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Costs and Benefits of Riparian Forest Management: A Literature Review

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INTRODUCTION

PURPOSE

The Minnesota Forest Resources Council (MFRC) is interested in developing a better understanding of the economic costs and benefits of riparian forest management for purposes of evaluating its voluntary site-level guidelines. The first step in this process is a comprehensive literature search and review. The purpose of the review is to support development of a practical approach to estimating costs and benefits of alternative riparian management scenarios. Recommended approaches will be addressed in a subsequent report.

ORGANIZATION OF REVIEW

Following an overview of our findings, we describe the approach taken to study identification and selection. The first section of the review summarizes literature relevant to riparian management benefits. These studies generally provide values for relevant natural resource and ecological services derived from revealed-preference studies (i.e., where value is expressed through actions in an existing market). This section is further divided into categories on riparian, wetland and non-timber forest values, water quality (and to a lesser extent, quantity) and recreation. The second section describes approaches to estimating costs associated with riparian management, where costs are expressed as forgone timber revenues and/or increased harvesting costs. The third section summarizes literature addressing cost-effective riparian management strategies. While these studies do not provide valuation information, they describe approaches and models potentially relevant to cost-benefit analysis of riparian management alternatives. The fourth and final section provides a brief description of cases in which ecological benefits analysis has been applied in a relevant context.

SUMMARY OF FINDINGS

Our searches and discussions with other practitioners yielded a substantial amount of published and gray literature. While the majority of these sources provide useful information, no one source or subset of sources addresses the specific policy question posed by the MFRC. That is, the marginal economic benefits associated with changes in riparian management zone (RMZ) width and management practices. The costs of such policies are more readily estimated, and several examples are included in this review. Below we summarize our three principal conclusions:

- **Existing bioeconomic models:** Several studies provide examples of integrated physical, biological and economic analysis of forest management and riparian restoration (e.g., Loomis, 1988 and 1989 and Watanabe, 2005). While these approaches are appealing in their sophistication, the specific examples are limited in scope in terms of biological and physical parameters. In addition, they generally consider significant changes in management (i.e., a scenario with or without buffers, or with or without logging); it is unclear whether such an approach would be sensitive enough to accommodate marginal changes in riparian management. Nonetheless, to the extent that similar integrated models exist, or could be developed and calibrated to the MFRC's objectives, these studies provide a useful framework in which to incorporate economic benefit measures.

- **Relevant benefit valuation literature:** The two areas of valuation literature most relevant to the MFRC's objectives are: 1) hedonic property value studies of water quality, and 2) aquatic-based recreational demand studies. Several hedonic studies have examined benefits associated with improving or preventing degradation of stream and lake water quality, which is likely to be directly affected by changes in riparian forest management (e.g., Epp and Al-Ani, 1979; Steinnes, 1992 and Michael et al., 1996). Because estimates from these studies implicitly incorporate the value of recreation and other activities/uses that good water quality supports, the need to link management practices to distinct biological changes may be obviated. Alternatively, in cases where biological relationships are more well-defined, or hedonic value estimates inadequate, a rich recreational fishing literature exists (Boyle et al. 1999a and 1999b provide summaries). Several studies have estimated values for changes in fishing quality relevant to riparian management practices (e.g., Feather, 1994 and Feather et al., 1995).

- **Spatial heterogeneity:** This review demonstrates that the benefits and costs of riparian management will vary depending on the location and attributes of the RMZ (e.g., species composition) and waterbody. For example, areas closer to population centers and accessible to the public will be more valuable, particularly with respect to recreational opportunities. These attributes are partially a function of ownership, and areas managed according to different objectives will generate different values. All of these findings speak to the spatially heterogeneous nature of efficient riparian management. Any approach to cost-benefit analysis of policy alternatives will necessarily involve GIS analysis. The proliferation of available data and analysis procedures has made GIS an invaluable tool in applied economic analysis in recent years (Bateman et al., 2002 and Paterson and Boyle, 2002).

Considering the complexity of the task, it is not surprising that economic studies of a comparable policy question do not exist. Our discussions with natural resource managers in several states indicate that although various riparian protection incentive programs are in place, broader benefits and costs are generally weighed qualitatively, or examined on a case-by-base basis.[1] Nonetheless, approximate benefit measures based on simplified physical and biological relationships may yet provide valuable information (e.g., Unsworth et al., 1991). Given that cost estimates can likely be defined with some precision, policy-relevant analysis is possible taking into account a reasonable range of benefit uncertainty.

LITERATURE REVIEW

APPROACH AND SCOPE

Our search procedures consisted of three parts. First, we conducted searches of several on-line databases.[2] Second, a comprehensive review of literature in our library and relevant project files was undertaken. Third, several academic and professional economists who have published in related areas were contacted regarding additional sources/references.

These efforts yielded over 100 potentially relevant sources. The following selection criteria were applied to identify the subset of studies appropriate for inclusion in this review:

- **Methodology:** This review focuses on studies that employ revealed-preference approaches. For example, Haefele and Loomis (2001) and Holmes et al. (2004) both apply stated-preference techniques to value forest health and riparian restoration, respectively. These studies were not included in the literature review.
- **Location:** Studies conducted in Great Lakes states or areas with similar physical and institutional environments were assigned priority. Specifically, the order of geographic priority was: Great Lakes, states adjoining Minnesota, Pacific Northwest, Maine, remaining New England and New York, all remaining domestic, and international. The location criterion was applied in two principal ways. In some cases, studies were eliminated because of the dissimilarity of

[1] We spoke with representatives from Wisconsin, Michigan, Oregon, Washington and Maryland.

[2] Databases included EconLit, Social SciSearch, SciSearch, AGRICOLA, CAB Abstracts, GEOBASE and CSA Environmental Pollution and Management Database. General Internet searches were also conducted.

environments considered.[3] For example, Colby and Wishart (2002) use the hedonic property value method to estimate the value of proximity to desert riparian corridors in the Tucson, Arizona metropolitan area. Alternatively, some studies provided relevant information that was also available in a study from a preferred location. For example, Dearmont et al. (1998) estimate sediment-related changes in water treatment costs in Texas. Included in the review are Holmes (1988) and Moore and McCarl (1987), which present similar information for the Great Lakes and Oregon, respectively.

- **Quality:** Studies that rely upon state-of-the-art methods and are of more recent vintage were assigned priority. Some studies provided insufficient detail to evaluate quality. For example, Lippke and Bare (1999) describe costs associated with riparian management alternatives in Western Washington. However, almost no detail on data sources or analytic methods is provided that would indicate the reliability of reported results.

- **Relevance:** Studies that did not contain pertinent economic information were not included.[4] For example, Brown and Daniel (1991) use survey methods to elicit scenic quality ratings for landscape aesthetics of riparian environments. More generally, changes in riparian forest management practices have the potential to affect the quantity and quality of a wide variety of natural resource and ecological services. Many of these services have been valued in some fashion within the economics literature. For purposes of this review, we focus on values estimated specifically in the context of riparian management, or for services most likely to be directly affected by such management (e.g., water quality). Values associated with more peripheral linkages are not discussed in depth. For example, changes in RMZ widths could alter the mix of game species within those areas, leading to changes in hunting participation or quality. While we acknowledge general sources for related economic values, we do not provide a comprehensive review of hunting valuation studies.

[3] Similarity, quality and relevance are standard criteria applied in benefits transfer analyses (e.g., see EPA, 2000). Benefits transfer refers to the adaptation of existing valuation research to an alternative policy setting or question.

[4] Our search identified a number of studies that address riparian management specifically with respect to agriculture or grazing. For example, Obermiller (1994) provides a basic overview of economic issues associated with riparian management on grazing lands, and Watson et al. (2000) provide a brief summary of this literature. Although many of the associated water quality issues are common to forest riparian management, we generally do not address such studies due to obvious differences in the management context. Some exceptions are studies where the economic implications are analogous to riparian forest management or that provide other relevant insights.

Finally, our literature search revealed a number of studies that have examined cost-effectiveness of riparian management schemes. That is, the maximization of ecological protection or improvement subject to some pre-defined budget constraint, or minimization of costs subject to some established protection standard. This literature does not speak directly to the MFRC's stated objectives in that it does not provide value measures. However, we feel that this literature highlights some of the physical, ecological, and socioeconomic attributes of management alternatives that would also be important in the context of cost-benefit analysis. Thus, several examples are summarized in the third section of the review.

RIPARIAN MANAGEMENT BENEFITS

Riparian, Wetland and Non-timber Forest Values

The studies summarized in this section largely rely upon the hedonic price method to estimate values for services relevant to riparian, wetland and forested areas. These values may apply to riparian management changes, should they alter the total amount and distribution of such areas.

Mooney and Eisgruber (2001) estimate changes in residential property values associated with forested riparian buffers in the Mohawk River watershed in western Oregon. Such buffers are encouraged through the Oregon Plan for Salmon and Watersheds.[5] Utilizing data on over 700 properties, the authors estimate that stream frontage increases property values by seven percent. However, they find that each additional foot of riparian buffer *decreases* property value, on average by .06 percent. Further, the authors find that this effect is greater for buffers less than 30 feet (the average buffer width). The authors speculate that wider riparian buffers may obscure residents' view of the stream, thus reducing property value. It should be noted that this study relies upon assessed property values versus actual market transactions. While this does not discredit the results of the study per se, it is not consistent with best practice.[6]

To the extent that changes in riparian management affect the quantity and quality of wetland areas, numerous relevant valuation studies exist. For example, Woodward and Wui (2001) conduct a meta-analysis of 39 wetland valuation studies that employ varying approaches, including replacement cost and hedonic methods. Their results highlight the broad range of estimated values that have appeared in the literature. Both Doss and Taff (1996) and Mahan et al. (2000) consider the influence of wetland proximity on property values. The former considers distance to four wetland types in Ramsey County, Minnesota. The authors find positive and significant premiums for proximity to scrub-

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[5] This is also the focus of the Watanabe et al. (2005) case study discussed in the third section of the review.

[6] Assessments, appraisals or self-reported values may not accurately reflect market value and could obscure relationships between environmental characteristics and property value (e.g., see Freeman, 2003).

shrub, open-water and emergent vegetation wetlands (ranging from $99 to $145 for a 10-meter decrease from the mean distance). A negative and significant implicit price is observed for forested wetlands. The authors do not provide any insight into this divergent result. As with Mooney and Eisgruber (2001), these results are based on assessed property values.

Mahan et al. (2000) conduct a more expansive and robust hedonic analysis of wetland proximity in the Portland, Oregon area. Their results suggest that proximity to, and size of wetlands positively influence property prices. Specifically, increasing the size of the nearest wetland by one acre results in a $24 increase in home value, while reducing distance to the nearest wetland by 1,000 feet (from an initial distance of one mile) increases home value by $436. These authors do not find any significant differences between the four wetland types described in Doss and Taff (1996). Finally, the authors note, based on other environmental attributes included in their model, that proximity to wetlands is not as desirable as proximity to lakes, but more desirable than streams.

Scarpa et al. (2000) employ an interesting revealed-preference approach to estimating non-timber forest values in Wisconsin. The authors rely upon data from roughly 600 U.S. Forest Service Forest Inventory and Analysis (FIA) plots to calculate actual harvest returns relative to an estimated profit-maximizing harvest. The difference between maximum timber revenues and actual revenues is interpreted to reflect the value of non-timber services to forest owners. This approach is also employed by Lee (1997) in a North Carolina case study. Scarpa et al. (2000) find that non-timber values were highest for national forests, roughly $50 per hectare per year, or ten times actual timber revenues. For non-national public forests non-timber values were roughly four times timber revenues ($20 to $24 per hectare per year), and non-timber values were roughly twice revenues for private non-industrial forests. Interestingly, non-timber values were slightly higher than timber revenues for industrial forests. This variation naturally reflects different underlying management objectives, property rights and forest attributes. In addition, the authors acknowledge that due to differing objectives, risk preferences, and imperfect information, forest owners may not behave according to a strict profit-maximizing model. Nonetheless, as this study seems to suggest, even industrial forests may have some incentive to sustain non-timber values for purposes of public relations or other motivations.

Scarpa et al. (2000) also develop a hedonic model to attempt to explain variation in non-timber values as a function of forest characteristics. In general, these results suggest that non-timber values are most significant for national forests and that larger trees are associated with higher values. Other attributes such as forest diversity, distance to roads, and county income and population density are not significant predictors of non-timber value.

In a related example, Kline et al. (2000) examine non-industrial private forest owners' willingness to forego harvest in riparian areas in exchange for tax incentives. This application is in the context of fish habitat restoration (similar to Watanabe, 2005 and Mooney and Eisgruber, 2001) in the 19 counties of western Oregon and the 19 counties of western Washington. The authors note that non-industrial ownership accounts for 27 percent of nonfederal timberland in the region and is more likely to be located in riparian areas. Based on survey responses, the authors categorize owners into four groups with differing management objectives (timber producers, multiobjective owners, recreationists and passive owners). Not surprisingly, required compensation to forego all harvest within 200 feet of riparian areas for 10 years differed widely across the groups, with timber producers requiring the highest payment.

Both of the above studies represent interesting applications of valuation techniques to forest-owner preferences and may reveal some information about non-timber values. Their direct applicability to analysis of riparian management alternatives is likely limited, however, to demonstrating that any changes in forest management will affect areas differently depending on ownership and management objectives.

Water Quality

Changes in water quality are likely the principal physical outcome of changes in riparian management practices. The economic value of water has been estimated in a wide variety of contexts. For example, Sedell et al. (2000) provides provisional estimates for the value of water flowing from national forests based on information from an unpublished report by Brown (1999). This information was later incorporated in Brown (2004), where the author develops a general conceptual model for estimating the marginal value of additional streamflow from national forests. The model considers a variety of offstream uses, instream recreation, hydroelectric power production and support of ecosystem functions. Drawing upon a wide variety of data sources, illustrative values are provided for each of 18 water resource regions.

Sedell et al. (2000) notes that while the majority of runoff in the country derives from forested areas, water yield increases through forest management are unlikely to be significant. However, management practices can have profound impacts on water quality through mitigation of temperature, nutrient and sediment loading and toxic contaminants.[7] Because the most direct and quantifiable benefits of riparian management and RMZs are likely with respect to improvements in water quality, we focus on related economic values in the remainder of this section.

Several hedonic property value studies have demonstrated the value associated with lake frontage or proximity (e.g., Boyle et al., 2002 and Lansford and Jones, 1995). Of relevance to this review are studies that have estimated values associated with variation in nearby or adjacent water quality. In an early application, Epp and Al-Ani (1979) estimate the influence of stream water quality on nearby properties in rural Pennsylvania. The authors test several water quality measures in the model, including pH, dissolved oxygen, biochemical oxygen demand, and nitrate and phosphate concentrations. Only pH is shown to have a statistically significant effect on property prices, with a one-point increase in pH leading to a six percent increase in value, on average. The authors speculate that this may be related to improved recreational opportunities, such as trout

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[7] Binkley and Brown (1993) provide a comprehensive summary of literature on the effects of forest practices on water quality.

fishing, that increased pH may afford. The authors also test a measure of subjective water quality, based on whether the property owner indicated that stream water quality precluded some beneficial use. In an alternative specification excluding the pH measure, this subjective measure is also shown to be a significant predictor of property prices.

In a hedonic analysis of properties on 50 small lakes outside of Detroit, Michigan, Brashares (1985) considers 20 different potential measures of water quality. Only two are shown to significantly affect property prices, turbidity and fecal coliform levels. This is not surprising, as many of the individual measures are likely to be correlated, or unobservable to property owners and buyers. The authors find that the mean level of turbidity depresses lakefront property values by over $400.

Steinnes (1992) presents a hedonic analysis of water quality for lakefront lots based on market appraisals from 53 lakes in unincorporated areas of northern Minnesota. The author considers three objective measures of water quality for each lake: percentage shallow water, amount of suspended organic material, and the number of feet below water that a secchi disc reading could be observed. Despite relatively poor explanatory power, the hedonic specifications yield relatively consistent estimates of the value of improved water quality, approximately $206 to $240 per lot for each one-foot increase in secchi disc depth.

Recent property value studies on Maine (Michael et al., 1996 and 2000 and Poor et al., 2001) and New Hampshire (Gibbs et al., 2002) lakes similarly demonstrate sensitivity to water quality. Michael et al. (1996) utilize data on over 500 lake front property transactions from 26 lakes in four different "market" areas of the state. To select an appropriate water quality indicator, the authors conducted a random survey of property purchasers on the lakes and correlated water clarity perceptions with actual conditions. The results suggest significant agreement between secchi disk readings of minimum clarity and respondent perceptions. Water quality variables based on secchi disk readings are significant in all four hedonic models, and imply an increase of between $11 and $200 per foot frontage for a one-meter improvement in water clarity across the lakes in the sample. Importantly, the authors note that other important lake characteristics that are likely to be correlated with water clarity, such as fishing, swimming, and potability, are not included in the models. Thus, the price estimates also reflect the contribution of water quality to these activities/uses.

Water quality, particularly with respect to sediment, has also been valued in an avoided-cost context. For example, Holmes (1988) estimates increased water treatment costs associated with sediment loading. Drawing upon data collected by the American Water Works Association on over 400 large utilities, the author estimates cost functions that relate treatment costs to intake water turbidity levels. Empirical estimates suggest that the average cost of turbidity is between four and $114 per million gallons. An alternative specification suggests that a one-percent increase in turbidity is associated with a .07 percent increase in operating and maintenance expenditures. For the Great Lakes ASA (the Water Resource Council's Aggregated Sub-Areas), estimated benefits associated with a 10-percent reduction in sediment loading are roughly $240,000 per year.

In a more localized case study, Moore and McCarl (1987) collected information on sedimentation in the Willamette River Valley, Oregon. Like Holmes (1988), they find that turbidity increases water treatment costs on average, in this case by $20 per million gallons. Similarly, the authors estimate that a one-percent increase in turbidity increases cost by 0.3 percent. Finally, the authors develop general estimates for costs associated with road maintenance (ditch and culvert cleaning) and river channel maintenance.

One of the most ambitious efforts to valuing benefits associated with erosion and sediment control is Ribaudo's (1989) national analysis of the Conservation Reserve Program (CRP). Because the CRP targets cropland and the economic analysis relies in large part on secondary sources, we do not describe the reported benefit estimates; however it is instructive to summarize the steps taken. First, the author estimates the reduction in erosion arising from conversion of cropland to grass or trees and compares this to baseline erosion levels from National Resources Inventory data. Second, existing estimates of waterway discharges from a national database are used to estimate CRP-related reductions in total suspended sediment, nitrogen and phosphorus discharges in 99 major river basins. Third, to establish a link between discharges and ambient water quality, average concentrations from the U.S. Geological Survey's National Stream Quality Accounting Network are related to material discharge, stream flow and total volume in a simple regression model for each watershed. Finally, drawing upon a number of existing sources (including Holmes, 1988), the author develops aggregate estimates of avoided damages to water storage, navigation, flooding, road maintenance, irrigation, water treatment, and industrial water uses.

Recreation

Changes to RMZ width and/or management practices could affect both terrestrial and aquatic-based recreational opportunities. For example, width changes may alter the total area of forest supporting certain types of recreational activities. Recreation on forest lands has been well-studied and economic values exist for a variety of activities (e.g., see McCollum et al., 1990). Changes in riparian management will also alter attributes of RMZs (e.g., tree density and size). Several studies examine recreationists' preferences for different forest attributes (e.g., Shelby et al., 2005) and employ recreation demand models to relate economic values to those attributes (e.g., Englin et al., 2001 and Hesseln et al., 2004 examine this issue in the context of forest fires).

Walsh et al. (1989) utilize a travel cost model to estimate changes in recreational value due to reduced tree density from pest damage. The authors estimate demand for recreational trips to sites in four national forests along Colorado's front range. During on-site interviews, recreationists were asked to identify tree density, and this was included as a quality attribute in the demand model. The authors estimate a loss of recreation benefits (reduced trips and value per trip) of approximately 14 to 16 percent for a 20-percent reduction in tree density. Similarly, an alternative application of the travel cost method by Englin and Mendelsohn (1991) examines the value of forest site attributes in Washington. The authors utilize data on visits to Four Forest Service Wilderness areas along the Cascade Mountains (Pasayten, Glacier Peak, Goat Rocks and Mount Adams) and associated trail characteristics. Results suggest that species mix and age, as well as the absence of clear-cuts, are valuable site attributes.

Aquatic-based recreation, particularly angling quality, is likely to be directly affected by changes in riparian management. Some efforts have been made to explicitly link changes in forest management practices to changes in the economic value of fisheries. For example, Loomis (1988 and 1989) present case studies for the Siuslaw National Forest in Oregon's Coast Range and the Porcupine-Hyalite Wilderness in Montana. In the Siuslaw case study, the author utilizes an existing habitat model that predicts carrying capacity for undisturbed and logged watersheds. This habitat index is then related to abundance of chinook salmon, coho salmon and steelhead. Finally, travel cost models for different sites/species are used to measure the benefits of increased catch under different timber management alternatives. For freshwater sport salmon, the results suggest that total benefits would be 40 percent higher under a scenario where timber harvest level and locations maximize fish production relative to current practices. In this example, Loomis (1988) also presents information on potential benefits of increased commercial harvest.

While we are not aware of any recreational fishing studies that have estimated values for changes arising specifically from riparian management practices, many studies have estimated relevant values for marginal changes in fishing quality. For example, Boyle et al. (1999a and 1999b) describe a database and meta-analysis of over 100 recreational fishing studies, including two studies that value fishing opportunities on Minnesota lakes under different water clarity conditions (Feather, 1994 and Feather et al., 1995). Feather et al. (1995) estimate changes in seasonal fishing benefits of two to 12 percent for improvements to roughly half of the state's lakes. Similarly, in a model of recreational site choice for Alberta anglers, Peters et al. (1995) demonstrate that water quality is important to anglers independent of catch rate, stocking, lake area and other quality attributes. This study also shows that forested fishing sites are preferred to those that are not.

Several studies estimate benefits for marginal changes in fish abundance and catch rate. For example, Johnson (1989) utilizes the travel cost method to estimate demand for trout fishing on the Cache la Poudre River in Colorado. The author estimates a per-day value of roughly $22 and that an increase in catch of one trout increases value by more than one dollar. The estimated demand function for fishing days also implies that each 10-percent increase in catch on the river would increase the number of fishing days for the average angler by two percent.

RIPARIAN MANAGEMENT COSTS

Relative to benefits, estimating costs associated with changes in RMZ width or management practices is more straightforward. These costs include the value of merchantable timber precluded from harvest. For example, in a report prepared for the MFRC, Vasievich and Edgar (1998) estimate timber acreage and volume within Minnesota RMZs. Other costs include potential added costs of accessing and extracting timber from RMZs, and administrative costs of implementing riparian management guidelines. Several published case studies of such cost analyses exist. While they depend critically upon the topography, species mix and other site-specific attributes, they nonetheless provide insight into the nature of riparian management costs.

Olsen et al. (1987) present a detailed accounting of costs associated with riparian buffers in the Nettle Creek drainage on the Siuslaw National Forest, Oregon. The authors consider increased road costs, logging costs, and the value of timber stranded in buffers and inaccessible areas for three scenarios. The scenarios consist of current Oregon Forest Practice Rules, and two more restrictive scenarios where the average buffer width is increased, the percentage of Class II streams reclassified to Class I is increased, the percentage of conifer removal in buffers is reduced, and logging practices are constrained.[8] While harvesting costs do not increase substantially under the more restrictive scenarios (at most from $137 per million board feet to $140), road costs increase as much as 40 percent. In terms of value per acre, the second scenario is estimated to result in a present-value loss of $75 to $168 per acre, depending on timber size. These figures increase to $269 to $653 per acre for the most restrictive scenario. Again, it is important to note that these values are highly site-specific.

In an example from Victoria, Australia, Bren (1997) estimates costs associated with stream buffers (where harvest is not permitted) ranging from five to 300 meters in width in the West Tarago River basin. Using GIS, the author evaluates the reduction in volume per hectare and associated cost using prevailing stumpage prices. Results indicate that value per hectare decreases modestly with increasing buffer size, up to a width of 150 meters, after which value declines quickly. These results are largely a function of local stream density. This case study also highlights the possibility of creating uneconomic islands of trees as buffer widths are increased.

Recently, Ice et al. (2005) describe how stream density, stream classification and RMZ width and management restrictions determine the area and value of timber precluded from harvest. An example for a watershed in a research forest near Corvallis, Oregon is provided. The authors use GIS to compare percentages of watershed area under riparian management protection and associated costs for three different policy scenarios. This

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[8] The USFS defines Class I as perennial streams that provide a direct source of drinking water or provide habitat for large numbers of fish or are major contributors to a Class I stream. Class II streams are perennial streams that are used by moderate numbers of fish or are moderate contributors to a Class I stream or are major contributors to a Class II stream. Class III are all remaining perennial streams and Class IV are intermittent streams.

case study further demonstrates that the drainage network, extent of protected waterbodies, RMZ width and species distribution are the driving factors in determining riparian management costs.

COST-EFFECTIVE RIPARIAN MANAGEMENT

Recognizing the inherent difficulties associated with estimating benefits of riparian protection and enhancement, several studies have suggested strategies for cost-effective design and implementation. As noted, this does not conform strictly to the MFRC's goal of supporting cost-benefit analysis; however, this literature does provide certain insights. In particular, these studies demonstrate the benefit of flexible riparian management approaches, recognizing heterogeneity in physical, biological and socioeconomic conditions.

In two general examples, Azzaino et al. (2002) and Ferraro (2001) compare approaches to riparian land buffer acquisition subject to a fixed budget. The case study is the Skaneateles Lake watershed in upstate New York, a high-quality source of drinking water for the city of Syracuse. An agreement with the Department of Health required the city to institute a long-term watershed management program (including riparian buffer establishment) to reduce pathogen, chemical, nutrient and sediment loading into the lake in order to avoid construction of a $70 million filtration plant. Azzaino et al. (2002) compare two approaches. The first involves a commonly applied parcel scoring system based on a weighted average of parcel attributes (e.g., parcel size, stream footage, and distance to the city water intake pipes). The second approach is referred to as a parcel-pollutant-weighting model, which takes into account current land-use/cover and associated pollutant loading. This information is used to develop an index of parcel effectiveness in mitigating pollutants. The authors note that a preferred approach to constructing the pollutant-weighting index would incorporate a non-point source simulation model such as the Riparian Ecosystem Management Model (REMM) (Lowrance et al., 2000) calibrated to the watershed.

Ferraro (2001) advocates a "distance-function" approach to selection of riparian buffers. The author argues that there is often inadequate information to specify a function that converts multiple biological and physical attributes into an expected environmental benefit measure. The nonparametric, distance function-based approach combines relevant parcel attributes (including cost) to produce a production frontier. In the simple case of only two attributes (e.g., cost and size), the frontier is a line that traces out the most efficient parcels. Parcels are then ranked based on their distance to the frontier and assigned a measure between zero and one that indicates the percentage change in cost necessary for a parcel to reach the frontier. A principal benefit of the measure is its flexibility: parcel ranking can be re-calculated readily if costs change (as in the case of negotiations) without re-solving an optimization model.

Watanabe et al. (2005) present a sophisticated approach to establishing efficient riparian restoration and zone width. The example is a program designed to target stream temperature and improvements in juvenile salmonid abundance through increased shading in the Grande Ronde basin in northeastern Oregon. The authors note that conservation efforts should account for heterogeneity in stream and riparian conditions, cumulative and threshold effects of restoration activities, and public preferences and land ownership patterns. As such, they develop a system containing a physical model that links riparian structure to water temperature, a biological model that links water temperature to salmonid abundance, and an economic model that describes minimum-cost conservation scenarios subject to water temperature or fish abundance objectives. The authors demonstrate alternative allocations of restoration efforts depending on whether stream temperature or fish populations are targeted, owing to the heterogeneity of fish distribution, riparian conditions and temperature levels. While this example considers only one water quality measure and biological outcome, it demonstrates an integrated modeling approach, and highlights spatial heterogeneity inherent in riparian management.

Yang and Weersink (2004) also combine hydrologic and economic models in a GIS framework to determine a cost-effective distribution of stream buffers in the Canagagigue Creek watershed in Ontario. This example is agricultural in nature, where costs are measured in terms of forgone crop yields, but the conclusions are relevant to forest riparian management.   The model is run for multiple sediment abatement goals where riparian buffer strips are allowed to vary in increments of five meters throughout the 250 sub-catchments in the watershed. The authors find that for a given sediment abatement objective, total costs are 14 percent higher when uniform buffers are implemented versus allowing them to vary. In describing extensions to this work, the authors note that buffers also provide wildlife habitat. However, these benefits are likely to be limited if buffer design is highly fragmented. In this manner, the scale and distribution of buffers as it relates to habitat benefits could be incorporated in the model.

APPLICATIONS

Non-market benefits have been implicitly or explicitly incorporated in forest management for some time. For example, promoting ecosystem health and recreational opportunities are primary goals articulated in the U.S. Forest Service's Strategic Plan (USFS, 2000). Surprisingly, our search did not uncover any practical economic analyses of riparian management practices. In this section, we briefly summarize two examples that draw upon information and themes highlighted in this review.

In an analysis prepared for the U.S. Environmental Protection Agency, Unsworth et al. (1991) utilize existing information (including several sources cited above) to value timber and non-timber losses associated with reduced forest area in South Carolina due to climate change. The intention of this analysis was to provide a rough approximation, and considered a basic, with and without forest scenario. Estimated non-timber values include recreation, erosion control and flood control. The authors find that non-timber values account for 25 percent of total annual benefits.

An interesting international example was recently mentioned in an article in *The Economist* (April 23, 2005) and is described by Chomitz et al. (1998) and Malavasi and

Kellenberg (2002). After decades of deforestation, Costa Rica adopted a law in 1996 that explicitly recognizes four environmental services of forests: carbon fixation, hydrological services, biodiversity protection and provision of scenic beauty. Subsequently, the Payments for Environmental Services Program was instituted, which negotiates site-specific contracts with landowners for forest conservation, sustainable management, or reforestation. Payments for the three contract types range from $210 per hectare (distributed evenly over five years) to $537 per hectare. These payments are generally designed to equate to returns to unsustainable logging and conversion to agriculture. For example, the incentive for reforestation is roughly comparable to the rental price for pasture. The program is funded by a fuel tax and in part by private sector beneficiaries, such as hydroelectric-power producers.

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