A Cost-Effectiveness Analysis of Actions to Reduce Stream Temperature at the Watershed Scale

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Introduction and Rationale

Increasing public attention has been focused on resource use for multiple economic and environmental goals. In Oregon, this public interest resulted in the establishment of watershed councils. These councils work with government agencies and interest groups to design and implement plans for watershed restoration and protection. In many cases, participation by local interest groups is voluntary although some funding, technical assistance and incentive schemes are available. Many watershed councils conduct an assessment of their watershed and use this as a starting point to develop plans for resource enhancement. However, in many cases the councils do not have an estimate of the overall cost or distribution of costs that would be incurred between interest groups if the plans were implemented. Assessing the economic and environmental tradeoffs faced by local interest groups is an important step in the planning process. Knowledge of the potential tradeoffs can indicate to planners whether their proposals are likely to be successful and can also identify whether particular groups might need special incentives to participate in the scheme.

This paper uses a cost effectiveness analysis to examine economic and environmental tradeoffs as a result of planting treed riparian buffers to reduce stream temperature in the Mohawk watershed, western Oregon. The economic model estimates the total costs of each alternative considered as well as the distribution of those costs between the timber, agriculture and residential sectors within the watershed. Only the estimates of total cost are discussed in this paper due to space limitations.

The Mohawk watershed is a multiple ownership, multiple use watershed spanning approximately 177 square miles (113,625 acres). Industrial timber lands, both public and private, dominate the higher elevations transitioning through non-industrial timber lands to a mix of agricultural and residential activities on the valley floor. The Mohawk River and one of its major tributaries, Mill Creek, are listed as water quality limited on the basis of temperature by the Oregon Department of Environmental Quality (ODEQ 1996). Streams are listed if the average maximum daily water temperature for the streams' warmest consecutive seven-day period during the year exceeds 64 ^{o}F.

High stream temperatures are a concern as they have been shown to reduce the survival, growth and reproduction rates of steelhead trout and salmon (Hostetler 1991) and reduce the available dissolved oxygen for all aquatic biota (Boyd 1996). Improving water quality within the Mohawk watershed is a goal of the local watershed council. However the council is unclear concerning the degree to reduce water temperature below the standard, what measures are necessary to do this or the total cost and distribution of costs between interest groups within the watershed.

Selecting Actions to Reduce Stream Temperatures

There are many factors that influence stream temperature (Beschta *et al.* 1987). However, the primary source of energy for stream heating during the summer months is incoming solar radiation (Beschta *et al.* 1987). Riparian buffer strips[1] can be planted to provide shade and are thought to reduce stream temperatures (Brown 1983, Beschta *et al.* 1987, Sullivan *et al.* 1990, Boyd 1996). In addition to the incidence of shading, the location of shading is important (Beschta *et al.* 1987). Once stream temperature has increased, the heat is not easily dissipated even if the stream subsequently flows through a shaded reach (Beschta *et al.* 1987)

[1] A riparian buffer strip is a protective area adjacent to a stream that shields it from the effects of harmful management practices. Treed riparian buffers are considered in this paper.

indicating the importance of maintaining shade along the headwaters and tributaries of the stream in addition to the mainstem.[2]

Table 1.1 presents thirteen scenarios designed for this study that represent the base/current buffer and tax policy prescriptions in the watershed and combinations of alternative buffer scenarios and tax policies that vary by land use. Land use within the watershed is classified into four categories, industrial timber, non-industrial private timber, agricultural and residential.

Table 1.1. Summary of Riparian Buffer and Tax Policy Scenarios[a]

Tax Policies / **Buffer scenarios**	Policy 1 *Status quo*	Policy 2 *Farm or Forest Deferral*	Policy 3 *Riparian Tax Incentive Program*
Scenario 1 *Current Conditions*	**B***B*		
Scenario 2 *Agricultural Buffer*	**AB***B*	**AB***D*	**AB***TIP*
Scenario 3 *Agricultural and Residential Buffer*	**ARB***B*	**ARB***D*	**ARB***TIP*
Scenario 4 *Complete 50 foot buffer*	**50B***B*	**50B***D*	**50B***TIP*
Scenario 5 *Forest Practices Act*	**FPAB***B*	**FPAB***D*	**FPAB***TIP*

[a]The first part of the abbreviation refers to the buffer prescription and is noted in bold type. The second part of the abbreviation represents the tax policy and is noted in italics.

[2] In addition to providing stream shade, riparian buffers provide many other functions. O'Laughlin and Belt (1995) list the following beneficial functions: providing shade, organic debris, regulating sediment and nutrient flow, stream bank stabilization, moderating riparian micro-climate and providing wildlife habitat. The manner in which a riparian buffer provides these functions is described in O'Laughlin and Belt (1995).

Buffer scenario 1 (**B**) reflects the current situation. Riparian buffer widths are consistent with the Oregon Forest Practices Act[3] prescriptions on industrial timberland and observed buffer widths are assumed in other areas. In buffer scenario 2 (**AB**), riparian buffers consistent with the Oregon Forest Practices Act are assumed on large industrial and non-industrial timberlands. A 50-foot buffer is assumed on all agricultural land and existing buffer widths are assumed on residential lands. In buffer scenario 3 (**ARB**) riparian buffers consistent with the Forest Practices Act are assumed on large industrial timber and non-industrial timberlands. A 50-foot riparian buffer is assumed for all residential and agricultural lands. Buffer scenario 4 (**50B**) assumes a 50-foot wide riparian buffer across the entire watershed regardless of stream size or adjacent landuse. In buffer scenario 5 (**FPAB**), buffers consistent with the Forest Practices Act are assumed across the entire watershed regardless of land use.

Three tax policies are considered with the buffer scenarios. Policy *B*, is the *status quo*, or base tax policy.[4] The second policy (*D*) provides for a farm or forestland deferral on all lands that participate in the riparian planting scheme (except industrial timberland). The farm or forestland deferral applies to the entire tax lot not just the area planted in trees and reduces the assessed value of the entire tax lot upon which riparian plantings are made. The last policy (*TIP*) is based on the Oregon riparian tax incentive program. All land areas with a *bona-fide* riparian protection plan are totally removed from the owners tax base.[5] The remaining area of the land parcel is assessed at the regular value.

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[3] A buffer of 100 ft wide on large, 70 ft wide on medium and 50 ft wide on small streams with fish and domestic water use (Forest Practice Administrative Rules 1995).

[4] The amount of tax paid per acre of land is a combination of the assessed value of that land and the tax rate per $1000 of assessed value. Every landowner is taxed at the same rate. However, landowners can receive a tax break by lowering the assessed value of their land. The policies described alter the assessed value of the land, not the tax rate.

[5] That is their assessed value is zero.

Calculating Environmental and Economic Tradeoffs

In a situation where the outcomes of a range of actions are the same (or similar) a cost effectiveness analysis can be used to identify the least cost alternative that achieves a given environmental improvement. Economic welfare change and corresponding reductions in stream temperature are calculated for each riparian buffer prescription and tax policy alternative. Each pair of estimates can be plotted to identify the cost-effectiveness frontier. The most efficient alternatives for reducing stream temperature are located on the cost-effectiveness frontier. It is important to note that a cost-effectiveness frontier represents the least cost envelope of points only over the range of alternatives considered.

Model Description

The general problem faced by producers and consumers in the Mohawk watershed can be thought of as one of maximizing total welfare subject to technological, institutional, market, legal and other constraints such as the availability of productive land, buffer strip requirements, or restrictions on logging and grazing. A mathematical programming model is developed to generate empirical estimates of welfare change in response to the thirteen scenarios described in the previous section. A schematic of the model is shown in figure 1.1. The objective function is to maximise the returns to land from timber and agricultural production activities plus the current 30 year annuity value of expenditures on residential property (including taxes). The model does not optimize over housing choices. It takes existing housing choices as the given observable solutions to the individual consumer utility maximization problems.[6]

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[6] A detailed description of this model can be found in Mooney (1997).

The model has two problem specific features. A hedonic pricing analysis is used to provide an empirical estimate of the relationship between residential property values and an increase or decrease in riparian buffer width. This coefficient is used in the mathematical programming model to change the price of residential properties adjacent to a stream in response to changes in the width of the riparian buffer. The quantity of residential housing selected by the model remains constant between alternative buffer width scenarios. This constraint allows the model to calculate the dollar value of consumer welfare generated by a different bundle of environmental attributes, on existing residential properties, in relation to the previous utility maximizing choice. Stream temperature response to a change in riparian buffer width is calculated by taking the buffer widths specified within the mathematical programming model and using them as input to a stream temperature estimator, *Heat Source*.[7]

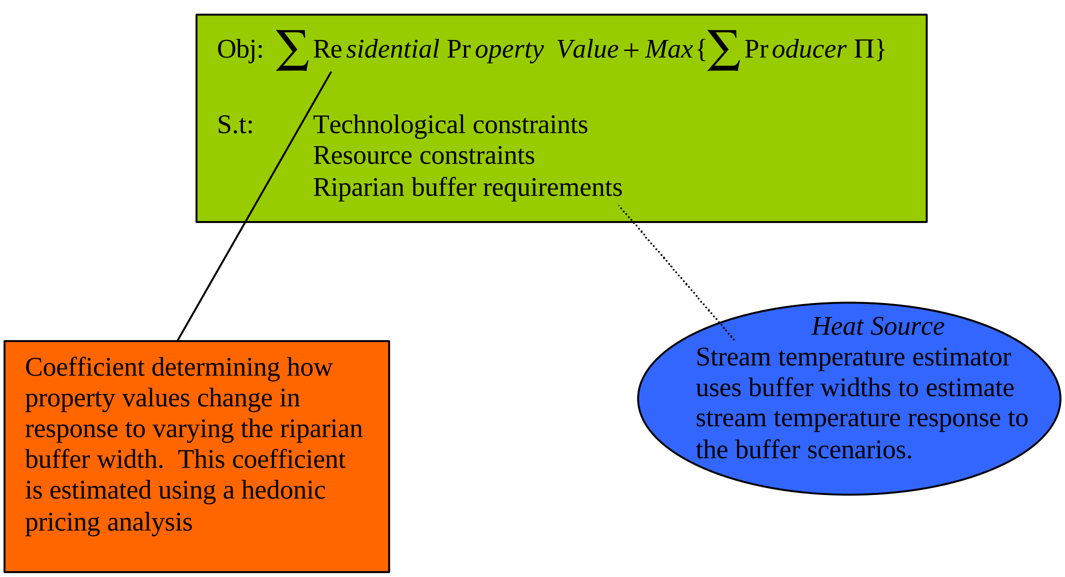

Figure 1.1. Schematic of Model

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[7] A detailed description of the model can be found in Boyd (1996).

Land area constraints provide a link between changes in the width of the riparian buffer on each land type and stream temperature response. The buffer width and linear feet of riparian frontage associated with each land type is used to calculate the total land area in a riparian buffer by land type.

Technical and rotational constraints are also included in the model. The Mohawk watershed has the potential to be an agriculturally productive area based on soil type and crop yield estimates. However, the area is currently used for production at a level significantly below its potential. Personal visits to the area, discussion with extension agents and the results of a personal interview survey of local residents indicate that the majority of the area is under or unutilized for agriculture. Current production estimates were obtained from local extension agents and aerial photograph interpretation.

Results

Table 1.2 presents the total dollar value of welfare change estimated by the mathematical programming model in response to each of the riparian buffer and tax policy scenarios. The corresponding effectiveness of each scenario in reducing stream temperature is also presented in table 1.2. An entire stream temperature scenario requires 164 consecutive runs of the stream temperature model, *Heat Source*, to account for water as it is transported from the headwaters to the confluence (see Mooney (1997) for more details). Each model run generates a daily maximum and minimum temperature for a stream segment. Temperatures from the upstream reach are used as input to generate temperature estimates for the next downstream reach. Effectiveness, or success, in terms of stream temperature reduction is measured as the percentage of these model runs for which the predicted maximum daily stream temperature is equal to or below 64^{o}F. A failure in terms of this standard differs from the conditions required to fail the standard set by ODEQ as it is based on a single temperature measurement above 64°F rather than a seven-day average.

Table 1.2. Total Welfare Change in Comparison to the Base Scenario **B***B* and Effectiveness of Each Scenario

Scenario	Welfare change from scenario BB	Effectiveness, % reaches ≤64 °F
B*B*	0,000	21
AB*B*	-10,553	36
AB*D*	127,209	36
AB*TIP*	-926	36
ARB*B*	-120,628	36
ARB*D*	17,134	36
ARB*TIP*	-110,890	36
50B*B*	-34,946	10
50B*D*	-102,816	10
50B*TIP*	-25,404	10
FPAB*B*	-552,133	44
FPAB*D*	-414,371	44
FPAB*TIP*	-533,121	44

Cost-Effectiveness Frontier

Figure 1.2 displays the cost (welfare change) and corresponding effectiveness of all buffer and tax policy alternatives reported in table 1.2. The cost of each scenario is measured on the x-axis as the total welfare changes from the base scenario **B***B*. The effectiveness of each measure in reducing stream temperature is plotted on the y-axis. The cost effectiveness frontier depicts the least cost alternatives (among those considered) that can be used to decrease overall stream temperature (i.e. increase the percentage of model runs with a daily maximum temperature equal to or below 64 °F).

Scenarios **AB***D* and **FPAB***D* are on the cost-effectiveness frontier. Under scenario **AB***D* the welfare of watershed residents increases by $127,000 in comparison to the base scenario and the percentage of stream reaches with a maximum temperature at or below 64 °F increases from 21 percent to 36 percent. These results indicate that an additional 15 percent of stream reaches can achieve the temperature standard and total welfare can be increased if the riparian planting scenario is accompanied by a policy that grants a tax deferral for all lots on which a riparian buffer is planted. The welfare increase is experienced across all land uses within the watershed.

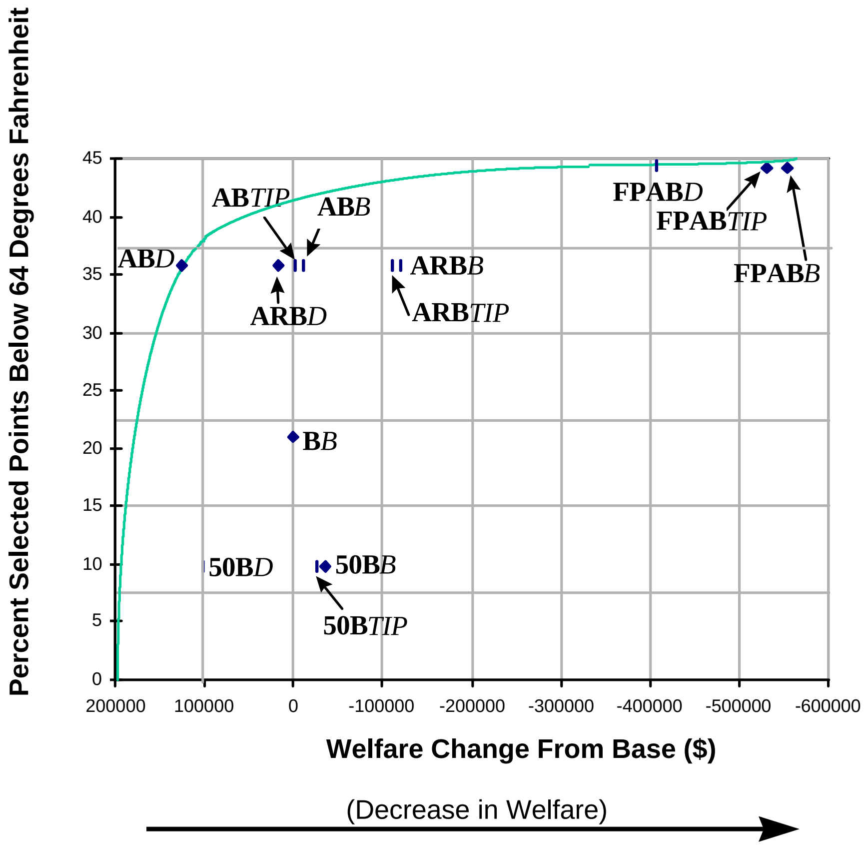

Figure 1.2. Cost and Effectiveness of Actions and Policies to Reduce Stream Temperature

However, it is important to note that this welfare gain is generated at the expense of a decline in property tax revenues which could reduce the services provided in the area or alternatively increase the tax burden faced by residents in other areas to make up the shortfall. The tax deferral will reduce tax dollars generated in the watershed by approximately $138,000 in comparison to the case where no tax incentive is offered for the same buffer requirement (scenario **AB***B*). A tax deferral in this case overcompensates property owners for planting a riparian buffer in trees.

Scenario **FPAB***D* provides for a riparian buffer strip consistent with the Forest Practices Act in addition to a tax deferral. An additional 23 percent of stream reaches meet or exceed the temperature standard under **FPAB***D* in comparison to the base scenario (an increase from 21 percent to 44 percent) at a cost of $414,371 across the watershed. The reduction in tax revenues in comparison to the case where no tax incentive is offered for the same buffer requirement (scenario **FPAB***B*) is also approximately $138,000.[8] Although the scenario results in an overall welfare loss this tax deferral scheme increases the welfare of agricultural and non-industrial timber producers in relation to the base case scenario. The agricultural sector experiences an increase in welfare as the decrease in tax liability exceeds the value of production on some lands. When this is the case landowners are better off switching land to riparian plantings rather than using it in production. The majority of costs associated with this scenario are experienced by the residential sector in the form of a lower willingness to pay for properties with wider treed riparian buffers.

Assuming that the tax incentives discussed are acceptable in practice, the choice of which policy to select from those on the frontier in figure 1.2 is a choice to be made by the residents of the Mohawk watershed. Both policies increase the percentage of reaches that meet the 64 ^{o}F temperature standard. However, they differ in their effectiveness, total costs and distribution of costs. From the perspective of a policy maker, both policies cost the same in terms of a reduction in tax revenues ($138,000), but scenario **FPAB***D* is more effective in reducing stream temperatures. Although the policy may appear to place a disproportionately heavy burden upon residential land owners in comparison the agricultural and forestry sectors, this cost is skewed as

[8] The difference will be the same no matter how much of the tax lot is planted in a riparian buffer as the whole lot is eligible for a deferral and so the tax cost is the same under this policy whether the area is planted in buffers 10 feet wide or 100 feet wide.

it does not take into account the welfare losses already accepted by the forestry sector as a result of the Forest Practices Act (this was taken to be the *status quo*).

Conclusions

A cost effectiveness analysis was shown to be a suitable means of examining tradeoffs between economic and environmental goals at the watershed scale. The analysis provides information for decision-makers and planners about the costs and effectiveness to reduce stream temperature. Riparian buffers were demonstrated to be an effective means of reducing stream temperature over part of the Mohawk watershed. However, the buffer scenarios considered could not reduce temperature in all reaches sufficiently to meet the temperature standard. It might be possible to reduce stream temperatures further by combining the riparian buffer prescriptions with additional practices such as flow augmentation.[9] The economic model identified that, in the absence of mitigating tax programs, measures to reduce stream temperature did decrease welfare in the watershed. The largest reduction of net annual welfare was $552,133 (scenario **FPAB***B*, table 1.2). Most of this decrease was experienced by the residential sector.[10]

The two tax programs considered, i.e., a tax deferral and riparian tax incentive, indicate that it is possible to alter the distribution of welfare changes between resource users and in some cases reverse the direction of welfare change in comparison to scenarios that do not consider incentive programs. This effect is particularly apparent on agricultural lands in the scenarios that consider a tax deferral. This indicates that an improvement in environmental quality need not come at any welfare loss to residents if the right incentive programs can be identified for different sectors. In fact it is probably possible to increase agricultural welfare without offering a

[9] Stream heating is inversely proportional to flow (Boyd 1996, Beschta *et al.* 1987).

[10] Note that the benefits generated from a decrease in stream temperature are not calculated in a cost-effectiveness analysis.

tax incentive. For example, riparian plantings could be combined with education to increase production efficiency, which could both increase the non-market amenities and agricultural welfare. The tax programs also influence welfare changes in the residential sector. However, in general the analysis showed that a reduction in tax revenues is not sufficient to offset the perceived amenity loss resulting from wider treed riparian buffers on residential properties.[11] The distribution of welfare changes between sectors will influence policy chosen from the frontier by local interest groups if riparian plantings are voluntary.

From a policy makers perspective each policy on the cost-effectiveness frontier results in the same decline in tax revenues. If the plantings were mandatory the choice of which policy to select will depend on whether a particular standard needed to be met or political factors such as the will of policy makers to request property owners to bear the welfare loss.

The location of riparian planting is an important consideration when designing riparian buffer prescriptions on the watershed scale. A comparison of the buffer prescriptions **50B** and **ARB** demonstrate the importance of keeping a stream shaded from the headwaters on down, to maximize the effectiveness of buffer prescriptions. This suggests that policies based on land use might not be as effective as policies that target lands on the basis of spatial location.

[11] Welfare losses in the residential sector are based on the assumption that the marginal willingness to pay for an additional square foot of trees in the riparian area is constant (that is, the marginal willingness to pay function is horizontal).

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