turn estimated for each reach from:
    - the total land area that drains into the reach,
    - the gradient of the reach, and
    - the sinuousity of the reach (the ratio of the over-land distance between the upstream and downstream nodes to the actual distance traveled by the river between these nodes).
- The vegetation characteristics in the current direction (Figure 2.6). Vegetation is sampled at eleven distance steps from the edge of the vegetated zone (based on the distance to vegetation). The first two distance steps are 5 meters long, and the remaining nine are 10 meters long for a total of 100 meters sampled in each direction. The sampling process at each distance step involves:
    - determining in which cell layer polygon the current distance step lands,
    - reading the fine articulation LULC_C code for that cell,

- translating this LULC_C code into estimated vegetation height (h_{Veg}) and density using a lookup table, and
- calculating the vegetation shade angle ($\theta_{VegShade}$) relative to the sub-node, taking into account a) the height adjustment due to topography (h_{Adjust}) and b) the vegetation overhang, which is estimated to be 10% of the vegetation height.

Also, for each direction, the maximum vegetation shade angle ($\theta_{MaxVegShade}$) and maximum vegetation density encountered while sampling are stored.

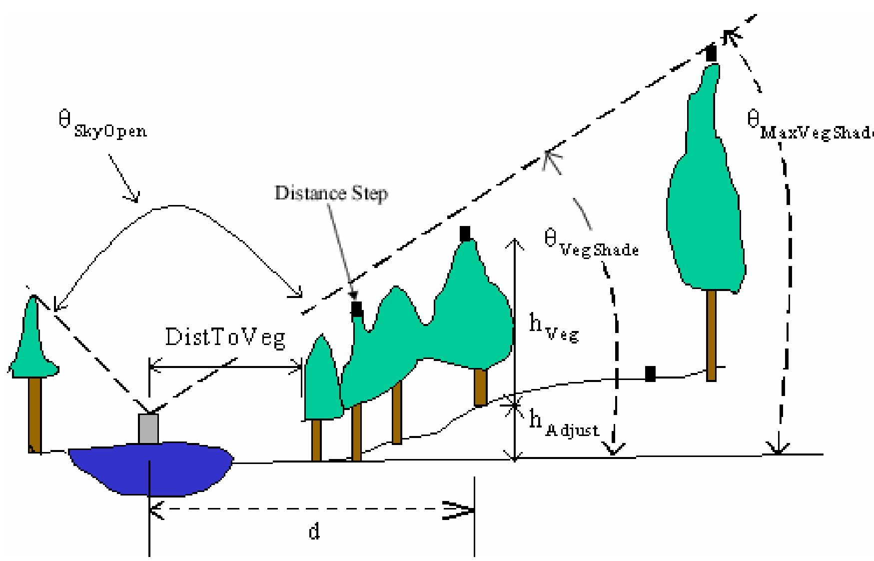

Figure 2.6: Vegetation parameters (adapted from Cox and Bolte 2007)

There are two remaining pre-processing operations that are important to shade calculations. The first is the determination of three values along the azimuths perpendicular to the left and right stream banks: the maximum vegetation shade angle, the maximum topographic shade angle and the maximum vegetation density. Information along these azimuths is used to calculate the attenuation of diffuse solar radiation (discussed in the next section). These two azimuths are simply 90 degrees to the left and right of the stream aspect. However, depending on the aspect, the azimuths may or may not align with one of the eight major directions for which vegetation information has been sampled. To account for this, the three values are interpolated by taking a weighted average of the maximum vegetation shade angle, maximum topographic angle and maximum vegetation density along the two major directions closest to each azimuth. The weight used is 45 degrees minus the distance in degrees from the major direction to the solar azimuth (Figure 2.7).

((Max Density 1 * Angle b) + (Max Density 2 * Angle a)) / 45 degrees

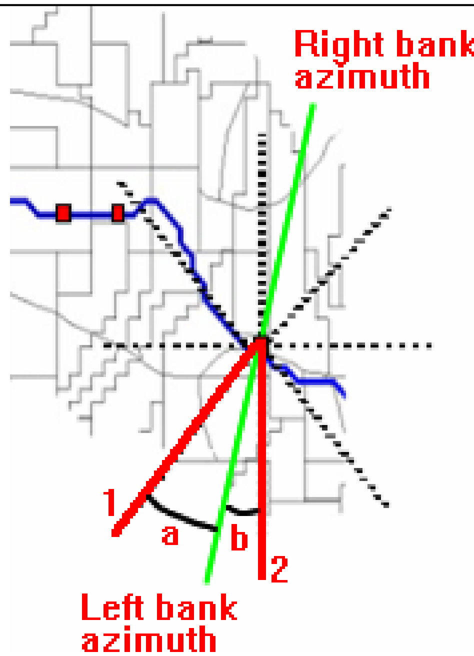

Figure 2.7: Interpolating between two major directions(adapted from Cox and Bolte 2007)

The final relevant pre-processing operation is the calculation of the amount of open sky above the stream. The amount of open sky governs how much diffuse solar radiation reaches the stream surface with no interference from either vegetation or topography. Open sky is represented as the percentage of the 180 degree possible horizon NOT blocked by topography or vegetation ($\theta_{SkyOpen}$, Figure 2.6).

2.4.2 *Modeling solar radiation at the stream surface*

In order to begin a WET_Temp simulation, the user provides a start time, a stop time and a time step, selects the reach or reaches to be analyzed, and then clicks on *RUN*. Once started, the model first initializes the data structures that collect shade and temperature information throughout the simulation and then begins stepping through the simulation time period. The start and stop times provided by the user are in Julian Day format, where 1 is January 1st, 365 is December 31st, and any decimal portion indicates a fraction of a day. The Julian Day is used at each time step to determine the relationship between the sun and the point on the earth (in latitude/longitude) where the input stream network is found. This relationship is represented by a solar azimuth (the angle of the sun from north) and a solar altitude (the angle of the sun from the horizon). These two values change over the course of the day, but are considered constant at a particular time step for all reaches in the stream network.

The relationship between the stream network and the sun governs the amount of extraterrestrial solar radiation present above the earth's atmosphere over the stream network, taking into consideration eccentricities in the earth's orbit. This extraterrestrial radiation is absorbed, reflected (scattered) or transmitted as it passes through the atmosphere, and whatever solar radiation remains above the vegetation canopy is referred to as "surface radiation". However, due to the scattering effect of the atmosphere, surface radiation is made up of two components which have different paths to the stream surface:

- direct radiation is the transmitted beam of radiation that follows a relatively straight path from the sun to a point on the stream surface, and
- diffuse radiation is the scattered radiation that essentially "bounces" to the stream surface through any opening it finds.

WET_Temp has an algorithm that divides surface radiation into its direct and diffuse components based on the ratio of surface radiation to extraterrestrial radiation. As with solar azimuth and solar altitude, surface radiation changes throughout the day, but is constant for all reaches in the stream network at a particular time step.

This is the point in the WET_Temp simulation where vegetation and topography in the eight major directions around a sub-node (discussed in the pre-processing section) play a part in attenuating solar radiation as it travels toward the stream surface. The amount of surface radiation that arrives at a sub-node is the sum of the direct and the diffuse solar radiation that makes it through the vegetation canopy. The approach for calculating each component at the sub-node is briefly outlined next.

The <u>direct solar radiation</u> that reaches the stream surface at a particular time step is computed as follows:

1) The two major directions on either side of the solar azimuth are determined.
2) WET_Temp loops through the 11 distance steps in each of these two major directions and calculates a) the average vegetation height, b) the average vegetation density and c) the solar path length for the direction. Solar path length is the vegetated distance between the sun and the sub-node, and it is a function of solar altitude, vegetation height and the distance of the vegetation from the stream. In Figure 2.8 below, Path Length 1 is shorter than Path Length 2 since Tree 1 is not tall enough to be in Path 1. However, if Tree 1 were closer to the stream, it would potentially contribute to Path Length 1.

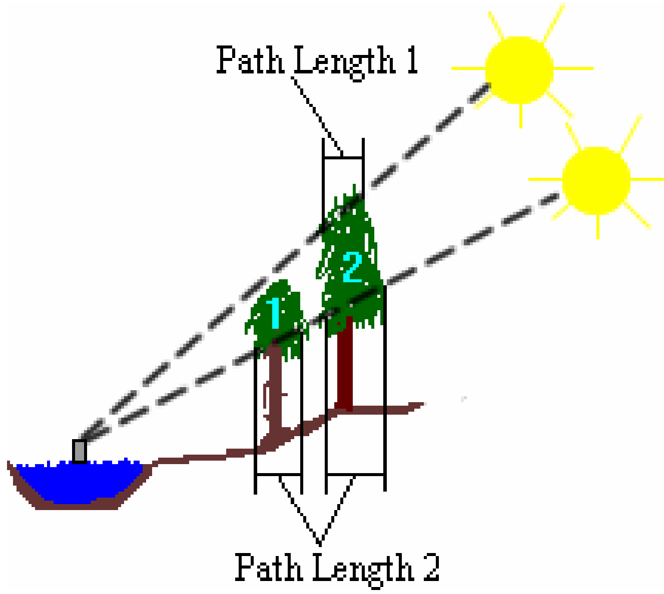

Figure 2.8: Solar Path Length Illustration

3) A weighted average of the path length and average density in each of the two major directions is computed in the same fashion as detailed in Figure 2.7.
4) The average height in the two directions is linearly averaged.
5) Finally, these values are used in Beer's Law, which describes direct radiation attenuation through a homogeneous medium (Cox and Bolte 2007):

$$\text{DIRECT}_{\text{below canopy}} = \text{DIRECT}_{\text{above canopy}} * e^{(-k * \text{path length})}$$

$$\text{where} \qquad k = \frac{-\ln(1 - \text{density \%})}{\text{average height}}$$

The <u>diffuse solar radiation</u> that reaches the stream surface at a particular time step is computed as follows:

1) The interpolated vegetation and topography information for the left and right stream bank azimuths is accessed.

2) The shaded angle on either side of the stream is calculated. This is merely the maximum vegetation shade angle minus the maximum topographic shade angle (Figure 2.9).

3) The total shaded angle is converted into the percentage of the 180 degree horizon (relative to the sub-node) that is vegetated.

4) The percent of the 180 degree horizon that is open sky was already calculated in pre-processing.

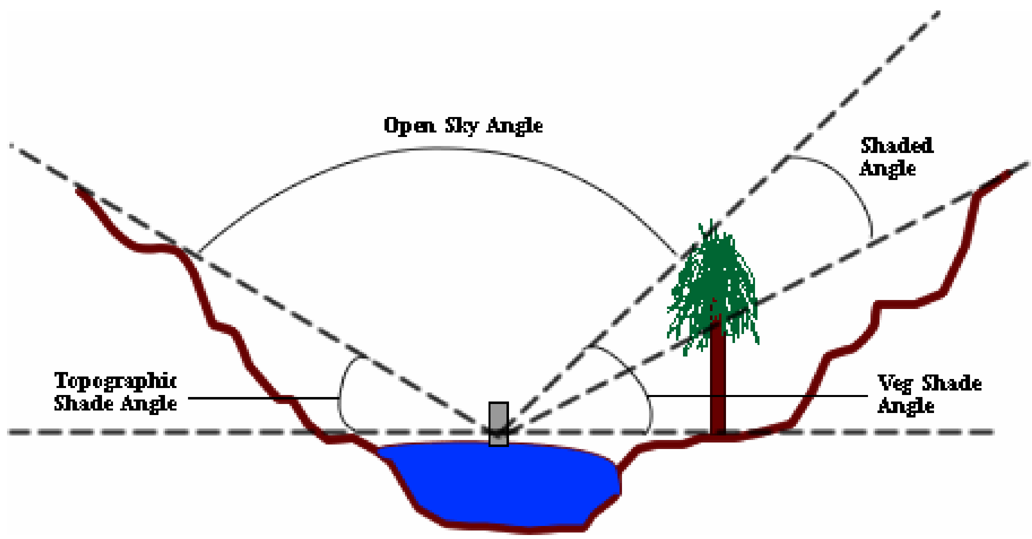

Figure 2.9: Angles involved in the diffuse radiation calculation

5) Imagining diffuse solar radiation bouncing toward the sub-node from all directions, the radiation that hits the open sky above the stream will make it to the sub-node, any that encounters topography will be blocked and any that encounters vegetation will be attenuated dependent on the vegetation density. Therefore, the formulas used to determine the diffuse radiation that reaches the stream surface are:

$$\text{DIFFUSE}_{\text{thru sky opening}} = \text{DIFFUSE}_{\text{above canopy}} * (\%\ \text{OPEN SKY})$$
$$\text{DIFFUSE}_{\text{thru left veg}} = \text{DIFFUSE}_{\text{above canopy}} * (\%\ \text{SHADED}_{\text{left}}) * (1 - \text{MAX DENSITY}_{\text{left}})$$
$$\text{DIFFUSE}_{\text{thru right veg}} = \text{DIFFUSE}_{\text{above canopy}} * (\%\ \text{SHADED}_{\text{right}}) * (1 - \text{MAX DENSITY}_{\text{right}})$$

$$\text{DIFFUSE}_{\text{below canopy}} = \text{DIFFUSE}_{\text{thru sky opening}} + \text{DIFFUSE}_{\text{thru left veg}} + \text{DIFFUSE}_{\text{thru right veg}}$$

3. METHODOLOGY

3.1. Modifying WET_Temp to examine shade incentive

The existing shade functions in WET_Temp focused on the amount of solar radiation in kilojoules per meter squared per hour (kJ/m^2/hr) that would reach the stream surface at each sub-node. Since the objective of this project was to explore the distribution of shade incentive (as defined by current policy) across the landscape, these functions needed to be expanded to focus on the contrasting quantity: how much solar radiation does not reach the stream surface? More specifically, when considering a shade incentive program:

a) how much incoming surface radiation is blocked by near-stream vegetation (within 100 meters in the eight major directions), not by topography, and

b) what percentage of this attenuated radiation is each cell in the surrounding landscape responsible for; that is, how much shade does each cell contribute?

The first step in dividing both diffuse and direct radiation attenuated to the surrounding cells was to add the appropriate data structures and modify the pre-processing operation so that, as vegetation information is being sampled, the process stores the ID of the cell encountered at each of the eleven distance steps in the eight major directions. The following sub-sections discuss the changes put in place to calculate the direct and diffuse solar radiation attenuation components and divide these values amongst shade-contributing cells.

3.1.1 Dividing DIRECT solar radiation amongst shade contributing cells

In WET_Temp, the amount of direct solar radiation blocked by near-stream vegetation is dependent on the height and density of this vegetation, the distance of the vegetation from the stream and the solar path length through the vegetation. Though height, density and distance from stream are pre-processed and do not change throughout the WET_Temp simulation, the path length and the major directions involved in the calculation are governed by the solar altitude and solar azimuth respectively, both of which change at each time step. Therefore, the logic for dividing direct solar radiation attenuated amongst shade-contributing cells needed to be time-dependent as well.

The calculation of direct radiation attenuated by near-stream vegetation at a sub-node is straightforward:

$$\text{DIRECT}_{\text{attenuated}} = \text{DIRECT}_{\text{above canopy}} - \text{DIRECT}_{\text{below canopy}}$$
$$= \text{DIRECT}_{\text{above canopy}} * \text{EFFECTIVE SHADE}_{\text{direct}}$$

$$\text{where EFFECTIVE SHADE}_{\text{direct}} = (1 - e^{(-k * \text{path length})})$$

Once this value is computed, one merely needs to know the percent contribution that each cell made to this equation (i.e. how much shade did the cell contribute) and multiply $\text{DIRECT}_{\text{attenuated}}$ by this percentage to determine the direct radiation attenuated by a given cell.

Since the relationship between the characteristics of a particular cell and $\text{DIRECT}_{\text{attenuated}}$ is non-linear and involves four variables (height, density, distance from stream and solar altitude), a simplified approach was used to quantify each cell's percent shade contribution rather than creating a complex expression to mathematically describe the relationship:

1) First, when stepping through the eleven distance steps in the two major directions on either side of the solar azimuth, WET_Temp flags the steps that have contributing vegetation. The vegetation is "contributing" if the solar altitude is <u>above</u> the topographic shade angle (below which all solar radiation is blocked) but <u>below</u> the vegetation shade angle at that step.

2) Next, EFFECTIVE SHADE $_{direct}$ is evaluated at each contributing distance step using the incremental path length, density and height for that step, weighted by the degree distance from the solar azimuth (as detailed in Figure 2.7).

3) This incremental EFFECTIVE SHADE $_{direct}$ is added to a running sum, TOTAL EFFECTIVE SHADE $_{direct}$.

4) Once all contributing cells have been visited, WET_Temp loops through these cells again and divides the EFFECTIVE SHADE $_{direct}$ for each cell by TOTAL EFFECTIVE SHADE $_{direct}$ to yield the percent shade contribution for the cell.

5) Finally, each cell's percent shade contribution (for direct radiation) is multiplied by DIRECT $_{attenuated}$ and stored as the amount of direct radiation attenuated by that cell.

The logic of this approach is that cells with high incremental EFFECTIVE SHADE $_{direct}$ would also weigh heavily in the calculation of the overall EFFECTIVE SHADE $_{direct}$.

3.1.2 Dividing DIFFUSE solar radiation amongst shade contributing cells

The amount of diffuse solar radiation blocked by near-stream vegetation in WET_Temp is dependent on the maximum shade angle and maximum density of vegetation found along the azimuths perpendicular to the left and right stream banks. The only portion of the calculation that varies with time is the amount of diffuse surface radiation above the tree canopy. All other variables are based on the vegetation and topography to each side of the stream and are determined during pre-processing; therefore, the primary changes required to divide diffuse solar radiation amongst shade-contributing cells were in the pre-processing modules. This means that for each vegetated state (such as the twenty-year system potential vegetation discussed in section 3.3), a different pre-processing *stream.wt* file had to be maintained.

As with the process used to divide direct solar radiation attenuated between the contributing cells at a sub-node, WET_Temp first determines each cell's percent contribution to the diffuse radiation attenuation equations and then multiplies this percentage by the amount of diffuse radiation blocked at that sub-node. The following approach is used during pre-processing to calculate the percent contribution of cells along each perpendicular azimuth:

1) The maximum shade angle and maximum density of vegetation along a stream bank azimuth are interpolated (during pre-processing) from the maximum values in the two major directions found on either side of the azimuth. Therefore it is necessary to figure out how much each of the two major directions contributed to the interpolated height and density. Recalling the weighted average equation used for interpolation (described in Figure 2.7) and recognizing that the equation for DIFFUSE $_{\text{below canopy}}$ is a linear function of the maximum vegetation height and density, the percent contribution of major direction 1 can be calculated as:

$$\frac{(\text{HEIGHT } 1 + \text{DENSITY } 1) * \text{WEIGHT } 1}{((\text{HEIGHT } 1 + \text{DENSITY } 1) * \text{WEIGHT } 1) + ((\text{HEIGHT } 2 + \text{DENSITY } 2) * \text{WEIGHT } 2)}$$

where WEIGHT = 45 – (distance in degrees between the major direction and the perpendicular azimuth)

2) Once the percent contribution for a major direction is known, this percentage is simply divided equally between all cells in that direction that have vegetation that is either the maximum height or the maximum density for the direction. If a cell's vegetation is both the maximum height and the maximum density, the cell is counted twice as a contributor.

The logic behind this approach is that, since the maximum height and density are the governing factors in how much diffuse solar radiation is attenuated, each cell with vegetation that is the maximum height or maximum density contributes equally to attenuation. If one of these cells were removed, the maxima would not change and the results of the calculations would be the same.

When the WET_Temp simulation is run, at each time step the amount of diffuse radiation attenuated by near-stream vegetation at a sub-node is computed with the following functions (refer to Figure 2.9):

$$\text{DIFFUSE BLOCKED}_{left} = \text{DIFFUSE}_{above\ canopy} * (\%\ \text{SHADED}_{left}) * (\text{MAX DENSITY}_{left})$$
$$\text{DIFFUSE BLOCKED}_{right} = \text{DIFFUSE}_{above\ canopy} * (\%\ \text{SHADED}_{right}) * (\text{MAX DENSITY}_{right})$$

where $\%\ \text{SHADED}_{left/right} = \text{VEG. SHADE ANGLE}_{left/right} - \text{TOPOGRAPHIC SHADE ANGLE}_{left/right}$

These equations do not consider topographic shade generated by a cell (i.e. a large cliff) to be a shade contribution; however, the topography beneath the vegetation is considered when calculating the vegetation shade angle in pre-processing and thus plays a role in the cell's shade contribution.

Once the amount of diffuse radiation attenuated in both the left and right directions is determined, the final step is to set the amount attenuated by each cell in the four major directions on either side of the left and right perpendicular azimuths. All cells with a non-zero percent contribution in the two major directions around the left stream bank azimuth are multiplied by $\text{DIFFUSE BLOCKED}_{left}$, and the same approach is taken for the right stream bank.

3.1.3 Final calculations and writing to cell layer

When WET_Temp has completed its final time step, there is a record of how much solar radiation was received at each sub-node over the course of the simulation (in $kJ/m^2/hr$) and how much was attenuated by the surrounding vegetation. There is also a record for each sub-node that provides a breakdown of all of the shade-contributing cells around it and how much solar radiation (in direct and diffuse components) each cell attenuated. Before finishing, WET_Temp visits each shade-contributing cell one final time and a) computes the cell's average radiation attenuated by summing the direct and diffuse components and dividing by the number of time steps in the simulation and b) converts the attenuation value to kilojoules per hour (kJ/hour) by multiplying by the surface area of the reach (following the shade calculation approach used by CWS, section 2.3). This value is then written from the data structures in memory to a field in the cell layer for further analysis in ESRI ArcGIS 9.1.

3.2. Gathering data for the WET_Temp simulation

As mentioned in the background, there are four sets of spatial input data necessary to run a WET_Temp simulation: a cell layer, a DEM, a stream network layer and a flow layer. The cell layer, stream layer and DEM used in this project originated from the work of the Pacific Northwest Ecosystem Research Consortium (PNW-ERC), which was made up of researchers from ten different Oregon institutions (including OSU). The group was founded by the Environmental Protection Agency in 1996 as part of a five year initiative to investigate the ecosystems of the Willamette Valley and the potential impacts of future management decisions. The datasets generated by this research are freely available and downloadable from the consortium's web page.

The cell layer used as input to WET_Temp for this project (Figure 3.1) is an update to the PNW-ERC "Land Use / Land Cover circa 2000" dataset, converted from raster to polygons with partitioning based on tax lot information and, within these tax lots, by unique land cover. This conversion was done by researchers at both OSU and the University of Oregon for the EvoLand policy analysis tool. The cell layer is in the Universal Transverse Mercator (UTM) Zone 10 projection and is based on the NAD 1927 datum. The original "Land Use / Land Cover circa 2000" dataset was created using a supervised classification of Landsat Thematic Mapper imagery taken in 2000 and 2001. The results of this classification were refined using circa 2000 US Geological Survey (USGS) Ortho-Quadrangle maps and tax lot records.

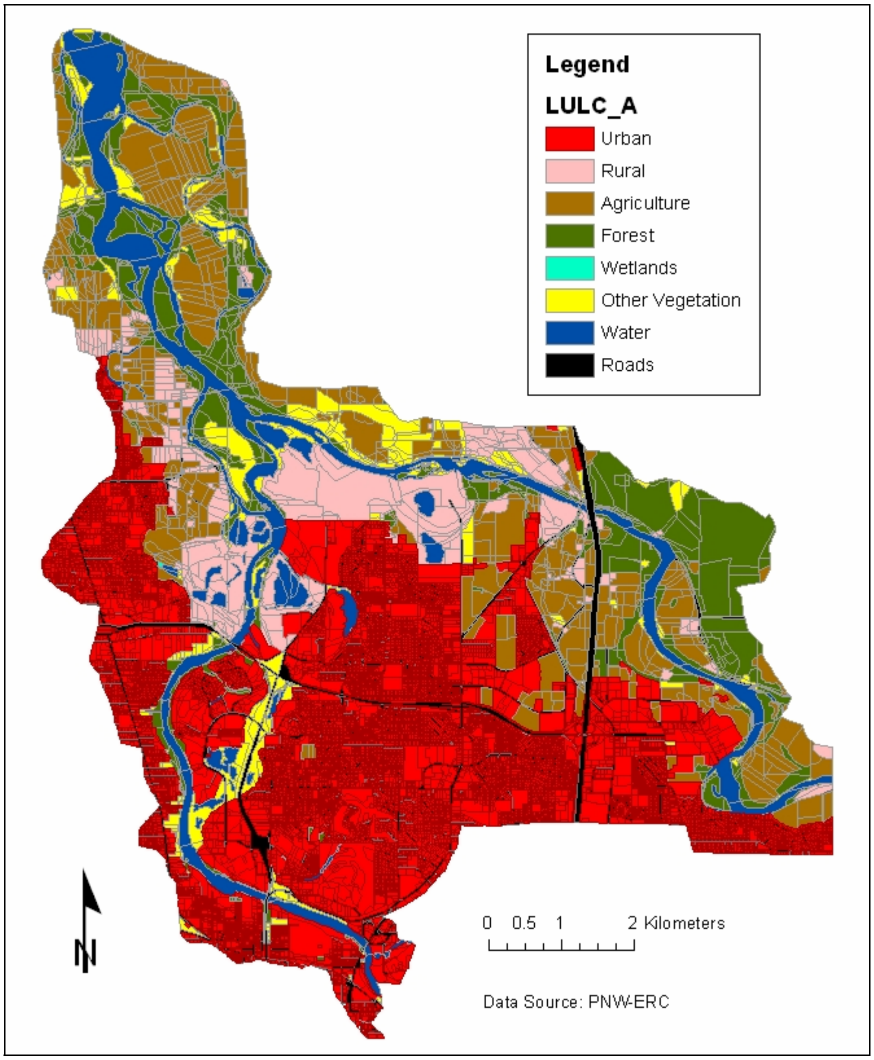

Figure 3.1: Input cell layer for WET_Temp

The DEM used in this project (Figure 3.2) was downloaded directly from the PNW-ERC Datasets web page, re-projected to align with the cell layer, clipped to the study area and converted to ASCII (the format WET_Temp requires) using ArcGIS 9.1. The PNW-ERC dataset was created at the University of Oregon from a set of one-degree DEM blocks compiled by the State of Oregon Geospatial Enterprise Office as part of their Baseline 97 project. Oregon Baseline 97 data were obtained from the USGS, US Forest Service and the US Bureau of Land Management. The one-degree blocks covering the Willamette Valley were merged by the PNW-ERC and checked for errors. Elevation values are in meters and are at 30 meter resolution.

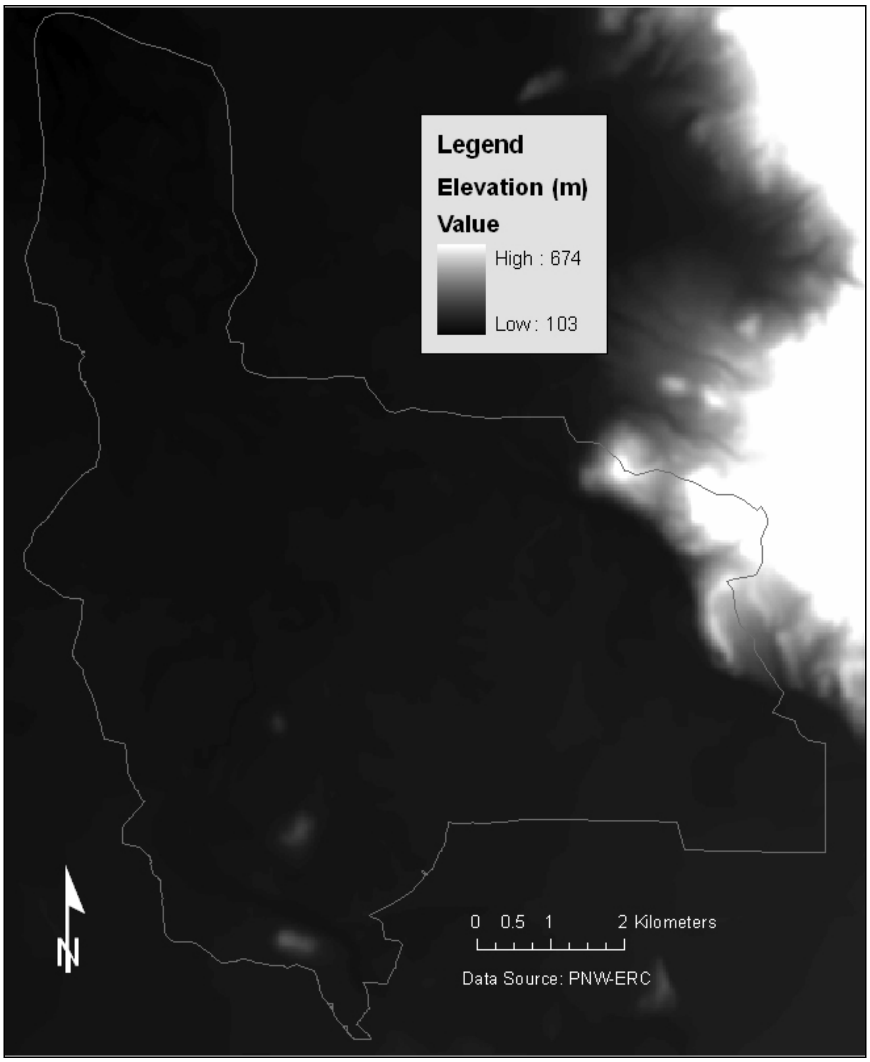

Figure 3.2: Input DEM for WET_Temp

The stream layer (Figure 3.3) for this project involved a bit more processing to be ready for use in WET_Temp. This is largely because of the model's requirement that each polyline be a reach, that the last vertex in each polyline be the downstream node and that each cell in the cell layer be associated with a particular reach. After exploring these complexities a bit, the final process for generating a WET_Temp input stream layer was as follows:

1) Download the "Rivers" data layer from the PNW-ERC dataset page.
2) Using the input DEM and the ArcHydro 1.2 Beta extension in ArcGIS 9.1, step through the process for defining a stream network based on elevation. The ArcHydro steps involve:
    a. filling non-existent sinks in the DEM,
    b. determining flow direction at each 30-meter grid cell based on the slope to the surrounding cells,
    c. generating a raster flow accumulation layer, where the value at each grid cell is the number of grid cells that flow into that cell,
    d. choosing a stream definition threshold which indicates the number of cells that need to flow into a cell for it to be considered part of the stream,
    e. segmenting the raster stream network that results from step d) into reaches,
    f. defining catchments (sub sections of the watershed) that drain into these reaches based on the flow direction determined in b) above, and finally
    g. converting the raster catchments to polygons and the raster stream network to polylines and then linking these reaches to their corresponding catchments.

NOTE: in step d) above, several thresholds were explored until the resultant stream network covered and extended beyond the PNW-ERC "Rivers" layer.

3) Next, spatial queries were performed in ArcGIS to select cells in the cell layer that had their geometric center in a particular catchment, and then link each selected cell to the reach associated with this catchment via the *HydroID* field.

4) Finally, the new stream network was trimmed to align with the more accurate PNW-ERC "Rivers" layer. For each trimmed reach, a query was performed to set the *HydroID* of cells that drain to this trimmed reach to the *HydroID* of the next downstream reach.

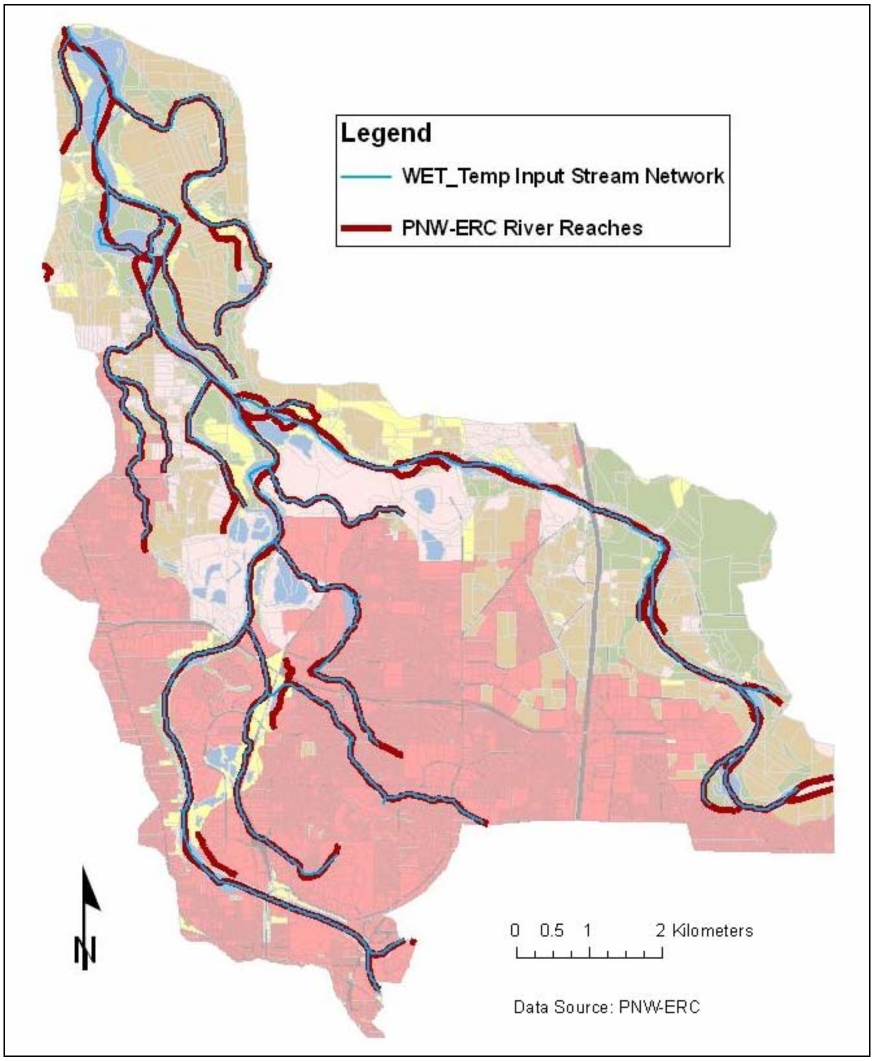

Figure 3.3: Input stream layer for WET_Temp

The final input layer needed for this project was the stream flow layer (Figure 3.4). As mentioned in the "Background", the flow layer consists of data points along the stream network where a measured flow value at that point could be acquired. WET_Temp only requires one point at the furthest downstream node and will interpolate flow throughout the network based on estimated channel dimensions; however, more flow points can be provided and will be used in the interpolation. Since flow information is primarily used for stream temperature calculations in WET_Temp, precise data were not imperative for the shade calculations considered in this project. However, stream flow is used to estimate stream depth, which in turn is used when calculating sub-reach surface area, and the surface area is used to convert $kJ/m^2/hr$ to kJ/hr in the final radiation attenuation equations.

The two flow points used as input for this project were the USGS gage on the McKenzie near Coburg (gage 14165500) and the USGS gage at Harrisburg (gage 14166000). Though Harrisburg is approximately 7 miles (11.25 km) downstream from the McKenzie/Willamette confluence, there are no major tributaries that empty into the Willamette between Harrisburg and the confluence, so gage readings at Harrisburg should be reasonable flow estimates to use for the confluence. The first step to downloading flow data was to determine the time period of interest, which for stream temperature is the hottest period of the summer. Temperature maxima recorded in Eugene between 1971 and 2000 were examined, and July 29th was found to be the hottest day on average of the year for that time period (*Thirty Year Daily Temp., WRCC* 2005). Based on this finding, flow data for July 29th from the Harrisburg gage were averaged over the years having measured data (the past eleven years), and this value, in cubic feet per second, was used as the measured flow value for the data point at the confluence of the Willamette and McKenzie. The Coburg gage had no flow data beyond 1972, so the flow on July 29th, 1972, was used as the flow value for the Coburg data point.

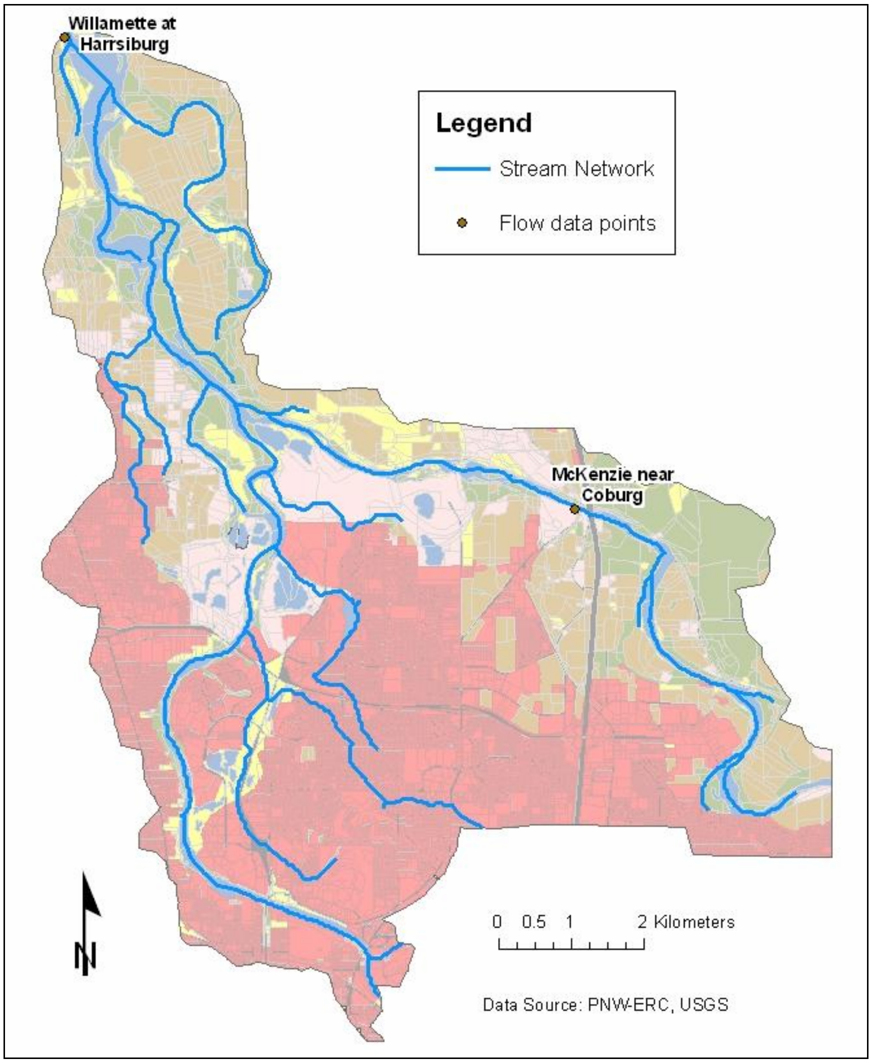

Figure 3.4: Input flow layer for WET_Temp

3.3. Twenty-year system potential vegetation (SPV)

To explore the concept of shade incentive within the study region, it was necessary to compare the radiation attenuated by existing vegetation to the radiation that would be blocked in a maximally shaded potential landscape. Areas where the difference between these two values is the greatest represent prime management targets, but also will tend to have higher land owner incentive in the form of shade credits. Since shade credit value in the CWS plan is based on estimated vegetation height and density twenty years after planting, each cell in this potential landscape should be populated with the tallest, densest vegetation that would be reasonable after twenty years, given that cell's characteristics.

How does one determine the tallest, densest vegetation that a particular cell might support? ODEQ confronted this same question when generating TMDL documents for the Willamette Basin, as discussed in section 2.2. The ODEQ system potential vegetation rules were a good starting point for generating the maximally shaded potential landscape for this project. However, two issues with using the ODEQ rules directly required some additional thought. First, ODEQ's predicted height and density values assume vegetation growth with no anthropogenic influence over whatever amount of time it might take to reach maximum vegetation height and density. The potential landscape for this project, on the other hand, needed to have vegetation that could realistically result after twenty years from management decisions made now upon *the existing landscape*, not a landscape devoid of human influence. For twenty-year SPV height and density, CWS refers to a set of fixed values when modeling (*CWS Temp. Mgmnt. Plan* 2004). These values are:

Forest:	Height = 18.3 meters,	Density = 75%
Savanna:	Height = 6.1 meters,	Density = 75%
Wetland:	Height = 6.1 meters,	Density = 75%
Emergent Marsh:	Height = 1.2 meters,	Density = 95%

This brings us to the second issue with both the ODEQ and CWS approaches as they relate to this project: for its shade calculations, WET_Temp uses a table of vegetation height and density estimates based on the fine articulation LULC_C vegetation code of a cell (i.e., "closed conifer forest, 41-60 years old" versus simply "forest"). Therefore, the potential landscape for this project needed to be represented at this detailed level as well. Also, operating at a finer level of abstraction allowed more complex logic to be put in place to describe the transition from one land use to another over the course of twenty years. However, each of these transitions were evaluated to make sure that the resultant vegetation height and density did not exceed the twenty year values used by CWS listed above.

The approach used to generate the twenty-year system potential landscape in this project was to create a transition matrix that, when supplied the existing vegetation code and geomorphic class of a cell, provides a corresponding potential vegetation LULC_C code for that cell. The first step in creating this transition matrix was to obtain a GIS layer of the geomorphic classes in the study region from ODEQ (Figure 3.5, Table 3.1).

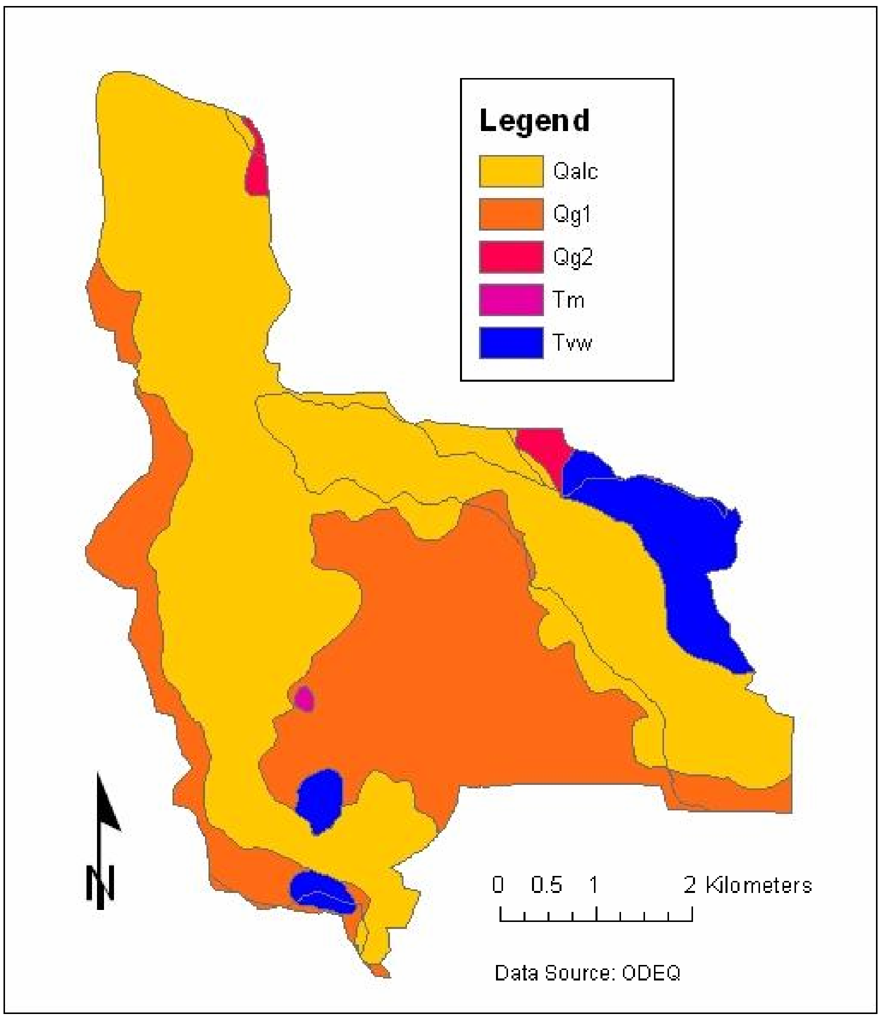

Figure 3.5: Geomorphic classes found in the study region

Geomorphic Class	Description
Qalc	Floodplain deposits of the Willamette River and major tributaries (Holocene and upper Pleistocene)
Qg1	Sand and Gravel that postdates Missoula Floods (upper Pleistocene)
Qg2	Sand and gravel that predates Missoula Floods (Pleistocene)
Tvw	Volcanic and volcaniclastic rocks in the Western Cascade Range, undivided (upper Eocene to Pliocene)
Tm	Marine sedimentary rocks (lower Miocene to Eocene)

Table 3.1: Geomorphic classes found in the study region (Willamette TMDL: Appx. C 2006)

Once this layer was obtained, spatial queries were performed in ArcGIS to tag each cell with the geomorphic class that its geometric center belonged to. Microsoft Access was then used to extract a grouped listing of all possible LULC_C and geomorphic class combinations, and this list was moved to Excel so that the twenty-year SPV logic could be manually applied. The resulting transition matrices (one per geomorphic class) can be found in Appendix 3.

The general logic used to create the twenty-year SPV transition matrices was as follows for each geomorphic class:

1) Determine the LULC_C code for the tallest, densest vegetation that would most likely be found on land of this geomorphic class based on the ODEQ SPV rules. For instance, the Qalc breakdown is 80% forest, and of this 80%, 93% is mixed conifer/hardwood. Therefore, the LULC_C code of 54 (“Forest Closed Mixed”, Appendix 2) was chosen as the maximum potential vegetation for Qalc.
2) Use this maximum vegetation code as the potential LULC_C for agricultural land, shrub land, grassland and open, non-vegetated areas that could be heavily planted.
3) For existing closed forests, the potential LULC_C is the same as the existing LULC_C. Do not assume any management decision to convert one closed forest to another.
4) For open or semi-closed forests, use the maximum vegetation code for potential LULC_C.

5) For water and existing transportation networks, the potential LULC_C is the same as the existing LULC_C. Do not assume the removal of water features or roads.
6) For urban areas, rural residential areas and civic open spaces use the code 49 ("Urban Tree Overstory") as the potential LULC_C. This vegetation is estimated to be 15 meters tall and 30% density, which could be achieved by planting trees where possible around urban and rural structures and civic areas.

It could be argued that assigning the maximum potential vegetation to every parcel in the landscape is unrealistic, since the probability that every parcel in the study region could achieve its potential is very low. However, when considering shade incentive, the maximum potential vegetation should be used so that each land owner on similar land has an equal shade potential to his/her neighbor. Issues with individual sites would be identified prior to planting, and the CWS management plan addresses the possibility of credit reduction if shade maintenance goals on a piece of land are not being met (*CWS Temp. Mgmnt. Plan* 2004).

3.4. Generating the incentive landscapes

The final methodological step in this project was to use the expanded WET_Temp simulation to calculate the amount of solar radiation attenuated at every sub-node in the stream network by various near-stream landscapes, distribute this amount between shade-contributing cells and examine the results using ArcGIS and Microsoft Access. Also, land management decisions to generate shade credits (that is, decisions to plant the twenty-year SPV) were simulated by setting LULC_C values using Microsoft Access and then re-running the WET_Temp simulation. The general steps for generating the various incentive landscapes found in the "Results" section are as follows:

1) The WET_Temp pre-processing operation was run for both the current vegetation and the twenty-year SPV. The result of this operation was the creation of two *stream.wt* files, essentially digital representations of the current and potential landscapes. These files were both labeled in their file properties so as not to confuse them.
2) Another outcome of the pre-processing operation was the setting of a flag in the cell layer that indicated which cells were considered "Near-Stream", i.e. those cells involved in WET_Temp calculations.
3) Once the *stream.wt* files were generated, the WET_Temp simulation was run once for all reaches in each landscape with a date of July 29th (Julian Day 210, determined to be the hottest day on average per year in region). The radiation attenuated by each cell in these two simulations was written to two fields in the cell layer.
4) After both simulations had been run, ArcGIS was used to select all near stream cells and save these selected cells as a new spatial layer. This essentially created a snapshot of the current and potential radiation attenuation values for all near-stream cells.
5) The radiation attenuation values output from WET_Temp were in kJ/hr. These values were converted to CWS shade credits (described in section 2.3) using ArcGIS and the following formula:

$$\text{Shade credits} = \text{kcal/day} * \text{safety factor}$$

$$= \frac{\text{kilojoules}}{\text{hour}} * \frac{\text{24 hours}}{\text{day}} * \frac{\text{1 kcal}}{\text{4.18 kilojoules}} * \text{safety factor}$$

where safety factor = 0.5

6) ArcGIS was then used to create and calculate an INCENTIVE field, where INCENTIVE = potential shade credits – current shade credits. At this point, the current and potential radiation attenuation landscapes as well as the incentive landscape could be visualized and explored in ArcGIS.

7) To examine the characteristics of high incentive cells, the next step was to determine the top 50% of the highest incentive cells and flag them as such. This was done in Microsoft Access by ordering cells by descending incentive, filtering out negative and zero values, and then flagging the first and second highest 25% (580 cells each) in the cell layer.

8) At this point, the top 50% of highest incentive cells were flagged. To simulate a management decision to plant the twenty year SPV in the top 25% of highest incentive cells, a query was performed in Microsoft Access to set a dummy LULC_C field in the input cell layer to the potential LULC_C if the cell was among the top 25%, and to the current LULC_C otherwise.

9) The WET_Temp pre-processing operation was run for the new landscape (creating another *stream.wt* file to keep track of) and then the simulation was run for July 29th. Steps 4) through 7) above were repeated to create a new layer representing the results of the first management decision.

10) Also of interest were the incentive landscapes at various vegetation heights between the initial planting and the twenty-year potential height. To simulate the landscape at half and three-quarters vegetation heights, WET_Temp was simply modified to multiply the twenty-year potential height by 0.5 and 0.75. Once again, the pre-processing operation was run, the simulation was run for July 29th and steps 4) through 7) above were repeated for the two layers. In these scenarios, vegetation height was halved, but density was kept the same. This

decision was based on the observation that vegetation density in the WET_Temp lookup table does not change for forests of various ages.

4. RESULTS

4.1. The Incentive Landscape

The first set of maps generated from the WET_Temp shade output show the current (Figure 4.1) and twenty-year system potential (Figure 4.2) distributions of average near-stream radiation attenuation in the landscape (in megajoules per day; MJ/day) as well as this value converted to shade credits (unitless) as described in the methodology. For these maps, five color ranges were defined based on the standard deviation of the twenty-year system potential attenuation data. The first range represents minimal attenuation (0 – 20 MJ/day), the maxima of the next three ranges are spaced one standard deviation apart and the final range stretches from the third standard deviation to the maximum value in the dataset. Once defined, this color range was also applied to the current attenuation data for comparison.

The majority of the near-stream cells in the current radiation attenuation map (Figure 4.1) fall in the 0 to 20 MJ blocked per day range. However, assuming all cells in the region could plant and sustain their twenty-year SPV, the resultant landscape (Figure 4.2) would have very few cells in the 0 to 20 MJ blocked per day range and a majority in the 20 to 14,610 MJ blocked per day range. An interesting spatial detail to note is that, in both maps below, areas of high current or potential shading often occurred at the confluence of two stream reaches where vegetation planted on both sides of the cell would shade both reaches.

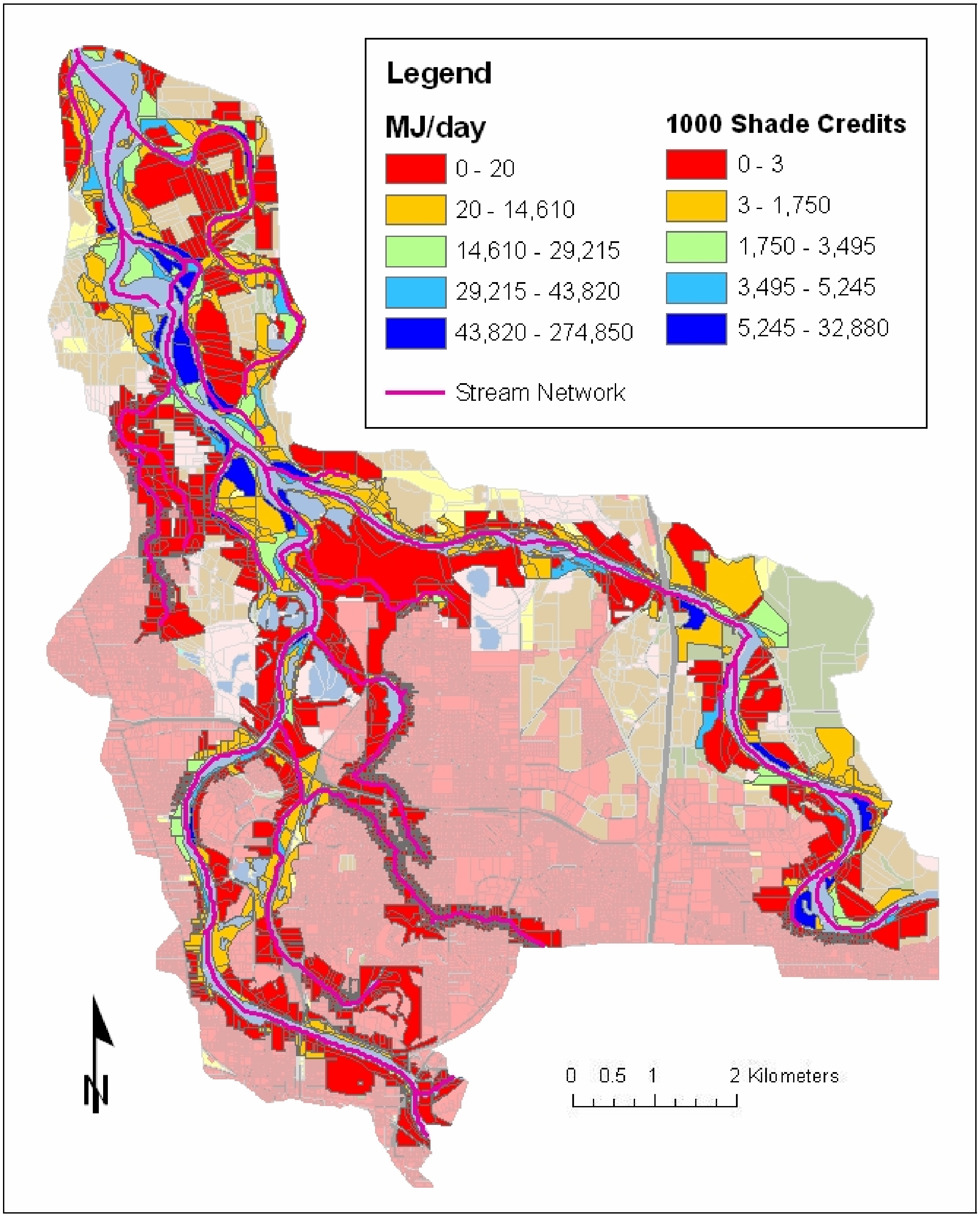

Figure 4.1: Current Radiation Attenuation

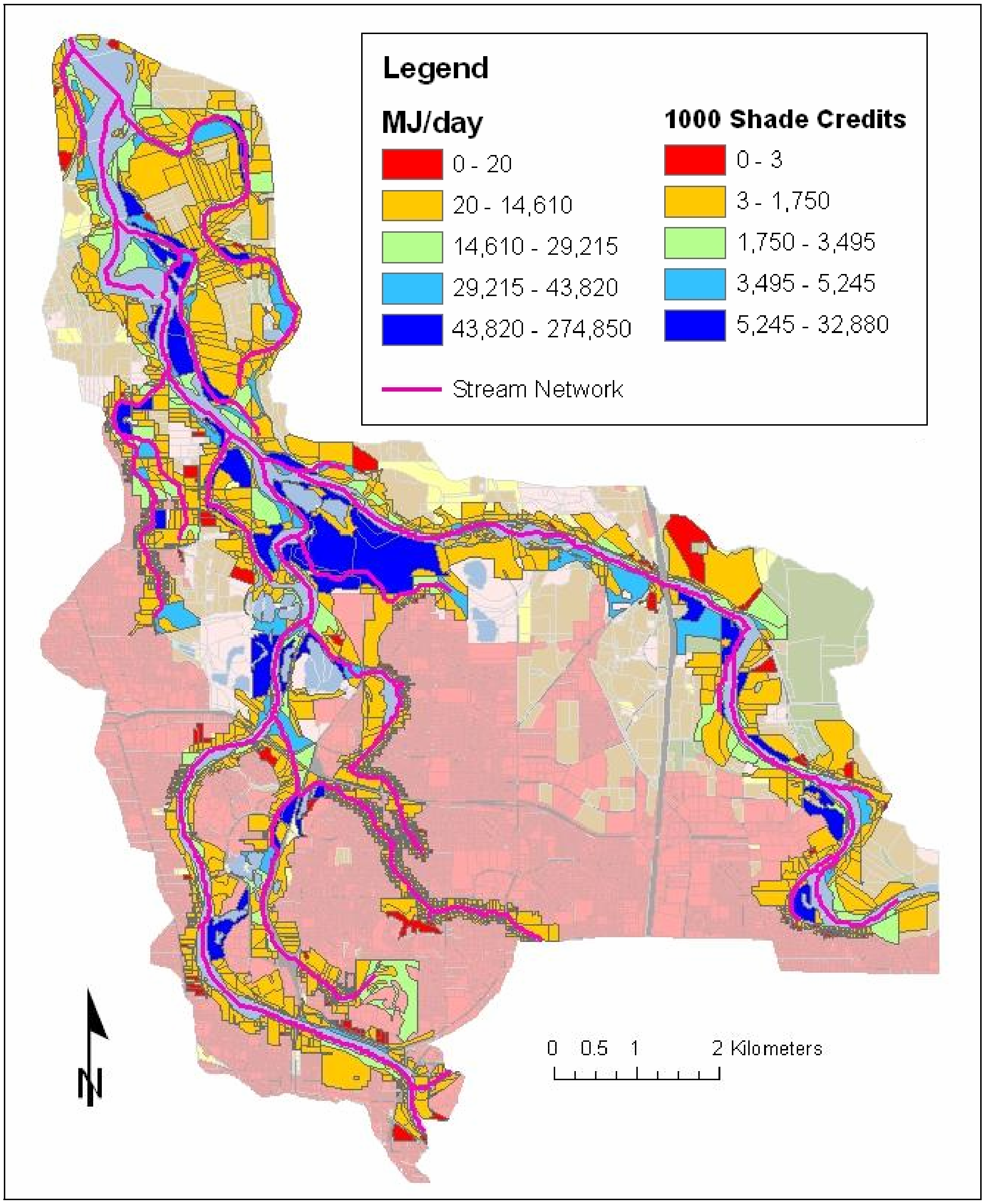

Figure 4.2: Potential Radiation Attenuation

These two maps give a perspective of shade as it is now and shade as it could potentially be, but a true tool to help land use managers focus their efforts would be a map showing the areas of highest incentive (cells with a low current attenuation, but a high potential attenuation). The map in Figure 4.3 illustrates this shade incentive landscape. As with the previous maps, color ranges were defined using the standard deviation of the dataset. There is a middle zone of minimal change (-3 to +3 shade credits), then three zones spaced at one standard deviation in both the positive and negative direction, then two final zones that stretch from the third standard deviation to the minimum and maximum values.

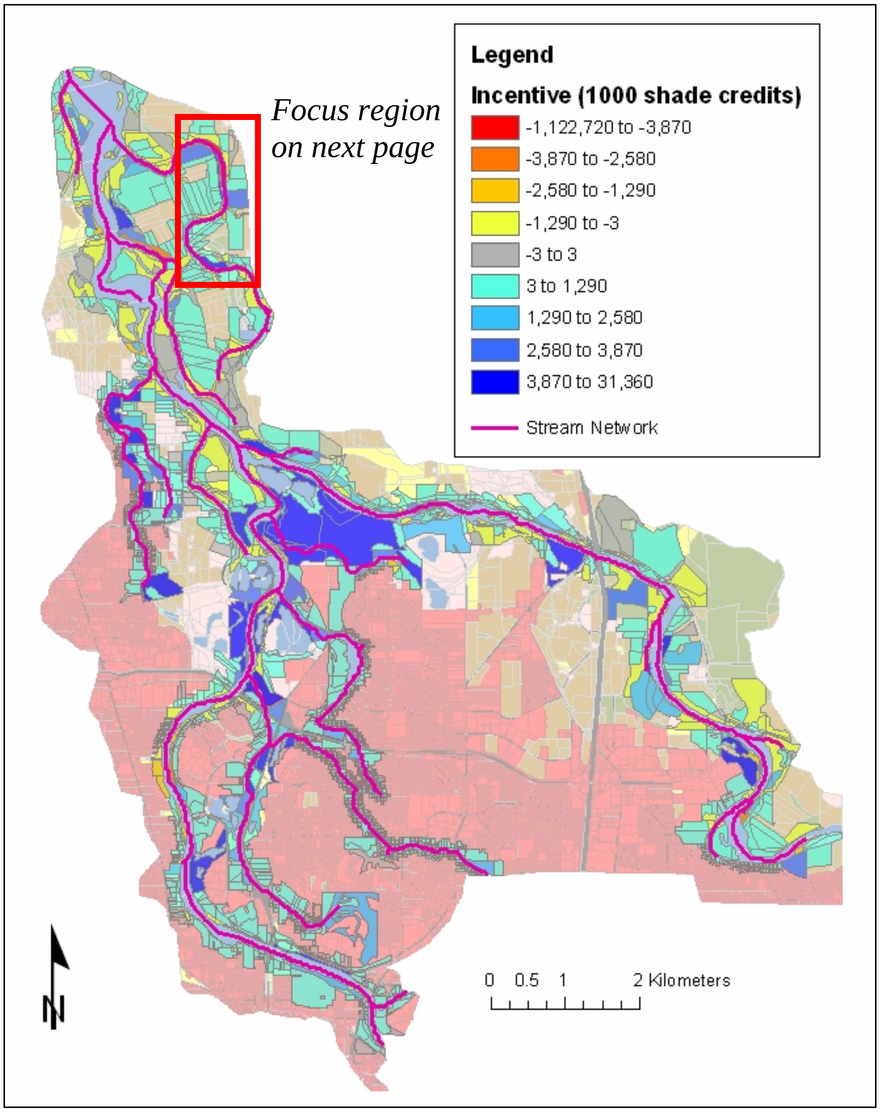

Figure 4.3: The incentive landscape based on 20-year SPV

Most of the cells in the incentive landscape above have the potential of generating an additional 3 to 1,290 shade credits, which could be predicted when comparing the current and potential attenuation maps. However, one fascinating aspect of the incentive landscape is that some cells actually have a negative incentive, meaning that their potential attenuation is less than their current attenuation. This phenomenon is illustrated at a larger scale below.

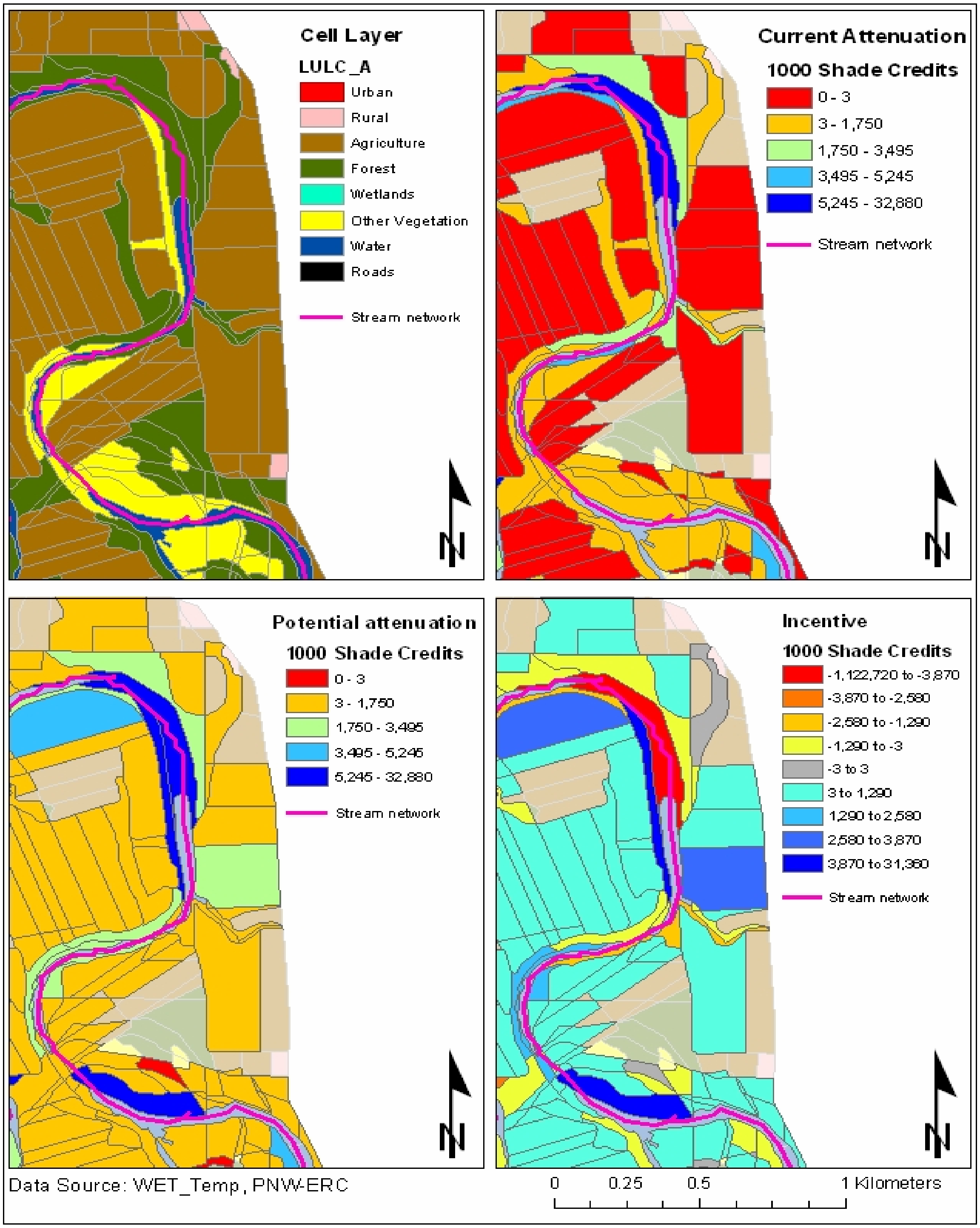

Figure 4.4: Components of incentive at a larger scale

Why does the amount of radiation blocked by a cell decrease, even though the vegetation of that cell has not changed? The example depicts a forested riparian area that currently is surrounded by low-shade agricultural land. Any solar radiation heading toward the sub-node over the course of the day arrives unfettered at this riparian vegetation, and any attenuation that occurs will occur because of this vegetation. In the twenty-year system potential landscape, the agricultural land is planted with trees, effectively building a wall in front of another wall. Less solar radiation now reaches the riparian area, and therefore less radiation is attenuated by this vegetation.

4.2. Highest incentive cells

Once the incentive was calculated for all cells in the landscape, it was now possible to isolate those cells with the highest incentive in order to a) get an idea of the characteristics of high incentive cells and b) to explore the effects of targeted management decisions (covered in section 4.3). Figure 4.5 highlights the cells that fall in the highest 50% of non-zero incentive, broken down between the first 25% and the second 25%.

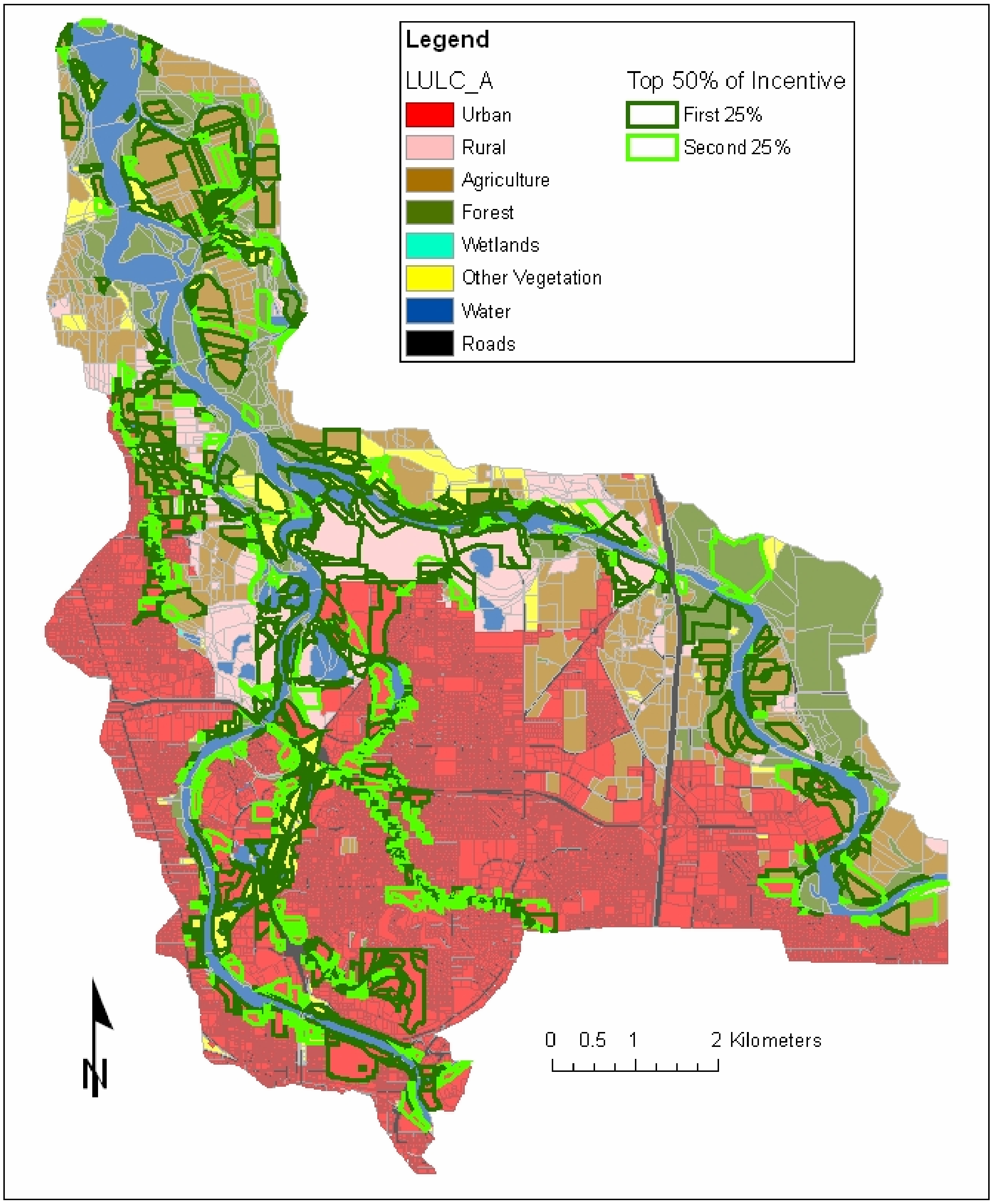

Figure 4.5: Top 50% of highest incentive cells

The top 50% illustrated above appears to be fairly equally distributed across the landscape and includes cells classified as urban, rural, agricultural and forest. Which current land uses have the highest incentive? Figure 4.6 shows the amount of incentive of the first 25% in order of increasing incentive, broken down at the medium articulation level (LULC_B). Included for comparison are the potential attenuation of these first 25% and the overall near-stream acreage for each land use/land cover. One detail to note is that the highest amount of incentive exists in areas of "Other Vegetation" (which in this case consist of natural shrubs along stream banks), even though the amount of acreage occupied by "Other Vegetation" is half of the acreage occupied by "Forest Hardwood", which is at the bottom of the first 25%.

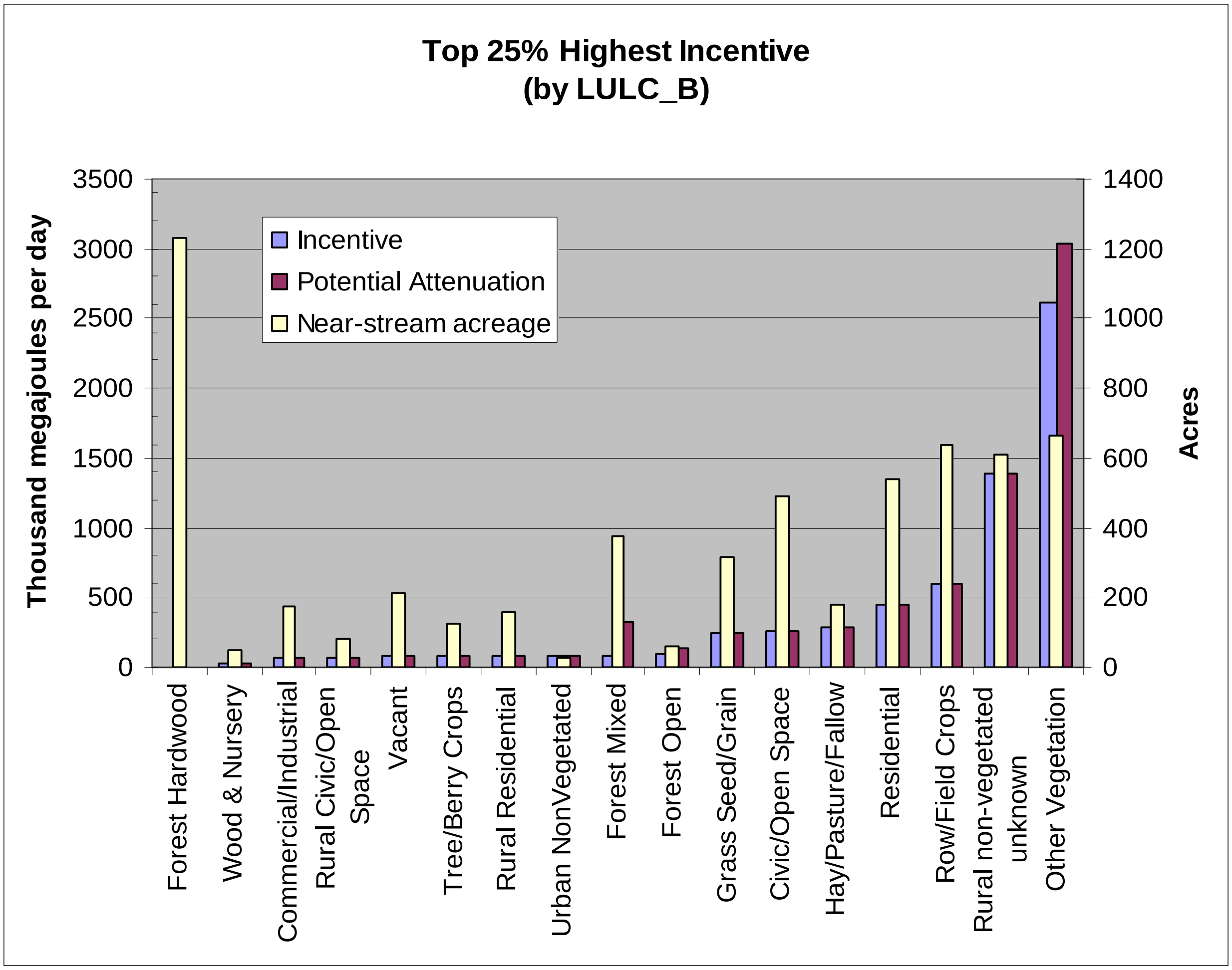

Figure 4.6: LULC_B breakdown of top 25% highest incentive

Another interesting consideration is the breakdown of land uses with the highest potential attenuation, regardless of incentive. Figure 4.7 displays the top 25% of highest potential radiation attenuation, in ascending order, broken down at the LULC_B level. Also included are the current attenuation for these cells and the overall near-stream acreage for each LULC. The "Forest Hardwood" class has the potential to block 4.4 million MJ of solar radiation per day in the study region, with the next two closest being “Other Vegetation” (capable of blocking 3 million MJ/day) and “Rural non-vegetated” (capable of blocking 1.4 million MJ/day).

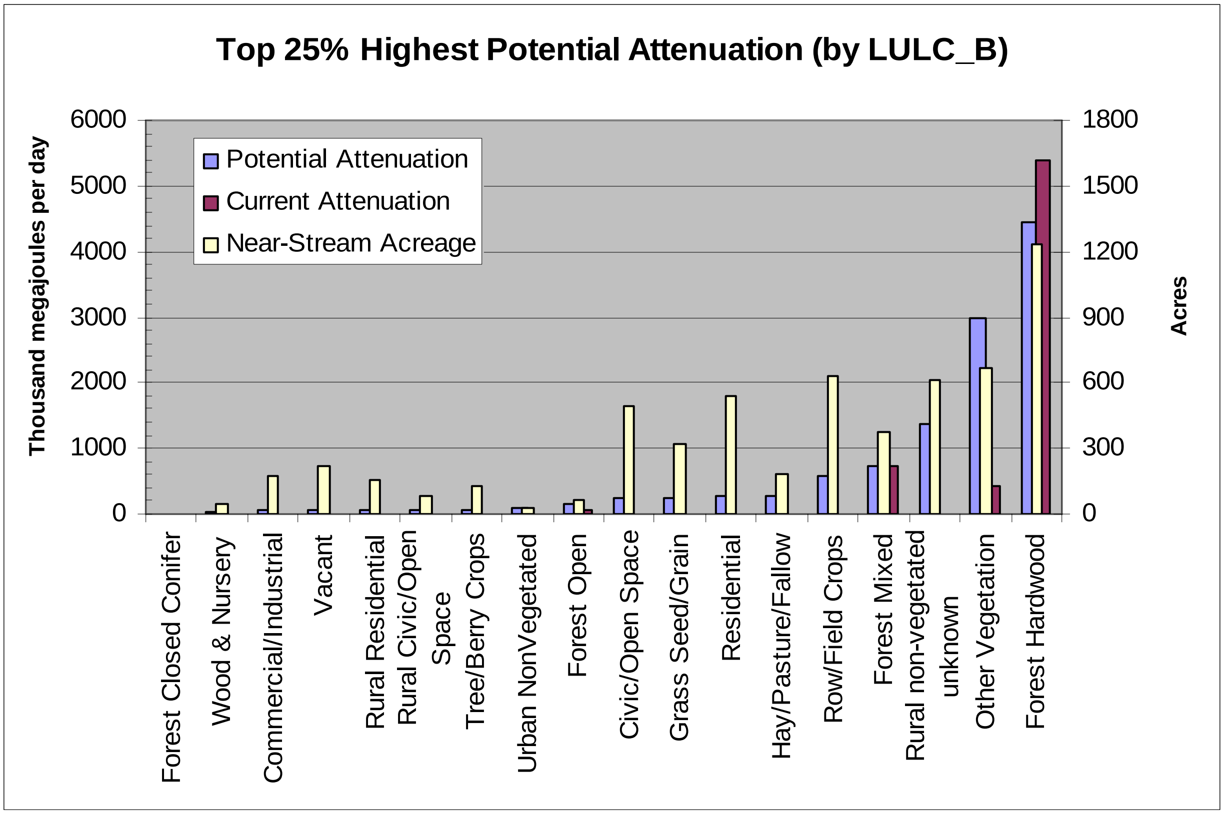

Figure 4.7: LULC_B breakdown of top 25% highest potential attenuation

4.3. Effects of management decisions on the incentive landscape

The final steps of this research project involved simulating a management decision by “planting” the twenty-year SPV in the top 25% of highest incentive cells, then exploring the new incentive landscapes that resulted. This top 25% was a group of 580 cells, which will be called the “*Original First 25%*” from here on. The incentive landscape exploration was done at three points in time: when the newly planted vegetation was a) half of its twenty-year height, b) three-quarters of its twenty-year height and c) its full twenty-year height. Primarily of interest was how the 580 cells with the highest incentive in the new incentive landscapes (called the “*New*

Top 580" from here on) compared to the second 25% of highest incentive cells in the original incentive landscape (called the "*Original Second 25%*" from here on). In other words, how does the distribution of incentive change when the landscape is altered as a result of management decisions or otherwise?

The outcomes of this exploration are illustrated in the figures on the next two pages. Figures 4.8 and 4.9 compare the *Original Second 25%* to the *New Top 580* when the vegetation is at half and three-quarters of its twenty-year height respectively. Cells that would have been in a second wave of plantings based on the original incentive breakdown, but are no longer in the top 580 highest incentive cells are displayed in red. Cells that would not have been in the second wave of plantings, but are now considered high incentive, are displayed in green, and cells that stayed high incentive are displayed in yellow. From Figure 4.8 alone, it is evident that the incentive landscape has changed as a result of the introduction of trees, even at half of their potential height. The changes to the incentive landscape that occur between half and three-quarters vegetation height are not as readily obvious, so several of these changes are indicated by black circles.

Figure 4.10 contrasts the *Original Second 25%* with the *New Top 580* once the newly planted vegetation has reached its twenty year-height. Interestingly, the figure indicates that this incentive landscape is much more similar to the original incentive landscape than the previous two. This indication is further accentuated in Table 4.1, which sums the change in potential radiation attenuation (in both kJ/day and shade credits) that would result from altering the second wave of plantings according to the incentive landscapes at the various vegetation heights.

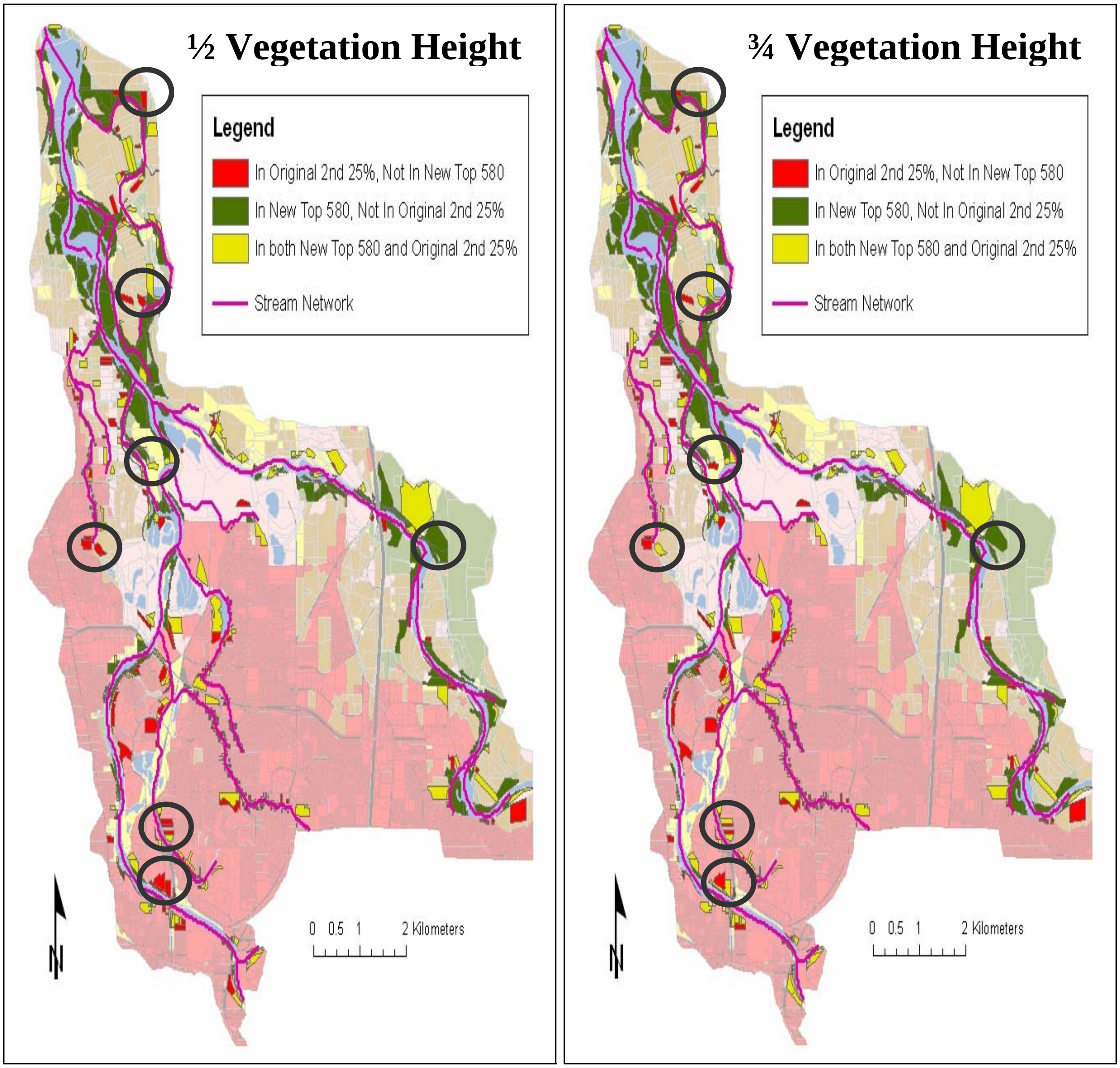

Figure 4.8:(left)Comparison of "Original 2nd 25%" and "New Top 580" at ½ of 20-year vegetation height

Figure 4.9:(right) Comparison of "Original 2nd 25%" and "New Top 580" at ¾ of 20-year vegetation height

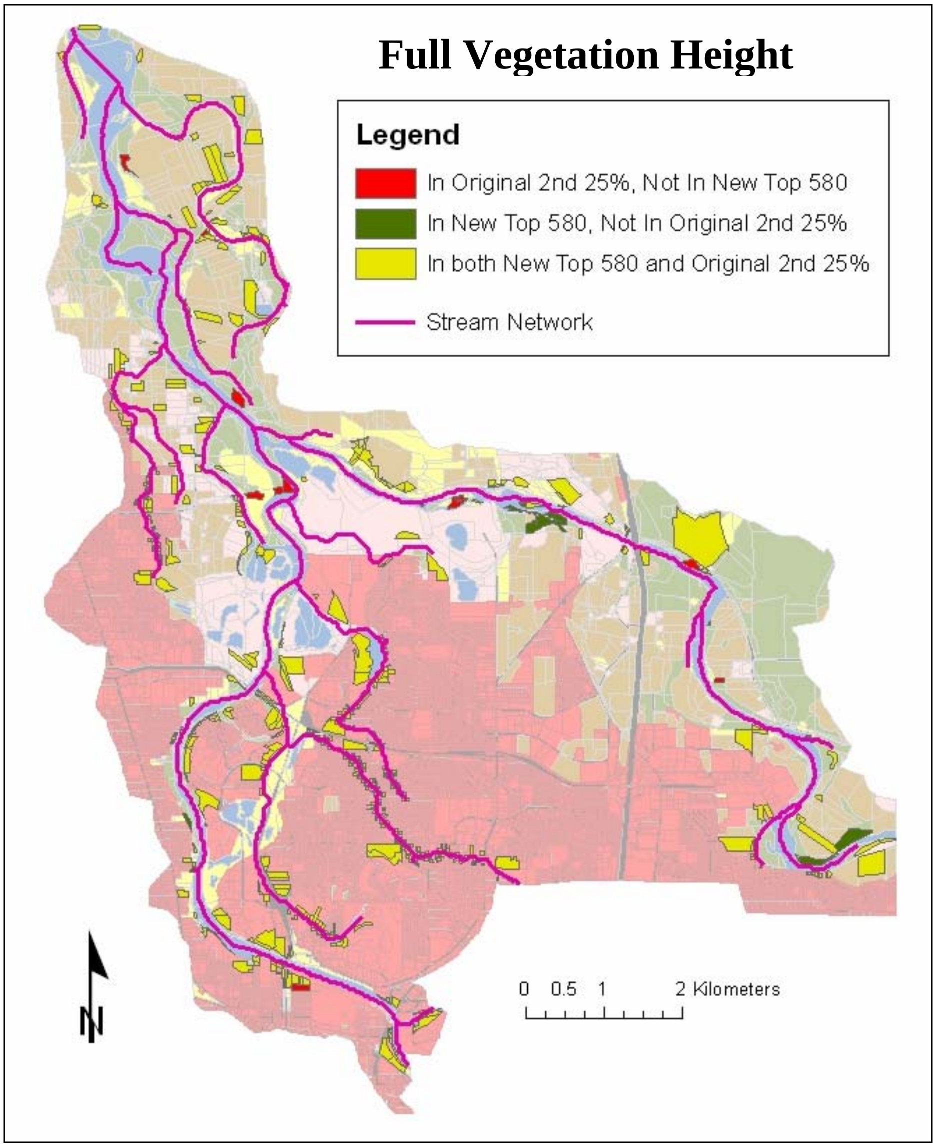

Figure 4.10: Comparison of "Original 2nd 25%" and "New Top 580" at full 20-year vegetation height

	1/2 OF 20-YEAR HEIGHT		3/4 OF 20-YEAR HEIGHT		AT 20-YEAR HEIGHT	
Cells	**Potential Attenuation (MJ/day)**	**Shade Credits**	**Potential Attenuation (MJ/day)**	**Shade Credits**	**Potential Attenuation (MJ/day)**	**Shade Credits**
Added (green)	4,742,849.29	567,326.47	4,464,052.71	533,977.60	132,617.61	15,863.35
Removed (red)	142,299.72	17,021.50	112,888.05	13,503.35	110,388.25	13,204.34
Difference	**4,600,549.57**	**550,304.97**	**4,351,164.67**	**520,474.24**	**22,229.36**	**2,659.01**

Table 4.1: Effect (in potential radiation attenuated) of altering second wave of planting based on the incentive landscape at various vegetation heights

5. Discussion

The outcomes illustrated in the "Results" section above have several implications for policy and for land use planners. First and foremost is the benefit of using a spatially-explicit stream temperature model in the planning process. The spatial input datasets used in WET_Temp are relatively easy to obtain, thus removing the initial processing and analysis needed to create a Heat Source spreadsheet and allowing for more efficient updates as the landscape changes. The spatial output of the WET_Temp model can be analyzed in a GIS alongside a myriad of other spatial datasets, bringing a level of complexity to the analysis that is not readily available with non-spatial data. Finally, the spatially-aware nature of the WET_Temp simulation allows it to be easily modified to consider other geographic information during processing as important spatial relationships emerge, such as the influence of hyporheic flow on stream temperature.

With the current focus on watershed-level planning, the shade incentive landscape maps illustrated above would be a valuable tool for a land use planner. Rather than approaching the challenge of achieving TMDL requirements on a case-by-case basis, an incentive landscape map would allow a planner to make informed planning decisions and target areas with the highest shade potential within the watershed. Also, having this watershed-level perspective allows the viewer to explore the geographic characteristics of cells with high shade potential and to look for patterns that may not be evident in a non-spatial view. For instance, the recognition that areas of high shade potential were often located at the confluence of stream reaches (due to the fact that vegetation on both sides of the cell would shade both reaches) might suggest that land owners of these cells should be among the first targeted when marketing shade incentive programs.

Another point of discussion that arises from the incentive landscape maps above is the potential positive effect of implementing shade incentive programs for non-agricultural areas. Subject to the assumptions made in the 20-year SPV transition matrices, much of the non-agricultural land in the study region is capable of generating shade. In fact, two of the top five land use/land cover classes found in the top 25% of highest incentive cells (Figure 4.6) are either "Rural" or "Other Vegetation". This fact contrasts sharply with the LULC_A breakdown in Figure 2.2 which shows that these two classes have the least amount of near-stream acres and lag behind the next class ("Agriculture") by 8% of the overall acreage. As mentioned in the "Results", "Other Vegetation" in this case refers to shrubs (LULC_C = 87, Appendix 2) that are located along streams in both urban and rural areas in the study region (shown as yellow on the cell layer map in Figure 3.1). The high incentive of these areas is due to their proximity to streams, not to some inherent characteristic of shrub lands; however, these areas may face less opposition to plant, have high shade potential and would be completely ignored with the current set of agriculture-focused shade credit programs.

A topic that Clean Water Services touches upon in their temperature management plan is their initial consideration of providing credit for the protection of existing shade. This idea was deemed to need more research, but will be part of a future pilot project (*CWS Temp. Mgmnt. Plan* 2004). Data gleaned from the incentive landscape would help to support this protection approach. Figure 4.7 indicates that the land use class with the highest potential for radiation attenuation is "Forest Hardwood". Though these areas have very low or even negative incentive (evident when one compares the current and potential attenuation in Figure 4.7), their potential attenuation exceeds the potential of the next highest land class, the shrub lands discussed previously, by 1.4 million MJ/day. Granted, the near-stream acreage of "Forest Hardwood" is nearly twice that of the shrub lands, which would easily account for this difference; however, this is somewhat irrelevant when considering a watershed-level planning approach, since the geography of each watershed should dictate the best shade program portfolio.

A final discussion point that surfaces in the "Results" is the inherent geographic nature of the incentive landscape. Spatial and temporal landscape changes affect the geometry of near-stream shade, which in turn affects the distribution of incentive in the landscape. A good example of this evolving near-stream shade geometry was seen in the negative incentive cells in Figure 4.4 (where the potential attenuation is less than the current attenuation).

This observation is particularly interesting when considering changes to near-stream shade geometry (and consequent changes to the incentive landscape) that result from land use planning decisions. If trees are selectively planted in areas with the biggest net gain in shade potential (i.e. highest incentive), how might this initial set of plantings influence future planning decisions as the shade landscape changes? Figures 4.8 through 4.10 show that as the newly planted vegetation grows, the resultant incentive landscape is altered from the original incentive landscape that informed the first prioritization of planting locations. This difference was most pronounced when the first wave of vegetation was at half of its twenty-year potential height, but when trees reached their potential height, the new incentive landscape more closely resembled the original incentive landscape. This is due to the fact that once the vegetation had reached its twenty-year potential height, the landscape was more similar to the potential attenuation landscape in Figure 4.2 (upon which the original incentive map was based) than the landscape in which this vegetation is at only half of its potential height. As can be seen in Table 4.1, altering the management plan based on the new incentive landscape at half vegetation height could, in twenty years, result in an additional eight million kJ of solar radiation being blocked per day relative to the original management plan.

The idea of incorporating landscape feedbacks into the management process is a tenet of the theory of "adaptive management", introduced as an approach to resource management by C.S. Holling at the University of British Columbia in the late 70's. Adaptive management, in theory, treats policy development as a series of experiments where careful design and monitoring allow the results of each management "treatment" to be analyzed, and inferences drawn from these results are used to inform the next wave of policy and monitoring (*An Introductory Guide to Adaptive Management* 2005). According to Gunderson, "adaptive management … views policy as hypotheses; that is, most policies are really questions masquerading as answers" (Gunderson 1999). In practice, this approach often runs into institutional and social complications (Lee 1999), but the concept, however loosely tied to the actual theory, still shows up frequently in management plans. For example, outcome three of the Oregon Plan for Salmon and Watersheds' Monitoring Strategy (created by the Oregon Watershed Enhancement Board) describes the need to "implement efficient monitoring, employ scientific assessments, and report results in ways that promote adaptive response [emphasis added] and informed participation" (*Oregon Plan, OWEB* 2003). This form of adaptive management, where landscape feedbacks influence management practices without rigorous experimental constructs, has been referred to as "passive adaptive management" (*An Introductory Guide to Adaptive Management* 2005).

Making use of the incentive landscape comparisons simulated above would be an application of passive adaptive management. The comparisons illustrate that the shade potential of a second wave of plantings can be optimized by adapting the original management plan based on landscape feedbacks. These adaptations would come in the form of changes to policy and shade incentive programs so as to target a new set of high incentive cells. In a shade credit program, "targeting" is done by adjusting the components of the shade credit calculation to favor high incentive cells in the hopes that increased shade credit value will influence the owners of these cells. Clean Water Services currently determines the number of shade credits based entirely on near-stream geometry, but has plans to use the RESTORE stream restoration prioritization model to include other important ancillary benefits of shade generation in the shade credit calculations. The incentive landscapes generated by WET_Temp could be expanded to include these considerations and could then be used to explore iterative shade management scenarios that would optimize ancillary benefits while attempting to efficiently achieve TMDL's.

5.1. Potential Sources of Error

This project, like any, has possible sources of error that may have influenced the results. One potential source of error is the accuracy of the input data. Lett (2002) compared the wetland classification done by the PNW-ERC to two other common classification systems used in Oregon and found discrepancies between the acreage and types of wetlands represented by each system (Lett 2002). Misclassification of input cells would affect the initial vegetation height and density estimates and would likely affect the potential landscape as well, since current LULC is an input to the SPV transition matrices. The assumptions used to create the transition matrices (Appendix 3) are another source of error in this project. Can the shrub lands along the stream banks really support a forest? Is it realistic to say that commercial land can support the 15 meter tall vegetation described by "Urban Overstory"? As with any modeling exercise, assumptions should be reviewed and revised as new information becomes available, and model results should be investigated on-the-ground prior to policy implementation.

6. Conclusions

This project has highlighted the benefits of using a spatially-explicit stream temperature model such as WET_Temp in planning efforts to reach stream temperature TMDL's. The project also introduced shade incentive landscape maps as a potential tool for land use planners to target ODEQ's high priority areas and "adaptively" manage their shade incentive programs. One area of future work would be to compare and calibrate the radiation attenuation output of WET_Temp to that of Heat Source, since the Willamette Valley TMDL documents and the CWS shade credit program depend on the latter. Also, the watershed-level capabilities of WET_Temp should be used to explore the impacts of these shade-focused management programs on stream temperature in order to see how the program results translate to actual achievement of temperature goals throughout the watershed. Since the Long Tom watershed is planned to be the next area for shade credit trading (through funding from the Willamette Partnership), this project should be repeated in the Long Tom region to give insight into the initial steps of the program implementation. Finally, the other potential approaches to stream temperature reduction that are currently being explored by the Willamette Partnership (such as the use of cold water refugia and/or hyporheic flow) should be incorporated into the incentive landscape analysis.

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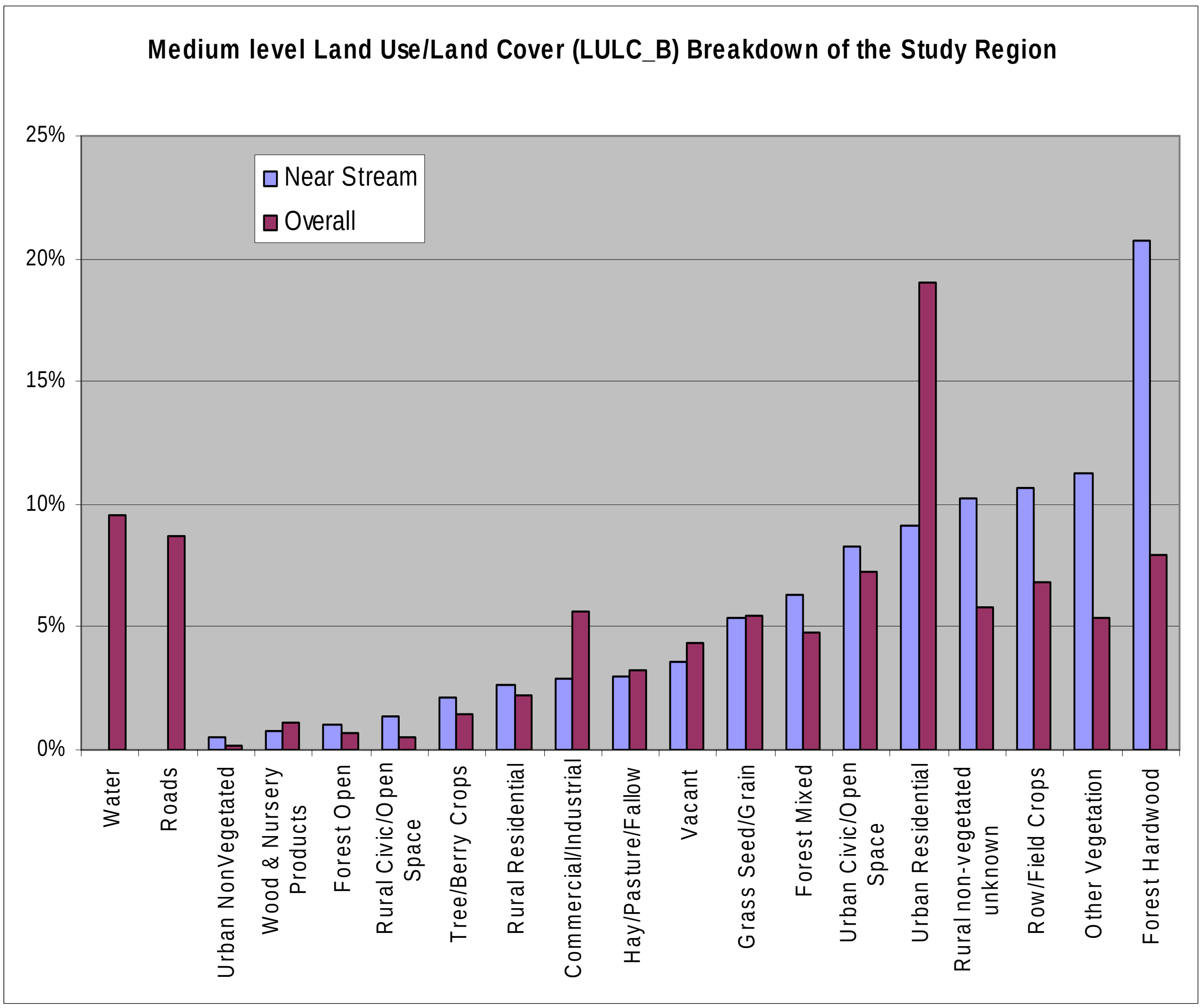
APPENDIX 1: LULC_B BREAKDOWN OF THE STUDY REGION

LULC_A = Coarse articulation
LULC_B = Medium articulation
LULC_C = Fine articulation
(see Appendix 2 for examples)

NOTE: Near stream refers to land within 100 meters of a stream that could be planted with riparian vegetation. Water and road LULC's were not included in the near stream group because they can not be planted.



APPENDIX 2: LAND USE / LAND COVER CLASSES & LEVELS OF ARTICULATION
(*LULC Descriptions* 2004)

Coarse LULC_A	Medium LULC_B	Fine LULC_C
Urban	Residential	Residential 0-4 DU/ac
		Residential 4-9 DU/ac
		Residential 9-16 DU/ac
		Residential >16 DU/ac
	Commercial/Industrial	Commercial
		Industrial
	Civic/Open Space	Civic/Open Space
	Vacant	Vacant
	Urban Non Vegetated	Urban Non Vegetated
Rural	Rural Residential	Rural Residential
	Rural non-vegetated unknown	Rural non-vegetated unknown
	Rural Civic/Open Space	Rural Civic/Open Space
Agriculture	Tree/Berry Crops	Orchard
		Vineyards/Cane berries
	Hay/Pasture/Fallow	Hay
		Pasture
		Bare/fallow
	Grass Seed/Grain	Grass seed
		Grain
	Row/Field Crops	Row crop
		Field crop
		Turf grass/park
	Wood & Nursery Products	Christmas trees
		Nursery Crops
		Hybrid poplar
		Woodlot
Forest	Forest Open	Forest open
	Forest Mixed	Forest Semi-closed mixed
		Forest Closed mixed
	Forest Hardwood	Forest Semi-closed hardwood
		Forest Closed hardwood
	Forest Semi-closed conifer	Forest Semi-closed conifer
	Forest Closed Conifer <= 80 Years	FCC 0-20 yrs
		FCC 21-40 yrs
		FCC 41-60 yrs
		FCC 61-80 yrs
	Forest Closed Conifer > 80 Years	FCC 81-200 yrs
		FCC > 200 yrs

Wetlands	Wetlands	Non-tree wetlands
		Flooded Marsh
Other Vegetation	Other Vegetation	Oak savanna
		Grassland
		Shrub lands
Water	Water	Channel non-vegetated
		Stream orders 1-4
		Stream orders 5-7
		Water
Roads	Roads	Primary roads
		Secondary roads
		Light duty roads
		Other roads

APPENDIX 3: TWENTY-YEAR SYSTEM POTENTIAL VEGETATION TRANSITION MATRICES

Geomorphic Class = Qalc

DEQ Modeling Breakdown (*Willamette TMDL: Appx. C* 2006)

Forest: 80% --> Conifer: 4%; Mixed hardwood/conifer: 93%; Hardwood: 3%

Savanna: 17% --> Mixed hardwood/conifer: 80%; Hardwood: 20%

Prairie: 3%

Tallest, densest vegetation for geomorphic class = mixed hardwood/conifer (LULC = 54)

LULC_C	LULC Description	Veg. Height (m)	Veg. Density (%)	Potential Veg.	Potential Vegetation Description	Veg. Height (m)	Veg. Density (%)
1	Residential 0 - 4 DU/ac	0	0	49	Urban Tree overstory	15	30
2	Residential 4 - 9 DU/ac	0	0	49	Urban Tree overstory	15	30
3	Residential 9 - 16 DU/ac	0	0	49	Urban Tree overstory	15	30
4	Residential > 16 DU/ac	0	0	49	Urban Tree overstory	15	30
5	Vacant	0	0	49	Urban Tree overstory	15	30
6	Commercial	0	0	49	Urban Tree overstory	15	30
8	Industrial	0	0	49	Urban Tree overstory	15	30
11	Urban non-vegetated unknown	0	0	49	Urban Tree overstory	15	30
12	Civic/Open Space	0	0	49	Urban Tree overstory	15	30
16	Rural structures	0	0	49	Urban Tree overstory	15	30
18	Railroad	0	0	18	Railroad	0	0
20	Secondary roads	0	0	20	Secondary roads	0	0
21	Light duty roads	0	0	21	Light duty roads	0	0
22	Other roads	0	0	22	Other roads	0	0
24	Rural non-vegetated unknown	0	0	54	Forest closed mixed	20	80
26	Rural Civic/Open Space	0	0	49	Urban Tree overstory	15	30
29	Main channel non-vegetated	0	0	29	Main channel non-vegetated	0	0
30	Stream orders 1-4	0	0	30	Stream orders 1-4	0	0
31	Stream orders 5-7	0	0	31	Stream orders 5-7	0	0
32	Stream orders 5 - 7	0	0	32	Stream orders 5 - 7	0	0
51	Forest open	20	15	54	Forest closed mixed	20	80
52	Forest semi-closed mixed	20	55	54	Forest closed mixed	20	80
53	Forest closed hardwood	15	80	53	Forest closed hardwood	15	80
54	Forest closed mixed	20	80	54	Forest closed mixed	20	80
58	Forest closed conifer 41 - 60 yrs.	22	85	58	Forest closed conifer 41 - 60 yrs.	22	85
67	Grass seed rotation	0	0	54	Forest closed mixed	20	80

71	Grains	0	0	54	Forest closed mixed	20	80
72	Nursery	0	0	54	Forest closed mixed	20	80
73	Berries & vineyards	0	0	54	Forest closed mixed	20	80
79	Row crop	0	0	54	Forest closed mixed	20	80
83	Hayfield	0	0	54	Forest closed mixed	20	80
85	Pasture	0	0	54	Forest closed mixed	20	80
86	Natural grassland	0.5	80	54	Forest closed mixed	20	80
87	Natural shrub	4	60	54	Forest closed mixed	20	80
88	Bare/fallow	0	0	54	Forest closed mixed	20	80
89	Flooded/marsh	0	0	89	Flooded/marsh	0	0
90	Irrigated field crop	0	0	54	Forest closed mixed	20	80
91	Turfgrass	0	0	54	Forest closed mixed	20	80
92	Orchard	0	0	54	Forest closed mixed	20	80
93	Christmas trees	0	0	54	Forest closed mixed	20	80

Geomorphic Class = Qg1

DEQ Modeling Breakdown (*Willamette TMDL: Appx. C* 2006)

Forest: 41% --> Conifer: 8%; Mixed hardwood/conifer: 59%; Hardwood: 33%

Savanna: 44% --> Mixed hardwood/conifer: 50%; Hardwood: 50%

Prairie: 15%

Tallest, densest vegetation for geomorphic class: mixed hardwood/conifer (LULC = 54)

LULC_C	LULC Description	Veg. Height (m)	Veg. Density (%)	Potential Veg.	Potential Vegetation Description	Veg. Height (m)	Veg. Density (%)
1	Residential 0 - 4 DU/ac	0	0	49	Urban Tree overstory	15	30
2	Residential 4 - 9 DU/ac	0	0	49	Urban Tree overstory	15	30
3	Residential 9 - 16 DU/ac	0	0	49	Urban Tree overstory	15	30
4	Residential > 16 DU/ac	0	0	49	Urban Tree overstory	15	30
5	Vacant	0	0	49	Urban Tree overstory	15	30
6	Commercial	0	0	49	Urban Tree overstory	15	30
8	Industrial	0	0	49	Urban Tree overstory	15	30
12	Civic/Open Space	0	0	49	Urban Tree overstory	15	30
16	Rural structures	0	0	49	Urban Tree overstory	15	30
18	Railroad	0	0	18	Railroad	0	0
19	Primary roads	0	0	19	Primary roads	0	0
20	Secondary roads	0	0	20	Secondary roads	0	0
21	Light duty roads	0	0	21	Light duty roads	0	0
22	Other roads	0	0	22	Other roads	0	0
24	Rural non-vegetated unknown	0	0	54	Forest closed mixed	20	80

30	Stream orders 1-4	0	0	30	Stream orders 1-4	0	0
31	Stream orders 5-7	0	0	31	Stream orders 5-7	0	0
32	Stream orders 5 - 7	0	0	32	Stream orders 5 - 7	20	80
52	Forest semi-closed mixed	20	55	54	Forest closed mixed	20	80
53	Forest closed hardwood	15	80	53	Forest closed hardwood	15	80
54	Forest closed mixed	20	80	54	Forest closed mixed	20	80
67	Grass seed rotation	0	0	54	Forest closed mixed	20	80
72	Nursery	0	0	54	Forest closed mixed	20	80
73	Berries & vineyards	0	0	54	Forest closed mixed	20	80
79	Row crop	0	0	54	Forest closed mixed	20	80
83	Hayfield	0	0	54	Forest closed mixed	20	80
85	Pasture	0	0	54	Forest closed mixed	20	80
86	Natural grassland	0.5	80	54	Forest closed mixed	20	80
87	Natural shrub	4	60	54	Forest closed mixed	20	80
88	Bare/fallow	0	0	54	Forest closed mixed	20	80
90	Irrigated field crop	0	0	54	Forest closed mixed	20	80
92	Orchard	0	0	54	Forest closed mixed	20	80

Geomorphic Class = Qg2

DEQ Modeling Breakdown (*Willamette TMDL: Appx. C* 2006)

Historically, this geomorphic class would have been 90% prairie along streams. However, due to water diversions in these areas to maintain summer flow, ODEQ feels that historic vegetation is not a good indicator of potential vegetation and recommends using the nearest adjacent land cover.

LULC_C	LULC Description	Veg. Height (m)	Veg. Density (%)	Potential Veg.	Potential Vegetation Description	Veg. Height (m)	Veg. Density (%)
8	Industrial	0	0	Used the transition matrix of the nearest adjacent geomorphic class. There were only ten parcels that fit into this geomorphic class, and all of them either had a portion of their land in another geomorphic class or were VERY close to another geomorphic class.			
12	Civic/Open Space	0	0				
16	Rural structures	0	0				
21	Light duty roads	0	0				
24	Rural non-vegetated unknown	0	0				
30	Stream orders 1-4	0	0				
53	Forest closed hardwood	15	80				
67	Grass seed rotation	0	0				
71	Grains	0	0				
73	Berries & vineyards	0	0				
79	Row crop	0	0				
85	Pasture	0	0				
87	Natural shrub	4	60				
88	Bare/fallow	0	0				

Geomorphic Class = Tvw							
DEQ Modeling Breakdown (*Willamette TMDL: Appx. C* 2006)							
Forest: 57% --> Conifer: 84%; Mixed hardwood/conifer: 16%							
Savanna: 39% --> Mixed hardwood/conifer: 45%; Hardwood: 55%							
Prairie: 4%							
Tallest, densest vegetation for geomorphic class: forest closed conifer 21-40 years (LULC = 57)							
LULC_C	LULC Description	Veg. Height (m)	Veg. Density (%)	Potential Veg.	Potential Vegetation Description	Veg. Height (m)	Veg. Density (%)
1	Residential 0 - 4 DU/ac	0	0	49	Urban Tree overstory	15	30
2	Residential 4 - 9 DU/ac	0	0	49	Urban Tree overstory	15	30
3	Residential 9 - 16 DU/ac	0	0	49	Urban Tree overstory	15	30
4	Residential > 16 DU/ac	0	0	49	Urban Tree overstory	15	30
5	Vacant	0	0	49	Urban Tree overstory	15	30
6	Commercial	0	0	49	Urban Tree overstory	15	30
8	Industrial	0	0	49	Urban Tree overstory	15	30
12	Civic/Open Space	0	0	49	Urban Tree overstory	15	30
16	Rural structures	0	0	49	Urban Tree overstory	15	30
22	Other roads	0	0	22	Other roads	0	0
51	Forest open	20	15	57	Forest closed conifer 21-40 years	14	85
52	Forest semi-closed mixed	20	55	52	Forest semi-closed mixed	20	55
53	Forest closed hardwood	15	80	53	Forest closed hardwood	15	80
54	Forest closed mixed	20	80	54	Forest closed mixed	20	80
60	Forest closed conifer 81 - 200 yrs.	43	85	60	Forest closed conifer 81 - 200 yrs.	43	85
79	Row crop	0	0	57	Forest closed conifer 21-40 years	14	85
85	Pasture	0	0	57	Forest closed conifer 21-40 years	14	85
87	Natural shrub	4	60	57	Forest closed conifer 21-40 years	14	85
90	Irrigated field crop	0	0	57	Forest closed conifer 21-40 years	14	85
92	Orchard	0	0	57	Forest closed conifer 21-40 years	14	85

Geomorphic Class = Tm							
DEQ Modeling Breakdown (*Willamette TMDL: Appx. C* 2006)							
Forest: 56% --> Conifer: 40%; Mixed hardwood/conifer: 60%							
Savanna: 39% --> Mixed hardwood/conifer: 59%; Hardwood: 41%							
Prairie: 5%							
Tallest, densest vegetation for geomorphic class: mixed hardwood/conifer (LULC = 54)							
LULC_C	LULC Description	Veg. Height (m)	Veg. Density (%)	Potential Veg.	Potential Vegetation Description	Veg. Height (m)	Veg. Density (%)
1	Residential 0 - 4 DU/ac	0	0	49	Urban Tree overstory	15	30
2	Residential 4 - 9 DU/ac	0	0	49	Urban Tree overstory	15	30
3	Residential 9 - 16 DU/ac	0	0	49	Urban Tree overstory	15	30
5	Vacant	0	0	49	Urban Tree overstory	15	30
12	Civic/Open Space	0	0	49	Urban Tree overstory	15	30
22	Other roads	0	0	22	Other roads	0	0