Efficient Patterns of Conservation Activities in a Watershed:

The Case of the Grande Ronde River, Oregon

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I. INTRODUCTION

Salmonid populations have declined in many stream systems in the Pacific Northwest (PNW). To date, six salmonid species have been listed as threatened or endangered under provision of the Endangered Species Act (ESA). One of the causes for this decline is high summer and early fall water temperatures, which frequently exceed sub-lethal levels (ODEQ, 2000). Temperature problems are particularly acute in their rearing and spawning habitat areas. In order to decrease water temperature and improve fish habitat, a range of conservation practices have been suggested and implemented (Northwest Power Planning Council, 2000). The efficacy of these practices has been questioned, given the substantial resources expended and the relatively poor success to date in recovering endangered stocks.

This paper reports on research that examines efficient allocations of conservation practices in a representative Pacific Northwest watershed to meet water temperature targets. As defined here, an allocation of conservation practices is efficient if the temperature target is attained at minimum cost. In this research, a simulation study is conducted that integrates hydrological, biological, and economic models, and is based on GIS and spatially referenced data. Results from the simulations provide insights into the role of spatial considerations in managing complex bioeconomic problems.

The focus of the study is the Grande Ronde River basin, a tributary of the Snake River, located in northeastern Oregon. The area is an important spawning and rearing habitat for spring/summer chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (O. mykiss), species listed as “threatened” under the Endangered Species Act. The study sub-basin is the upper portion of the basin and includes approximately 200 miles of the mainstem and six tributary systems in the Grande Ronde basin. Most segments of the upper basin violate maximum water temperature standard, and are subject to Total Maximum Daily Load (TMDL) regulations (ODEQ, 2000). Due to the current high water temperatures, chinook salmon and steelhead trout rely on thermal refugia for their survival. Decreasing water temperatures will reduce their dependence on the thermal refugia, and is expected to increase salmonid populations (Ebersole, 2001). Since 1985, over 30 million dollars have been spent in the Grande Ronde River Basin in an attempt to increase salmonid populations.

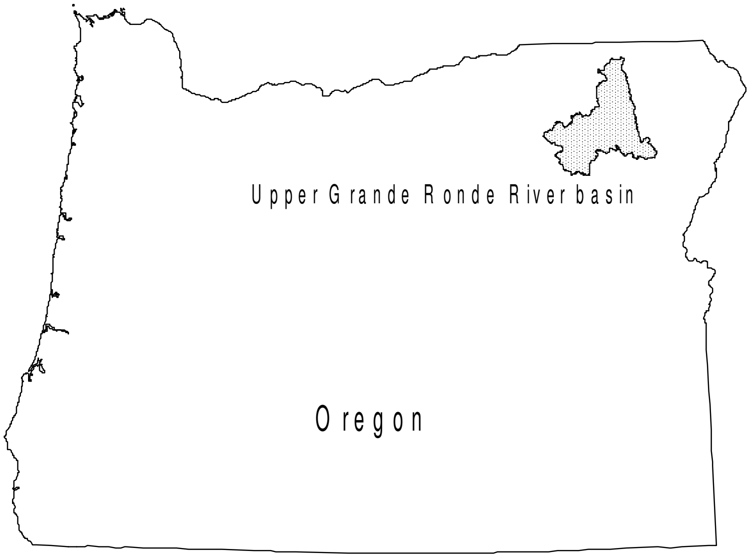

Figure 1. Location of the Upper Grande Ronde River Basin

The specific objectives of this research address the following two questions:

1. What is the efficient allocation of restoration efforts in the basin to attain certain TMDL temperature targets?
2. How does the allocation of restoration efforts under a temperature goal differ from one focused on fish abundance?

The first question aims to gain insight on the spatial configuration of restoration alternatives. For example, should restoration activities focus on the mainstem or the tributaries if the goal is to decrease temperatures in the mainstem? Likewise, should restoration efforts be concentrated near the point where temperatures are to be reduced or should they be spread along the upstream reaches and tributaries? In other words, which is more effective in reducing temperatures, the local effect or longitudinal (cumulative) effect? The second question addresses the spatial distribution of restoration efforts under two different targeting scenarios: one based on physical criteria (such as temperature targeting) and the other based on the value of environmental services (such as fish abundance). Previous economic literature indicates that conservation efforts are generally not implemented efficiently if they are allocated based on physical criterion (see *e.g.,* Wu *et al.*, 2000).

The rest of this paper is structured as follows. Section 2 reviews the literature on the efficient allocation of water resources associated with water quality. Section 3 explains the methodology of the simulation study, followed by the results in Section 4. This paper is concluded by summarizing major findings in section 5.

II. LITERATURE REVIEW

A number of studies have examined the efficient allocation of water resources in a riverine setting, including both water quantity and water quality issues. For example, Kanazawa

(1991) used a conceptual model to derive conditions for efficient water uses in a stream with saline water quality problems. More recently, Weber (2001) developed a more general theoretical model of water consumption and pollutant discharge along a stream to meet both minimum flow and water quality requirements. Both Kanazawa and Weber demonstrate that the social cost of discharging pollutants into a stream decreases as one moves downstream. Therefore, less water pollutants should be discharged in the upstream reaches. In terms of empirical studies, Scherer (1977) developed a dynamic programming technique to examine an efficient allocation of consumptive water uses along a stream to improve water quality (salinity) problems. Booker and Young (1994) examined salinity problems in the Colorado River basin, and showed that efficient allocation would require large transfers from existing consumptive users in the upper basin. Paulsen and Wernstedt (1995) applied an optimization framework to the Columbia River basin to examine the cost and biological tradeoffs to rebuild salmonid populations.

While efficient allocation of water resources associated with water quality problems has been extensively investigated in these and other studies, few economic studies address water quality problems associated with water temperatures. A number of studies do exist in the fisheries literature. For example, Theurer et al. (1985) used ecological and biological principles to examine the impact of different riparian vegetation and discharge scenarios on water temperatures and salmonid abundance in Tucannon River, Washington. Using four scenarios involving different riparian vegetation and stream morphology conditions, they found that juvenile fish production more than doubled under specific vegetation restoration. Bartholow (1991) evaluated the effectiveness of alternative practices to reduce summer maximum water temperatures for the Cache la Poudre River, Colorado. The alternatives included increasing discharge, doubling riparian shading, and halving stream width; increasing discharge was determined to be the most effective in reducing water temperatures. More recently, Hickey and Diaz (1999) developed an integrated model of fish populations, physical habitat, water temperature and water allocation, and analyzed alternative water allocation regimes to increase low winter flows in Colorado.

Efficient use of water resources has also been examined from the aspect of conservation fund allocations. Several studies suggest that conservation programs have not been implemented efficiently. For example, Ribaudo (1986) argued that conservation programs have historically been designed to protect specific resources and targeted on the basis of onsite physical criteria, such as soil erosion rates, rather than on the values (benefits) of environmental services provided. Reichelderfer and Boggess (1988) examined the performance of Conservation Reserve Program in 1986 and found that the implementation was suboptimal in the sense that net government cost of the program could have been reduced while simultaneously increasing the level of erosion reduction and supply control achieved. Recently, Wu and Boggess (1999) developed a theoretical model that showed that in the presence of threshold effects, the allocation of conservation fund based on onsite physical criteria could result in little environmental quality improvement.[1] Then, Wu *et al.* (2000) empirically demonstrated the existence of threshold effects in the relationship between water quality and fish abundance in the John Day River basin in eastern Oregon. The existence of threshold effects determines the efficiency in the use of scarce conservation funds.

Another key issue in dealing with environmental quality management is the existence of heterogeneity. Sanchirico and Wilen (1999) focused on the role of heterogeneous resources

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[1] These effects are called “cumulative effects” in Wu and Boggess (1999).

in an evaluation of how a patchy environment affects biological as well as economic efforts in a marine environment. They showed that where there is a human influence, equilibrium depends on both economic and biological parameters. An implication of their research to the present study is that the pattern of restoration activities must consider the heterogeneous nature of habitat conditions in the basin. Fish responses to a change in temperature are likely to vary across stream segments due, for example, to different riparian conditions. An efficient allocation of restoration efforts in a riverine setting should therefore consider this heterogeneity.

III. Procedures

For brevity, theoretical underpinnings of the following simulation model are not discussed here. Details can be found in Watanabe (2003). The model is a spatially explicit conceptual dynamic model associated with water temperature, which is based on Weber's (2000) general theoretical model of water consumption and pollutant discharge.

This section explains the methodology employed in developing a simulation model that reflects the physical and economic conditions in the Grande Ronde River basin. Because of the interdisciplinary nature of the study, multiple steps are taken in developing and implementing the simulation model. They are presented below.

(1) Divide the study basin into reaches.

The study basin is divided into 41 reaches, based on stream orders, geomorphologic characteristics and land ownership patterns. Figure 2 shows a schematic of these 41 reaches.

The numbers in Figure 1 are used to identify stream segments with multiple reaches. The identification of these reaches is provided in Table 1.

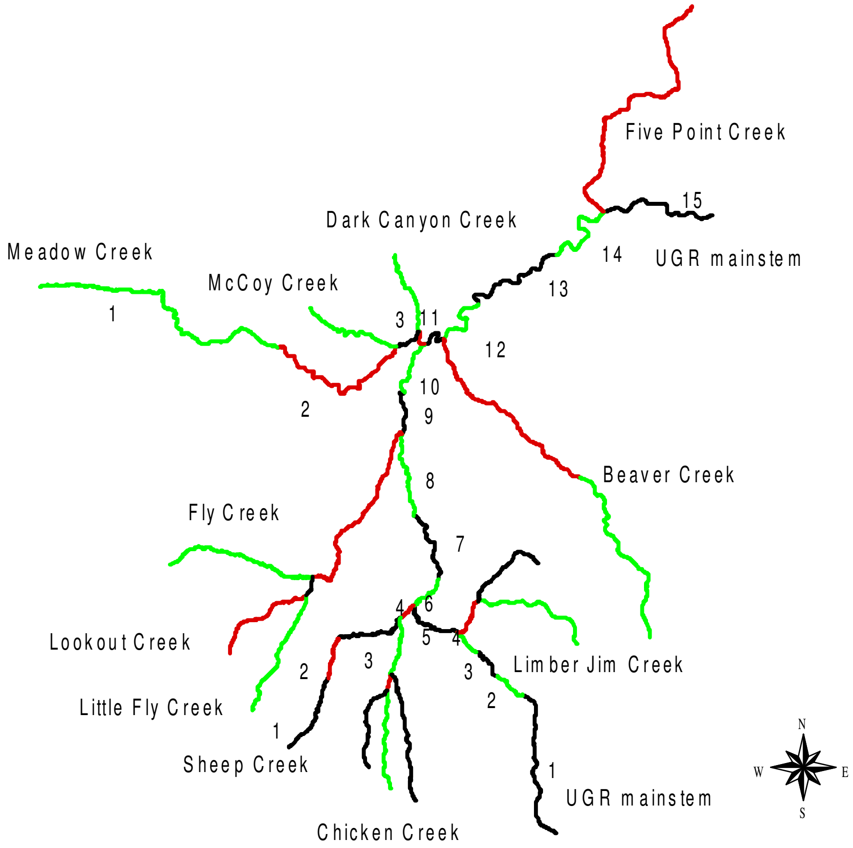

Figure 2. The Upper Grande Ronde River basin and reaches

The mainstem of the Upper Grande Ronde (UGR) River flows northward starting in reach “UGR mainstem 1” and then eastward to reach “UGR mainstem 15”. In general, reaches in the lower (southern) part of the map occur in higher elevations. The riparian zone in each reach is further divided into 10 vegetation/land use types, which are shown in Table 1. We will refer to these vegetation / land use types as sub-reaches.

Table 1. Riparian vegetation / land use types in each reach

Reach	Length	Agriculture	Emergent Vegetation	Scrub-Shrub	Herbaceous Uplands	Forest (Height)					Others
	(mile)	(AG)	(EM)	(SS)	(HU)	6-12m	12-18m	18-24m	24-30m	30m-	
UGR mainstem 1	6.61	0%	3%	2%	0%	0%	0%	18%	74%	0%	3%
UGR mainstem 2	1.51	0%	0%	36%	8%	0%	0%	17%	9%	0%	30%
UGR mainstem 3	1.68	0%	0%	3%	17%	0%	0%	27%	49%	0%	4%
UGR mainstem 4	2.20	0%	7%	4%	29%	0%	0%	0%	56%	0%	3%
UGR mainstem 5	3.37	49%	26%	1%	8%	0%	0%	0%	15%	0%	0%
UGR mainstem 6	2.20	31%	50%	2%	4%	0%	1%	1%	1%	0%	10%
UGR mainstem 7	3.71	0%	2%	24%	17%	2%	0%	1%	40%	0%	14%
UGR mainstem 8	4.02	0%	0%	35%	4%	0%	0%	0%	53%	2%	6%
UGR mainstem 9	2.09	0%	1%	28%	9%	6%	0%	3%	19%	0%	35%
UGR mainstem 10	2.72	18%	2%	22%	5%	0%	2%	2%	8%	0%	42%
UGR mainstem 11	1.52	0%	0%	9%	18%	0%	0%	0%	25%	0%	48%
UGR mainstem 12	3.15	0%	0%	13%	17%	0%	0%	0%	14%	0%	56%
UGR mainstem 13	5.41	13%	9%	4%	10%	0%	0%	0%	17%	0%	47%
UGR mainstem 14	4.47	2%	1%	17%	10%	0%	1%	1%	12%	0%	56%
UGR mainstem 15	5.64	0%	0%	2%	6%	0%	6%	0%	13%	0%	73%
Limber Jim Cr. Source	5.93	0%	5%	3%	4%	0%	0%	23%	65%	0%	0%
Limber Jim Cr. Mouth	2.38	0%	1%	4%	79%	4%	0%	6%	6%	0%	0%
Limber Jim N.Fk. Cr.	4.09	0%	0%	2%	6%	0%	0%	11%	79%	0%	2%
Sheep Cr. 1	4.00	0%	3%	1%	36%	0%	0%	5%	55%	0%	0%
Sheep Cr. 2	2.56	77%	8%	2%	1%	0%	4%	7%	1%	0%	0%
Sheep Cr. 3	5.35	61%	35%	2%	1%	0%	0%	0%	1%	0%	1%
Sheep Cr. 4	1.53	2%	97%	0%	0%	0%	0%	0%	0%	0%	1%
Chicken Cr. Source	6.11	0%	1%	1%	18%	0%	1%	6%	72%	0%	1%
Chicken Cr. Mouth	3.51	42%	50%	1%	7%	0%	0%	0%	0%	0%	1%
West Chicken Cr. Source	4.62	0%	0%	0%	13%	0%	0%	11%	76%	0%	0%
West Chicken Cr. Mouth	0.94	0%	0%	0%	82%	0%	0%	14%	4%	0%	0%
W.West Chicken Cr.	4.11	0%	0%	0%	11%	0%	0%	9%	81%	0%	0%
Fly Cr. Source	8.34	24%	13%	2%	37%	0%	0%	15%	8%	0%	0%
Fly Cr. Mouth	9.22	2%	10%	21%	10%	2%	0%	3%	51%	0%	0%
Little Fly Cr. Source	6.06	18%	1%	2%	17%	1%	0%	27%	29%	0%	4%
Little Fly Cr. Mouth	1.09	67%	17%	0%	7%	0%	0%	9%	0%	0%	0%
Lookout Cr.	4.95	4%	2%	0%	9%	0%	0%	36%	49%	0%	0%
Meadow Cr. 1	14.05	0%	14%	1%	24%	0%	2%	27%	31%	0%	0%
Meadow Cr. 2	8.13	6%	1%	29%	33%	2%	0%	3%	23%	0%	3%
Meadow Cr. 3	1.45	26%	6%	25%	5%	0%	0%	3%	34%	0%	0%
Meadow Cr. 4	0.75	0%	0%	42%	1%	0%	0%	0%	47%	0%	10%
McCoy Cr.	4.98	28%	3%	17%	28%	4%	7%	2%	10%	0%	1%
Dark Canyon Cr.	3.90	0%	0%	39%	3%	0%	0%	1%	55%	2%	1%
Beaver Cr. Source	9.29	0%	1%	19%	16%	0%	0%	7%	45%	0%	10%
Beaver Cr. Mouth	9.71	1%	2%	10%	12%	0%	0%	1%	72%	0%	1%
Five Point Cr.	13.83	1%	0%	10%	22%	0%	3%	0%	63%	0%	0%

Source: ODEQ (2000)

Among these vegetation / land use classes, agricultural land (AG), emergent vegetation (EM), herbaceous upland (HU) and scrub/shrub (SS) are the sites for potential restoration activities.

(2) Identify conservation practices

Many conservation activities have the potential to lower water temperatures and a variety of conservation activities have been implemented in the basin. The most popular activities are passive and active restoration efforts. Passive restoration allows a riparian zone to recover naturally by eliminating activities causing degradation, such as cattle grazing. The primary means of passive restoration is building fences along the stream to prevent livestock grazing or other disturbances in riparian areas. Active restoration includes vegetation planting and silvicultural options to accelerate riparian forest development (Kauffman *et al.*, 1997). These restoration activities affect riparian conditions by changing the vegetative species and their rates of growth.

Table 2. Major restoration projects in the Grande Ronde River basin since 1985

Work Type	Share
Fencing	19%
Vegetation Planting	14%
Livestock Water Development	10%
Large Woody Material Placement	7%
Structure Placement - Rocks	5%
Construction	4%
Structure Placement - Logs	3%
Bank Stabilization	3%

Source: Grande Ronde Model Watershed Program, 2002

Note: The share is based on the number of sites in the basin where each project type is implemented.

Other conservation practices, such as bank stability improvement and channel narrowing, are also available and have the potential to affect water temperatures. However, their impacts on water temperatures are harder to measure, and therefore are not considered in this study.

(3) Estimate the costs of conservation alternatives in each reach

First, tree species that are well suited to the riparian zone in each reach of the study basin are identified. Based on literature reviews and personal communications with foresters and others who practice restoration activities in the basin, it is determined that the following tree species will grow in each vegetation / land use types.

Table 3. Vegetation class and types of trees grown / planted

	AG	EM	SS	HU
Passsive restoration	Shrub/ Cottonwood/ Conifer	Shrub	Shrub/Conifer	Conifer
Active restoration	Shrub/ Cottonwood/ Conifer	Shrub	NA	NA

Note: Shrub primarily represents willow and alder. No active restoration is implemented in HU and SS because it is difficult for planted trees to be established due to the lack of adequate moisture.

Given that potential tree height is the most important determinant of effects on water temperature, growth curves of each tree species are estimated. They are shown in Figure 3.

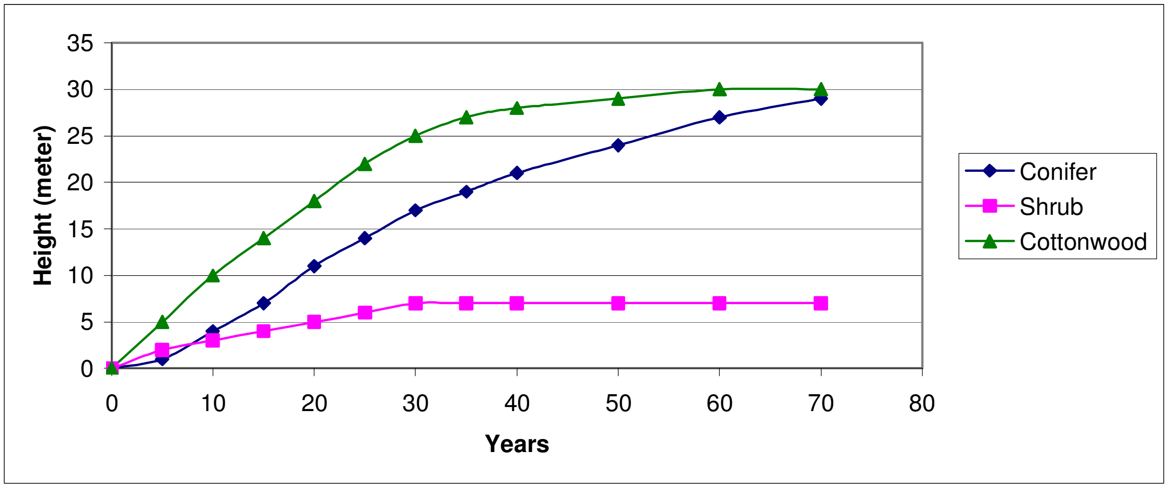

Figure 3. Tree growth curves

Using these tree growth curves, potential maximum tree heights in respective vegetation class resulting from passive or active restoration are then computed (Table 4).

Table 4. Potential maximum height in each vegetation / land use type

Landuse / vegetation type	Conservation Practice	In 10 years	In 20 years	In 40 years
		Vegetation height (m)		
AG	Passive restoration	4	9	18
	Active restoration/Shrub	4	6	7
	Active restoration/Conifer	5	12	22
	Active restoration/Cottonwood	11	19	28
EM	Passive restoration	3	5	7
	Active restoration/Shrub	4	6	7
SS	Passive restoration	2	9	10
HU	Passive restoration	4	8	14
	Existing height (m)	Mean height (m)		
Forest	6-12	17	22	26
	12-18	21	24	27
	18-24	24	26	28
	24-30	29	30	31
	30-	33	33	33

Table 4 shows, for example, it is possible to attain a 19 meter height in an AG landscape in 20 years if cottonwood trees are planted. Using cost data from past projects implemented in the basin (Grande Ronde Model Watershed Program, unpublished data, 2002) as well as information from the Oregon Department of Forestry and other conservation agencies, the costs of each restoration activity are estimated. These costs are assumed to be the same across the reaches and across vegetation types.

Using these data, the cost of passive and active restoration in each sub-reach in each time frame is estimated. The height used is the average vegetation height in each sub-reach. We assume that all restoration activities are implemented in year 0. The type of restoration practices to be employed in each sub-reach is determined at this stage. Table 5 shows restoration activities in each sub-reach in each time frame and their costs. The restoration types in Table 5 represent the minimum cost activities in each vegetation types and in each time frame. Thus, once a certain sub-reach is identified as an optimal site to receive restoration, then the restoration activity specified in this table is implemented in the sub-reach.

Table 5. Minimum cost restoration activities

		10 years	20 years	40 years
Restoration type employed	AG	Active restoration / cottonwood	Active restoration / cottonwood	Active restoration / cottonwood
	EM	Active restoration / shrub	Active restoration / shrub	Passive restoration
	SS	Passive restoration	Passive restoration	Passive restoration
	HU	Passive restoration	Passive restoration	Passive restoration
Cost per meter height per stream mile in dollars	AG	1155	668	454
	EM	3335	2223	1500
	SS	2625	1313	750
	HU	5250	1167	525
Cost for additional 5 meter of width per stream mile in dollars	AG	200	116	79
	EM	550	367	0
	SS	0	0	0
	HU	0	0	0

Table 5 shows that it is relatively inexpensive to apply restoration practices on agricultural land (AG) because potential maximum vegetation height is the highest in AG. It is interesting to see that in 10 year time frame, restoration in EM is less costly than HU, but in the 20 and 40 year time frames, restoration in HU is less costly than EM. This is because trees grow faster in EM in the short run, but their maximum potential height is lower than for land class HU. Therefore, in the long run, it is less costly to apply passive restoration efforts in HU than in EM.

(4) Estimate the relationship between riparian vegetation and water temperature

A state-of-the-art temperature model, WET-temp (Cox, 2002), was used to estimate temperatures in the mainstem, as well as in the tributaries, in association with riparian vegetation height.[2] The WET-temp model provides estimates of water temperature every 15 minutes at every 100 meters along the stream. Since we are interested in maximum water temperatures, the WET-temp model was calibrated to observed maximum daily temperatures in the UGR mainstem.[3] In general, WET-temp calibrates well for the mainstem of the upper Grande Ronde River (within a one degree Celsius difference). In some of the tributaries, the WET-temp tends to overestimate temperatures. Thus, for those tributaries, the WET-temp estimates are adjusted using the ratio of actual to estimated data. This ensures that the estimates follow the actual temperature patterns.

Since the conservation practices (passive and active) primarily affect the height and width of riparian vegetation, vegetation height and width are the control variables in WET-temp. Riparian zone management often takes place with the width of one tree height, which is about 30 meters in the basin (ODEQ, 2000). However, the WET-temp simulations indicate that riparian vegetation wider than 10 meter has little effect on stream temperatures. Thus, in the simulation analyses, the width of restoration activities is set either at 5 meters or 10 meters.

In estimating the relationship between vegetation height / width and water temperatures, 2000 runs were made for each time frame, each of which consists of different

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[2] A desirable feature of the WET-temp model is its ability to incorporate spatial GIS data. It is also less information intensive than other temperature models such as the Heat Source model used by the Oregon Department of Environmental Quality.

[3] WET-temp estimates are maximum daily temperatures, but temperature standards such as TMDL are 7-day averaged maximum daily temperatures (maximum 7-day temperature). To convert maximum daily temperatures to maximum 7-day temperatures, maximum daily temperatures are multiplied by 0.95. This value was obtained by comparing the measured maximum daily temperatures and the measured maximum 7-day temperatures in multiple monitoring points in several years.

combinations of vegetation height and width in each subreach. Then, maximum water temperatures at representative points (or the average of maximum temperatures at all the points in each reach) estimated by the WET-temp model are regressed against vegetation height and width in each subreach located in their upstream area. The following regression model was used to estimate the maximum water temperature at point *j*:

$$temp(j) = \alpha_j + \sum_{k=1}^{4} \sum_{i=1}^{I} \beta_{ik} h_{ik} + \sum_{k=1}^{4} \sum_{i=1}^{I} \gamma_{ik} h_{ik}^2 + \sum_{k=1}^{4} \sum_{i=1}^{I} \delta_{ik} w_{ik} h_{ik} \qquad (1)$$

where *i* = reach located in the upstream area of point *j*.

k = AG, EM, HU, and SS

h = vegetation height

w = dummy variable (*w* =1 if vegetation width is 10 meters, *w* =0 if 5 meters).

Squared height is included to capture a nonlinear relationship between vegetation height and water temperature. α_j is an intercept, and the sign of δ_{ik} is negative since an increase in vegetation width (from 5 meters to 10 meters) is expected to decrease water temperatures. The R-squares of these regressions estimated here exceed 0.95, with the majority (except for 3 models) higher than 0.97.

(5) Estimate the relationship between water temperature and fish density

To estimate the impact of temperature reductions on the number of salmonids, a fish density model was estimated using biological “first principles” and data collected by Ebersole (2002). Specifically, the following chinook salmon density model is estimated:

$$\begin{aligned} \text{LCHDEN} = \quad & -1.16676^{(**)} + 0.093038^{(**)}\,\text{Max7T} - 0.002280^{(**)}\,\text{Max7T}^2 \\ & - 0.626842^{(*)}\,\text{Fines} + 1.51145^{(**)}\,\text{Fines}^2 + 3.34798^{(**)}\,\text{MnD} - 7.02613^{(**)}\text{LMnD}^2 \end{aligned}$$

where LCHDEN = Log of juvenile chinook salmon density plus 1
LMnD = Log of mean depth of stream channel plus 1
Max7T = Seven-day maximum water temperature
Fines = percentage of fine substrate

(**) and (*) are significant at 5 % and 10% level, respectively.

The number of observation is 26, and R-square is 0.66.

It is known that the primary habitat area of Chinook salmon in the upper Grande Ronde river basin is limited to the UGR mainstem and Sheep creek (personal communication with Joe Ebersole, 2003). Therefore, in estimating the total number of chinook salmon, only reaches in UGR mainstem and Sheep Creek are considered.[4]

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[4] It is important to note that this fish analysis is considered exploratory due to several reasons. First, comprehensive data from the Oregon Department of Fish and Wildlife (ODFW, 1999) are available for most reaches, the data are not available in reaches UGR mainstem 7 and 8. Therefore, the fish analysis is conducted excluding these two reaches. Second, the year when fish data were collected differs from the year to which the WET-temp model is calibrated. Third, we assume that summer conditions, especially temperature, are a population "bottleneck" (limiting factor) although other factors such as the abundance and distribution of adult spawners also play an important role. Fourth, the temperature effect of riparian restoration on the fish abundance is only one of possible benefits of riparian improvements; these other effects were not considered. Fifth, an improvement in habitat conditions in a reach may promote fish migration across reaches; such effects were not considered.

(6) Specify policy options

Three general optimization problems are specified here to evaluate a range of policy options. The first objective (policy option) is to invest in restoration activities that minimize cost to achieve a certain temperature reduction at a given point.

$$\underset{h_{ik},w_{ik}}{Min} \sum_{i=1}^{I}\sum_{k=1}^{4}[C_h(h_{ik}) + C_w(h_{ik}w_{ik})] \tag{2}$$

$$\text{s.t.} \qquad \Delta temp_j = \Delta temp_j(h_{11}, w_{11}, \ldots., h_{ik}, w_{ik}, \ldots., h_{I4,} w_{I4}) \leq \Delta T \tag{3}$$

where j = a point in the stream where temperature is monitored

i = reach (i = 1,….,I)

k= vegetation class (k = AG, EM, SS, and HU)

h_{ik} = riparian vegetation height in reach i, vegetation class k

w_{ik} = riparian vegetation width ($w_{ik} = 1$ if width is 10m, $w_{ik} = 0$ if 0m)

$C_h(h_{ik})$ =restoration cost associated with vegetation height

$C_w(h_{ik}w_{ik})$ = restoration cost associated with vegetation width

$temp_j$ =water temperature at point j

Δ = change

T = temperature target

Since a change in temperature is negative, the constraint equation means that the reduction in temperature needs to be larger than a targeted temperature change (ΔT).

The second policy option is to invest in restoration activities to maximize stream length whose temperature decreases by a certain degree with a given budget constraint

$$\underset{h_{ik},w_{ik}}{Max} \quad \sum_{i=1}^{I}\left[s_i * L_i\right] \tag{4}$$

$$\text{s.t.} \qquad \Delta temp_{\hat{i}} = \Delta temp_{\hat{i}}(h_{11}, w_{11},....,h_{ik}, w_{ik},....,h_{I4,} w_{I4}) \qquad i = 1,\ldots,I \tag{5}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{4}\left[C_h(h_{ik}) + C_w(h_{ik} w_{ik})\right] \le B \tag{6}$$

$$s_i = 1, \text{ if } \Delta temp_{\hat{i}} \le \Delta T \qquad i = 1,\ldots,I \tag{7}$$

$$s_i = 0, \text{ if } \Delta temp_{\hat{i}} \ge \Delta T \qquad i = 1,\ldots,I \tag{8}$$

where s_i = dummy variable

$\hat{i}$ = a point which gives the highest water temperature in reach *i*

L_i = length of reach *i*

B = budget

It is assumed that once a point ($\hat{i}$) attains the temperature reduction target, the entire reach also attains the target. Then, the entire length of the reach is counted in the objective function. The temperature target is either a change in temperature or an absolute temperature level. In the latter case, deltas (Δ) in the above equations are omitted.

The third model specification is to simulate a policy to maximize fish numbers subject to a given budget constraint

$$\underset{h_{ik},w_{ik}}{Max} \quad \sum_{i=1}^{I}\left[Fish_i(temp_i, a_i) * L_i\right] \tag{9}$$

$$\text{s.t.} \qquad temp_{\hat{i}} = temp_{\hat{i}}(h_{11}, w_{11},....,h_{ik}, w_{ik},....,h_{I4,} w_{I4}) \qquad i = 1,\ldots,I \tag{10}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{4}\left[C_h(h_{ik}) + C_w(h_{ik} w_{ik})\right] \le B \tag{11}$$

where $fish_i$ = fish density in reach *i*

a_i = other variables that affect fish density

In this problem, the average maximum temperatures in each reach are used.

IV. RESULTS

The first simulation analysis performed here is to explore temperature changes in the mainstem without regard to the costs or locations of restoration activities. Using the WET-temp model, longitudinal temperature profiles in the UGR mainstem are estimated under the maximum restoration efforts in 10, 20 and 40 time frames. These profiles are depicted in Figure 4 for the base case (current situation) and the three time frames of restoration.

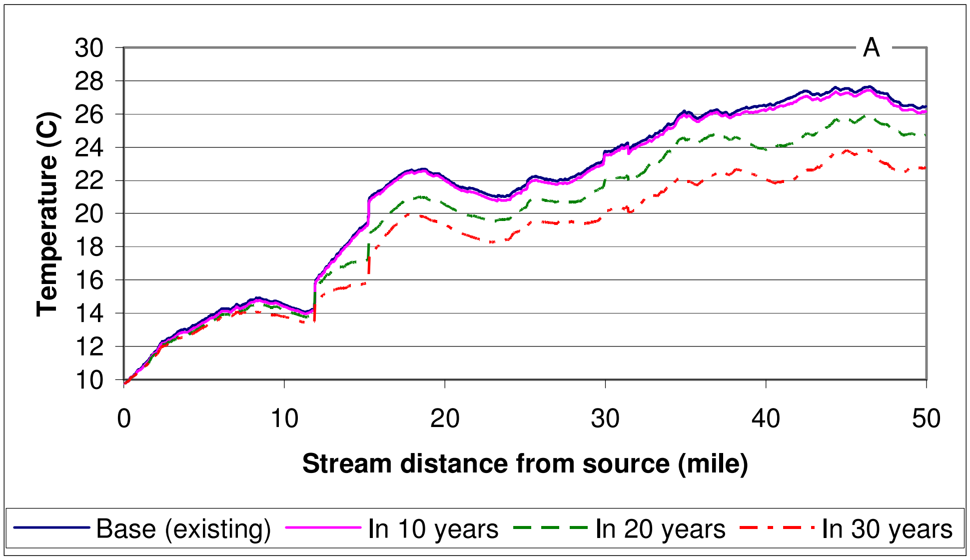

Figure 4. Longitudinal temperature profile in the UGR mainstem in 10, 20 and 40 year time frame when the maximum level of restoration efforts are implemented[5]

The TMDL water temperature standard in the upper Grande Ronde basin as set by the ODEQ (2000) is 17.8 ºC (64 ºF).[6] However, Figure 4 shows that it is not possible to obtain the

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[5] Water temperatures used here are the maximum 7-day averaged maximum daily water temperatures.

TMDL target in the UGR mainstem, even in 40 years, under an unlimited budget with the alternatives considered here.[7] As the figure shows, potential temperature decreases in the mainstem are limited to about 4 ºC, and less in the short run (10 years). While attaining the TMDL target is not possible for most reaches of the mainstem, it is still important to decrease water temperatures for the purposes of expected fishery benefits. As the fish density model shows, decreasing water temperature, even to levels above the target of 17.8 ºC, is still expected to increase salmonid populations. Therefore in the following analyses, spatial configurations of restoration efforts under different temperature targeting scenarios are examined.

The first economic analysis focuses on minimum costs of temperature reductions. Specifically, Figure 5 shows the costs associated with temperature reductions at a given point (point A) in Figure 4, in 20-year and 40-year time frames. Point A is the highest observed maximum temperature in the UGR mainstem. Figure 5 shows that the cost of temperature reductions is lower for small temperature reductions, but it increases rapidly once the magnitude of temperature reductions exceed 1 ºC (1.8 ºF) in the case of 20 year time frame and 3.5 ºC (6.3 ºF) in 40 year time frame. The curves also shows that if temperature reductions are targeted over a 40 year time frame, then a much larger temperature decline can be attained for a given cost.

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[6] Actually, the TMDL requirement is 17.8 ºC (64 ºF) or "no measurable surface water temperature increase resulting from anthropogenic activities is allowed" where 17.8 ºC is not attainable. However, according to the ODEQ, in most reaches in the study basin, 17.8 ºC is attainable if the potential maximum riparian vegetation were restored.

[7] This does not necessarily mean that TMDL is not attainable in 40 years. As discussed before, there are other restoration practices such as improving bank stability and reducing the width to depth ratio. If these activities are included, some additional cooling may result.

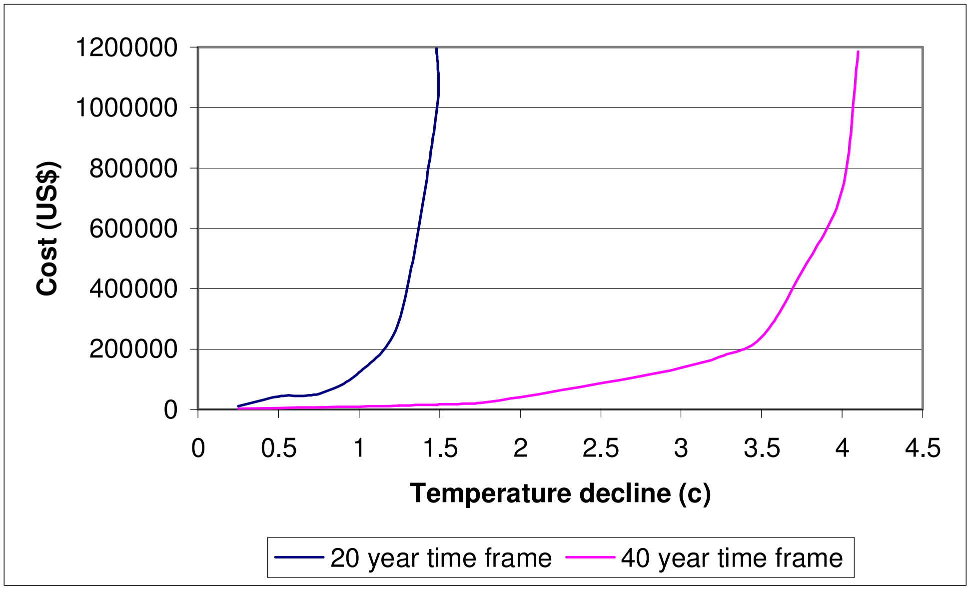


Figure 5. Costs of temperature reductions at a point in the lower UGR mainstem under 20 and 40 year time frames

The spatial configurations of restoration practices are examined for a range of water temperature decreases. Specifically, Figure 6 shows the minimum cost allocation of restoration activities when the water temperature at point A is decreased by 1, 2, 3, and 4 ºC degrees in the 40 year time frame, respectively. The figure depicts those reaches where restoration activities are applied. It shows that when the magnitude of desired temperature reductions is small, only the nearby reaches in the lower mainstem receive restoration efforts. However, as the desired magnitude of temperature reduction increases, it becomes necessary to apply restoration efforts in the upper stream reaches in the mainstem, and then to the tributaries. The spatial analysis also reveals the heterogeneous nature of temperature responses in the basin. For example, in one of the tributaries (Beaver Creek) restoration efforts in the upstream stretch will be given a higher priority than the downstream stretch. Similar spatial phenomena can be seen in the mainstem, Sheep creek, and Fly creek.

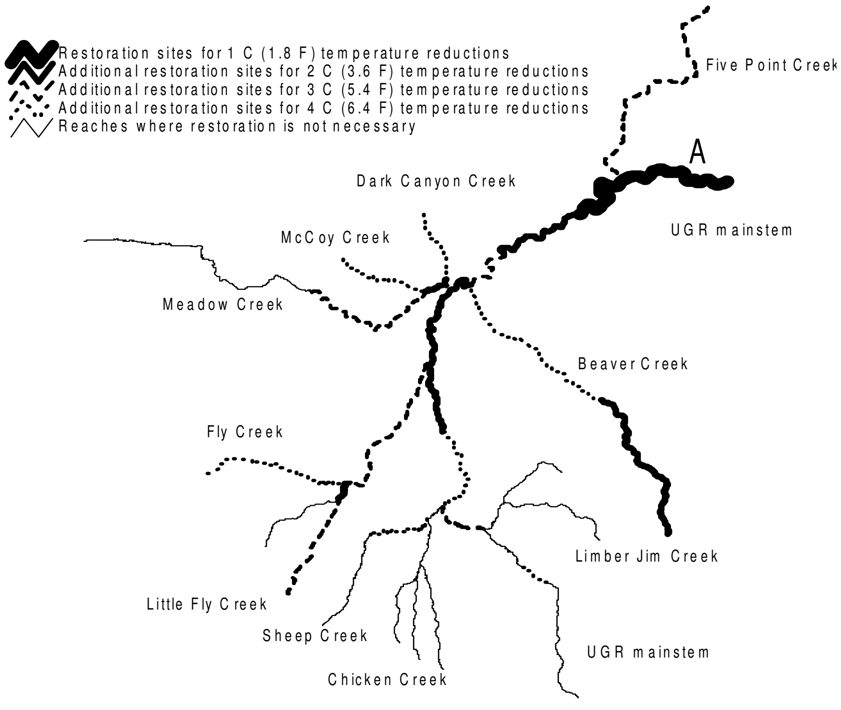


Figure 6. Minimum cost restoration efforts, by reach, when water temperature at point A is reduced by 1, 2, 3 and 4 ºC for a 40 year time frame.

Table 6 presents the cost allocation and contribution of each reach to temperature reductions at point A under the same scenario as in Figure 6. The reaches are divided into three groups: mainstem reaches located within 6 mile upstream of point A, the rest of the mainstem, and the tributaries. In order to decrease temperature by 3 ºC (5.4 ºF) at point A, only 27 percent of the total cost is allocated to the nearby reaches in the mainstem, but these reaches accounts for 67 percent of the temperature reductions. Table 6 shows that as the magnitude of temperature reductions increases, a larger share of the restoration budget is allocated to other reaches in the mainstem (beyond 6 miles from point A) and to the tributaries. As a result, costs per unit of temperature reductions increase. Since the marginal effects of restoration efforts on temperature reductions in distant reaches are small, the marginal costs of temperature reductions increase rapidly. This is consistent with the results in Figure 5.

Table 6. Efficient cost allocations among reaches
and their contribution to temperature reductions at point A

		-1.0C	-2.0C	-3.0C	-4.0C
Cost allocation					
Reaches in the mainstem	Upstream within 6 mile	100%	54%	27%	5%
	Beyond 6 mile	0%	39%	55%	35%
Reaches in tributaries		0%	7%	17%	60%
Total Cost (dollars)		8888	40545	138172	728096
Contribution to temperature reductions					
Reaches in the mainstem	Upstream within 6 mile	100%	87%	67%	50%
	Beyond 6 mile	0%	9%	26%	33%
Reaches in tributaries		0%	3%	7%	17%

The next analysis investigates how the restoration efforts should be allocated within the basin if the objective is to maximize the stream length whose water temperature is decreased by at least 1 ºC with a given budget constraint. Maximizing the stream length that experiences temperature reductions has important implications for fish recruitment. Also, while TMDL standards are based on absolute temperature levels, conservation agencies may choose to target temperature changes, given that absolute temperature levels vary from year to year. Figure 7 presents those reaches whose temperatures are decreased under different budget levels. It shows that tributaries such as Meadow Creek, Fly Creek, and McCoy Creek, as well as the lowest stretch of the mainstem, will be the first priority. If the budget is expanded, then the lower part of the mainstem as well as Five Point Creek and the lowest stretch of Chicken Creek will be targeted. In general, it is more efficient to decrease water temperatures in tributaries if the objective is to maximize stream length whose temperature decreases by a certain degree.

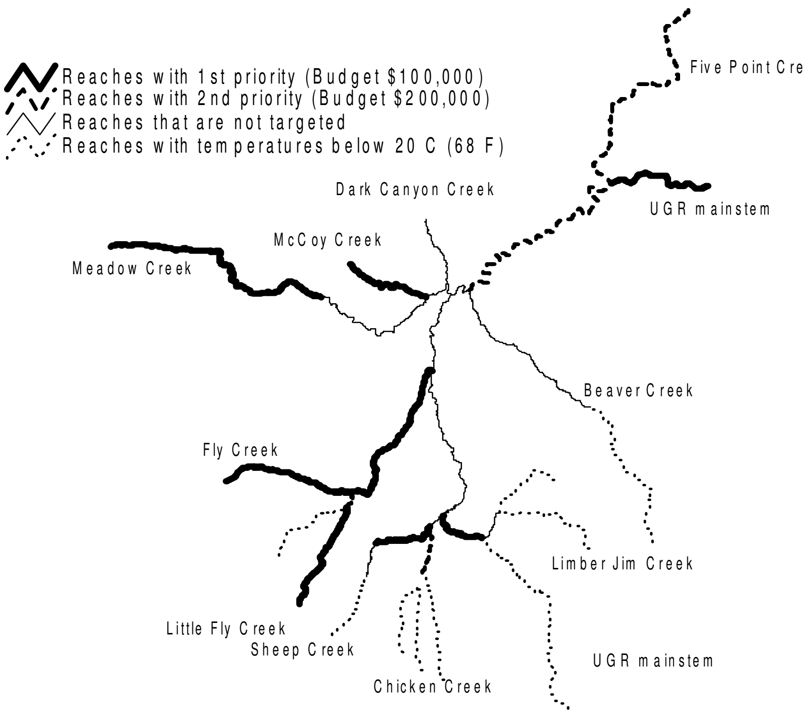
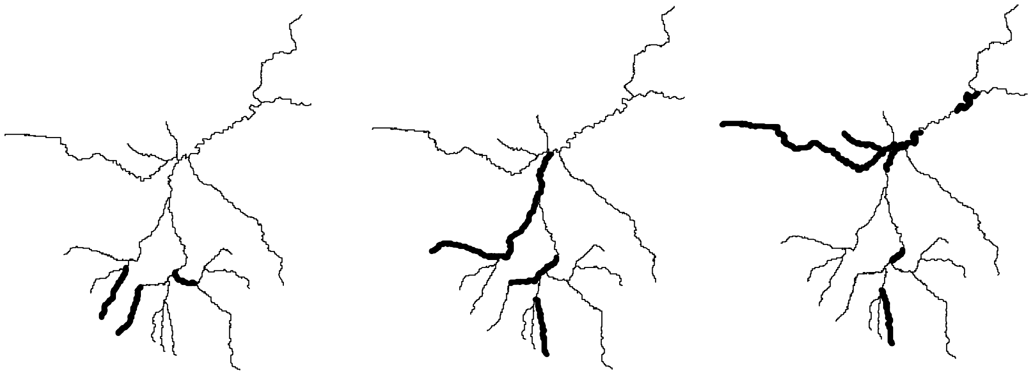


Figure 7. Targeted reaches when the objective is to maximize the stream length whose temperature decreases by at least 1 °C

Note: Bold reaches in Figure 7 are those whose temperatures are decreased, and are not necessarily the sites for restoration activities.
Reaches with maximum temperatures lower than 20 °C (68 °F) are not subject to this temperature reduction because their temperature levels are already low.

Thus far, we have examined efficient allocations of restoration efforts in association with temperature changes. However, water quality standards are typically set based on absolute temperature levels, and many stream flow benefits such as the status of a fish population are determined by absolute temperature levels. Thus, in the following analyses, we extend the analyses to absolute temperature levels.

First, we examine how the levels of temperature targets affect the spatial configuration of restoration efforts. Given the temperature needs of fish and varying budget constraints, conservation agencies may wish to pursue different temperature targets. For example, they may wish to minimize the stream length whose water temperature is very high (*e.g.*, over 27 ºC (80.6 ºF) degrees) or they may want to target the stream reaches whose water temperatures are already cooler (*e.g.*, below 20 ºC (68 ºF)) in order to improve habitat for coldwater fish species, ignoring reaches with high water temperatures. These different temperature targets will likely lead to different allocations of restoration activities and as a result have different impacts on the distribution of water temperatures. Figure 8 shows the efficient allocation of restoration efforts when the objective is to maximize stream length whose temperature is below targeted levels (20 ºC, 24 ºC and 27 ºC) with a given budget constraint (here, $100,000).



20 C (68 F) targeting

24 C (75.2 F) targeting

27 C (80.6 F) targeting

Figure 8. Efficient allocation of restoration efforts when the objective is to maximize stream length whose temperature is below target levels with a given budget constraint

Note: Bold reaches are where restoration efforts are implemented, and their temperatures are not necessarily below the target levels.

Figure 8 shows that depending on temperature targets, the spatial configurations of restoration efforts can vary greatly. It also shows that whatever the temperature target, reaches whose temperatures are just above the target levels are given the first priority. Thus, as the temperature target rises, the sites for restoration shift northward, where elevation is lower and temperature is generally higher. These differences in the spatial configuration of restoration efforts have significant impacts on water temperatures. Figure 9 shows the total stream length in each temperature range as a result of restoration efforts under the three different temperature targets.

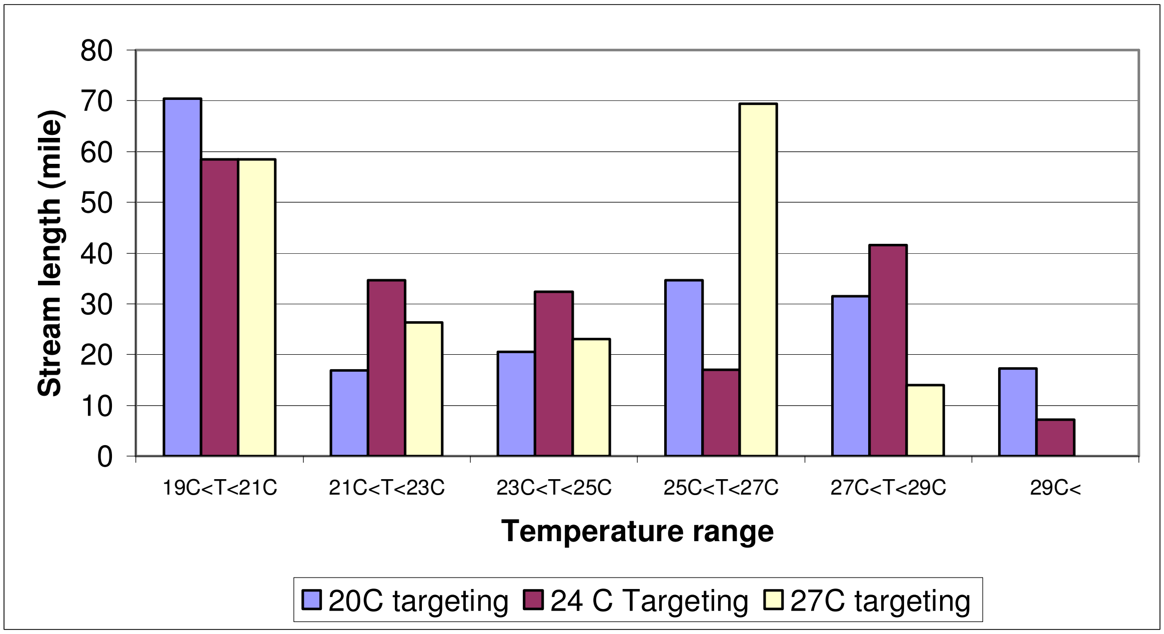


Figure 9. Stream length in each temperature range as a result of restoration efforts under different temperature targets

Figure 9 shows that if conservation agencies wish to target 20 ºC (68 ºF) then they can do so only at the expense of medium and high temperature reaches (*i.e.* stream length whose temperature is higher than 29 ºC (84.2 ºF) is the longest under 20 ºC targeting).

The final set of analyses draws on the efficient allocations of restoration efforts when the goal is to maximize fish populations. Figure 10 presents the spatial configuration of restoration efforts when the objective is to maximize the sum of chinook salmon populations in the selected reaches in the UGR mainstem and Sheep Creek in 40 years with a given budget constraint (again, $100,000). The figure shows the reaches where restoration efforts are implemented.

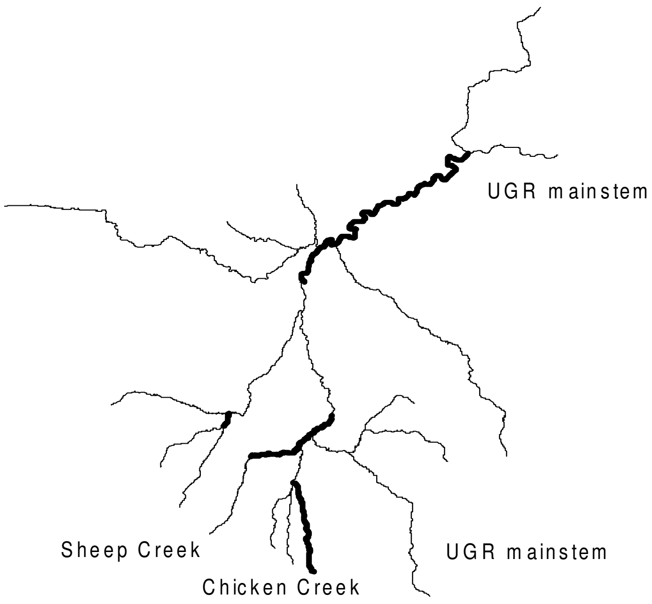


Figure 10. Restoration sites, by reach, to maximize fish populations with a budget constraint

Figure 10 shows that restoration efforts for benefits of salmon populations are implemented primarily in the UGR mainstem as well as in Sheep Creek. The cost breakdown shows that approximately 40 percent of the budget will be allocated to Sheep creek because of its productivity under reduced temperatures, although it consists of less than 20 percent of the reaches suitable for chinook salmon habitat.

To compare the efficacy of temperature targets versus fish targets, three temperature targeting scenarios are set up, and they are compared with the fish targeting scenario. The objective of the temperature targeting scenarios is to maximize stream length whose temperature levels are below certain targets (20 ºC (68 ºF), 23 ºC (73.4 ºF) and 25 ºC (77 ºF)) with a budget constraint (again $100,000). Then juvenile chinook salmon populations under each scenario are computed.

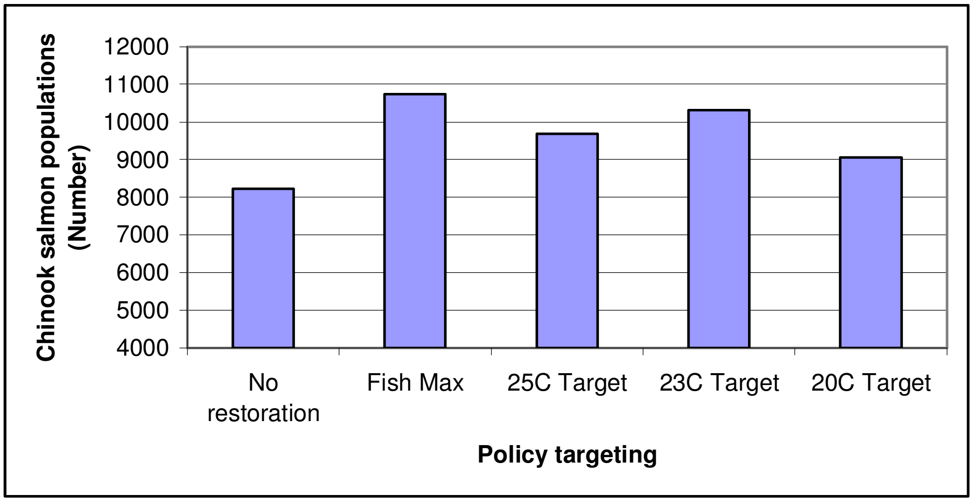


Figure 11. Total chinook salmon populations in 40 year time frame under different targeting scenarios

Figure 11 shows that a 23 ºC targeting policy produces almost the same number of fish as the fish maximization scenario (96 percent), followed by 25 ºC targeting (90 percent). The fish density model suggests that the marginal effect of a temperature reduction on fish population is greater at higher temperature levels.[8] Thus, if only temperature changes were considered, one would expect that a 25 ºC targeting should produce larger fish populations. However, the

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[8] The incipient lethal limit for salmon is set at 25.5ºC based on the data for this research (Ebersole, 2001) as well as the TMDL document (ODEQ, 2000). So if temperature is above this level, it is assumed that there is no fish population.

fact that a 23 ºC targeting policy actually produces larger populations reflects the heterogeneity associated with fish habitat conditions across reaches and reinforces the role of spatial conditions in managing a riverine system for ecological benefits.

V. KEY FINDINGS

This paper has examined the spatial configuration of restoration efforts to achieve different temperature targets for a riverine system in the PNW. Using the upper Grande Ronde River basin of northwest Oregon as a case study, we explore the biological and economic implications of alternative policies concerning stream temperature reductions and fish populations. Through a series of simulation analyses, important insights on efficient allocations of restoration efforts have been gained. These key findings are summarized below.

First, for this setting, the TMDL target established by the ODEQ is not physically attainable in 40 years, given the options considered here. Other measures for temperature reductions are available, but they generally are more expensive than riparian restoration. Second, localized effects of restoration efforts on temperature reduction dominate longitudinal (cumulative) effects. But as the desired magnitude of temperature reductions increases, restoration efforts must be expanded and extended to reaches located far from the monitoring point. As a result, the marginal cost of temperature reductions increases rapidly. Third, it is possible that implementing restoration efforts in more distant reaches of the watershed is more efficient than efforts nearer to the point of monitoring. This kind of policy guidance would not be possible without spatial detail. Fourth, if the objective of conservation agencies is to maximize the stream length whose water temperature decreases by a certain degree, then tributaries will need to be targeted first. Fifth, if agencies are concerned with absolute temperature levels, then the levels of those desired temperature targets have a significant impact on the spatial configuration of restoration efforts, and as a result, on the distribution of temperatures in the basin. Sixth, if the objective is to maximize fish populations, then not only water temperatures but also the heterogeneity in habitat conditions must be considered.

While this type of analyses demonstrates the importance of representing spatial heterogeneity in riverine management, a number of extensions are needed. First, the role of changes in stream discharge needs to be explored. In many streams in arid portion of the Pacific Northwest, a reduction in discharge resulting from water withdrawal for irrigation is one of the primary reasons for elevated temperature levels; an increase in stream flows has been found to be a cost-effective method in decreasing water temperatures (Barthlow, 1991). Since there is no water withdrawal for irrigation in the study basin, we did not examine the effect of stream flow augmentation. Further improvement in the WET-temp model, such as incorporating a discharge component would allow analyses in setting where discharge changes and other options are possible. A second need is to improve temperature estimates in the tributaries within the water temperature model. Currently, WET-temp uses the same values for some parameters for the entire basin. If different values were used for each tributary, temperature estimates in tributaries are expected to become more accurate. Such improvement will enhance the precision of the analysis and the value of spatial data in such environmental analyses.

References

Bartholow, J.M. "A modeling Assessment of the Thermal Regime for an Urban Sport Fishery." *Environmental Management* 15(1991): 833-845.

Booker, J.F. and R.A. Young, “Modeling Intrastate and Interstate Markets for Colorado River Water Resources,” *Journal of Environmental Economics and Management* 26 (1994): 66-87.

Cox, M.M. *A Spatially Explicit Network-Based Model for Estimating Stream Temperature Distribution*. Master’s Thesis. Oregon State University, Corvallis, OR. 2002.

Ebersole, J. L. *Heterogeneous Thermal Habitat for Northeast Oregon Stream Fishes.* Ph.D. Dissertation, Oregon State University, Corvallis, OR. 201 pp. 2001.

Hickey, J.T. and G.E. Diaz. “From Flow to Fish to Dollars: An Integrated Approach to Water Allocation.” *Journal of the American Water Resources Association* 35 (October 1999): 1053-1067

Kanazawa, M. “Water quality and the Economic Efficiency of Appropriative Water Rights” *The Economics and Management of Water and Drainage Agriculture*. A. Dinar and D. Zilberman eds., Boston, MA: Kluwer Academics, 1991.

Kauffman, J.B., R.L. Beschta, N. Otting, and D. Lytjen. “An Ecological Perspective of Riparian and Stream Restoration in the Western United States.” *Fisheries* 22 (May 1997): 12-24.

Northwest Power Planning Council. *Return to the River. Date: December, 2000.* Cited 5/2003. http://www.nwcouncil.org/library/return/2000-12.htm.

Oregon Department of Environmental Quality. *Upper Grande Ronde River Sub-Basin Total Maximum Daily Load (TMDL).* Salem, OR: Oregon Department of Environmental Quality. 2000.

Oregon Department of Fisheries and Wildlife. *Aquatic Inventories Project. Habitat and Reach Data Coverage Metadata. Date: May, 1999.* Cited 4/4/2002. http://osu.orst.edu/Dept/ODFW/freshwater/inventory/habitgis.html.

Paulsen, C.M. and K. Wernstedt. “Cost-Effectiveness Analysis for Complex Managed Hydrosystems: An Application to the Columbia River Basin.” *Journal of Environmental Economics and Management* 28 (1995)**:**388-400.

Reichelderfer, K., and W.G. Boggess "Government Decision Making and Program Performance: The Case of the Conservation Reserve Program." *American Journal of Agricultural Economics* 70(1988): 1-11.

Ribaudo, M.O. "Consideration of Offsite Impacts in Targeting Soil Conservation Prgrams." *Land Economics* 62(November 1986):402-411

Sanchirico, J.N. and J. E. Wilen. “Bioeconomics of Spatial Exploitation in a Patchy Environment.” *Journal of Environmental Economics and Management* 37 (1999): 129-150.

Scherer, C.S. “Water Allocation and Pricing for Control of Irrigation-Related Salinity in a River Basin.” *Water Resources Research* 13 (April 1977): 225-38.

Theurer, F.D., I. Lines, and T. Nelson. “Interaction Between Riparian Vegetation, Water Temperature, and Salmonid Habitat in the Tucannon River.” *Water Resources Bulletin* 21(1985): 53-64.

Watanabe, M. *The Efficient Allocation of Conservation Practices: Case of the Grande Ronde River Basin, Oregon.* Ph.D. Dissertation, Oregon State University, Corvallis, OR. 2003.

Weber, M.L. “Markets for Water Rights under Environmental Constraints.” *Journal of Environmental Economics and Management* 42 (2001): 53-64

Wu, J., R.M. Adams, and W.G. Boggess. "Cumulative Effects and Optimal Targeting of Conservation Efforts: Steelhead Trout Habitat Enhancement in Oregon." *American Journal of Agricultural Economics* 82(2000): 400-413.

Wu, J. and W.G. Boggess. "The Optimal Allocation of Conservation Funds." *Journal of Environmental Economics and Management* 38(1999): 302-321.