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Integrating resilience into floodplain restoration

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Abstract. This paper explores the role of geographic prioritization as a means of identifying lands that are especially well suited to restoration in the historical floodplain of western Oregon's Willamette River. The river and its floodplain have been extensively modified since 1850. As a result, the quantity and quality of river habitat have declined. The approach illustrated here explicitly links the potential for ecological benefits from restoration with the social and economic likelihood of restoration success. Using a consistent analytical framework, longitudinal patterns in selected biophysical and socioeconomic characteristics are quantified along the entire river length, from Eugene to Portland. Areas with high potential for ecological recovery and low socioeconomic constraints have the greatest potential for future restoration. Areas that combine low potential for ecological response with high demographic and economic costs are likely to be poor choices for restoration. Areas with high ecological potential and intermediate levels of socioeconomic constraints present intermediate opportunities for restoration. The paper identifies high priority locations for restoration, assuming the purposes of restoration are to increase river channel complexity, increase floodplain forest area, and increase natural water storage during floods. It concludes by discussing the role of visualizations in citizen involvement.

Keywords: floodplain restoration prioritization

Introduction

Over the past decade, a set of case studies has been developed in the United States applying alternative future approaches to the challenges of land and water use and management. These case studies have been applied in different regions of the country and they have addressed different drivers of change, different land use types (urban, suburban, exurban, agricultural, forested), and responses of varying resources to the envisioned changes (Santelmann *et al.*, 2001; Steinitz and McDowell, 2001). While issues of resilience and adaptability have not been foremost in these studies, alternative future projects are useful precisely because they allow exploration of the effects of alternative landscape patterns on various things people care about, (e.g., water quality, beauty, terrestrial and aquatic life, public costs of infrastructure, places for new residents to live, time spent stuck in traffic, value of market commodities produced, etc.). These studies also illustrate how certain constellations of policies and choices may lead to landscapes that are better able to sustain a richer mix of the things we hope for, or, no less importantly, of the things we fear.

So, we see in these studies an underlying motivation to anticipate how places may adapt or respond to altered trajectories of change, to disturbances of varying types, periodicities and origins. While not fitting precise definitions of *resilience* from the ecological literature of a system's potential to recover biophysical properties and processes following disturbance, this interest in the response and adaptability of complex systems to change is not far from it (Niemi *et al.*, 1990, Sedell *et al.*, 1990).

The theme we focus on here is what, precisely, we wish our cities to be resilient *to*? There is an extensive literature in the planning and design fields concerning cities and their evolution. However, with a few noteworthy exceptions, the ecological resilience of native plant and animal communities and the processes that sustain them have not been well represented in this literature. Historically, the territories required by these non-human processes were, to use the vocabulary of real estate development, subjected to "higher and better" uses as cities. This, of course, meant displacing native plant and animal communities for either the most intense human use that would produce the highest sustained monetary wealth over time or meet some equally pressing human need not motivated by wealth production alone (Hulse and Ribe, 2000). So, while changes to natural systems caused by the creation and expansion of cities are a relatively recent historical concern, creating urban forms with the ability to accommodate unspecified future human activities is not. Thus, in this body of work, we see careful thinking about making cities resilient to disturbances of human origin, but less often to the natural disturbances, e.g. floods or prescribed fires in urban areas, that are increasingly understood to be necessary parts of complex adaptive systems (Levin, 1998).

This paper explores the role of geographic prioritization as a way to identify riparian lands especially well suited biophysically and socioeconomically to the restoration of more natural disturbance regimes. In setting forward a workable way to identify such land/water areas, we assert that by integrating demographic and economic characterizations of candidate restoration areas together with biophysical characterizations, a more strategic conceptual framework emerges for prioritizing floodplain restoration. Further, we argue that by refining and adjusting the priority criteria for such locations at three different scales, the approach is better able to respond to the changes in political and biophysical priorities that accompany three scales of the study: river network, river reach, and focal areas.

The conceptions of resilience from the ecological literature imply that dynamic features of landscapes, like rivers, should be allotted more territory than the historically wealth-motivated processes of urban land use have been willing to give (National Research Council, 1992; Cowx and Welcomme, 1998; Riley, 1998; Walters and Korman, 1999; Hulse and Ribe, 2000). Landscape planners and resource managers throughout the world are faced with the challenge of maintaining dynamic processes of channel meandering (both channel erosion and deposition) and floodplain inundation while allowing people to use these areas of the river floodplain and invest in infrastructure in this ever-changing portion of the landscape. In the pages that follow we describe our attempt at rationalizing a way to gain more room for rivers in human-dominated landscapes, while acknowledging the real and largely irreversible investments that have already been made in these biologically and culturally important parts of human settlements.

Approach

Floodplains and riparian forests are some of the most dynamic zones of any landscape, and they contain some of the highest levels of biological diversity and habitat complexity (Gregory *et al.*, 1991; White *et al.*, 1999). These areas also are highly valued for their access to water, transportation potential, food and fiber production, recreation, and beauty. Historically, towns and cities along rivers have encroached on this zone and then attempted to create stable stream banks in areas that are, by nature, dynamic. This inherent contradiction is the basis for management of floodplains and riparian forests worldwide. Integrated regional assessment of biophysical and socio-economic patterns in rivers and floodplains improves our understanding of interactions between natural and cultural processes and provides greater potential for long-term effectiveness of river restoration efforts. Such assessments depend first on valid classifications of terrestrial and aquatic ecosystem status and trends, and second on conceptual frameworks for geographic prioritization that are consistent with the biophysical and human dynamics of the systems being managed.

Land use and other human activities have extensively modified rivers and their floodplains. In responding to these modifications, many restoration efforts are based on opportunities (e.g., willing land owners, public lands, and short-term funding sources) and are treated as add-ons to other river modification projects. These projects often lack a broader strategic framework based on both the ecological resources of the river *and* future pressures to develop land along the river. Particularly in the western United States where population centers typically occur at large river confluences, these future pressures are a foregone conclusion in a region where the human population is expected to double by mid-century (Hollman *et al.*, 2000). As a result, attempts to modify rivers or "restore" river systems often fall short of their goals. In some cases these attempts unintentionally cause detrimental changes to the ecosystem by not considering the larger river network and its biophysical/social interactions. Restoration efforts based on short-term opportunities are not undesirable. However, their success can be increased through the application of a strategic conceptual framework based on ecological potential and patterns of human activity within the river corridor.

Ecologically designed restoration efforts commonly are based on vegetation patterns (Olson and Harris, 1997), hydrology (Russell *et al.*, 1997), geomorphic processes (Petts, 1990), or floodplain dynamics (Tochner and Schiemer, 1997). These approaches tend to focus on the biological or physical components of rivers but rarely consider the human activities that shape the potential for ecological recovery and create future pressures to modify the river ecosystem. Patterns of human population densities and structural development, as well as economic values and productivity of the land along rivers, create critical constraints on the locations and outcomes of restoration.

Conceptual framework

The primary focus of this integrated analysis of biophysical and socio-economic potential for restoration is to (1) spatially identify ecological, demographic, and economic potential for riparian restoration and (2) identify changes in patterns, policies, or practices that influence the future likelihood of restoration. The conceptual framework is a simple one: places having *both* potential for ecological benefit from restorative acts *and* low constraints to doing so from human presence are the logical place to begin. These places, and others that don't have both these qualities, are arrayed conceptually in a simple four-box diagram (figure 1). With all territory in a study area located within this conceptual space, choices of where to restore when can be more clearly compared and contrasted for their relative advantages. In this way, patterns of critical riverine ecosystem components and major human population centers and land use investments create a spatial context for locating restoration efforts (Hulse and Gregory, 2001).

Important biophysical and socioeconomic parameters and processes interact differently at different spatial extents (figure 2), leading to changes in what matters most in prioritizing locations as one considers, first, the entire river network, then high priority river reaches within the network, and finally focal areas within priority reaches. These focal areas can range in size from a few to hundreds of hectares.

This approach assumes that potential for increased ecological function of various candidate river reaches and focal areas is related to the difference between current patterns and historical conditions in (1) river channel complexity and hydrology and (2) floodplain vegetation. Resilience, as conceived in this effort, is operationalized by locating places known to have had more floodplain forest and channel complexity in the past than they do at present. Constraints and incentives for restoration created by human systems are determined by (3) the patterns of human populations and structural development of the floodplain and (4) the economic values and productivity of the land within the floodplain. These features of the riverine landscape and associated human communities along the river are described more thoroughly in the section on Landscape Modeling Approach. We classified the floodplain along the Willamette River using two biophysical and two socioeconomic parameters, thereby providing a "proof of concept" quantitative basis for identifying areas with both high potential for increased ecological benefit and low socioeconomic obstacles to restoration.

High restoration potential

The lower right quadrant of figure 1 represents areas with high potential for ecological recovery and low constraint from human settlement and land value. These lands should have the greatest potential for future ecosystem recovery. Such areas are better suited for conservation and restoration because their ecological values could increase more than other areas. The efforts put forth and costs absorbed by communities to prevent channel change and flooding are often higher here than elsewhere because these are the most dynamic sections of rivers. Economic constraints and demographic pressures are frequently lower here as well. Ecological recovery is likely to be greater on these lands, while social pressures to reverse restoration are likely to be lower.

Potential for policy change and incentives

The upper right and lower left quadrants of figure 1 depict those areas that combine either high potential for increased ecological value with high demographic and economic

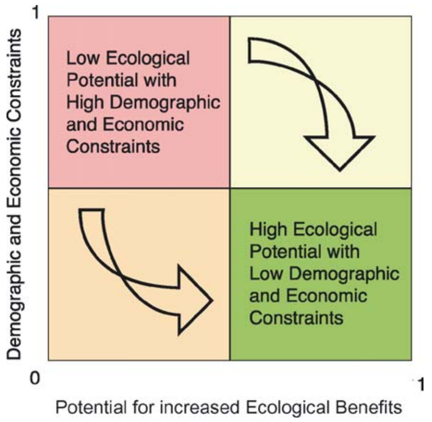

Figure 1. Conceptual framework for prioritizing restoration locations.

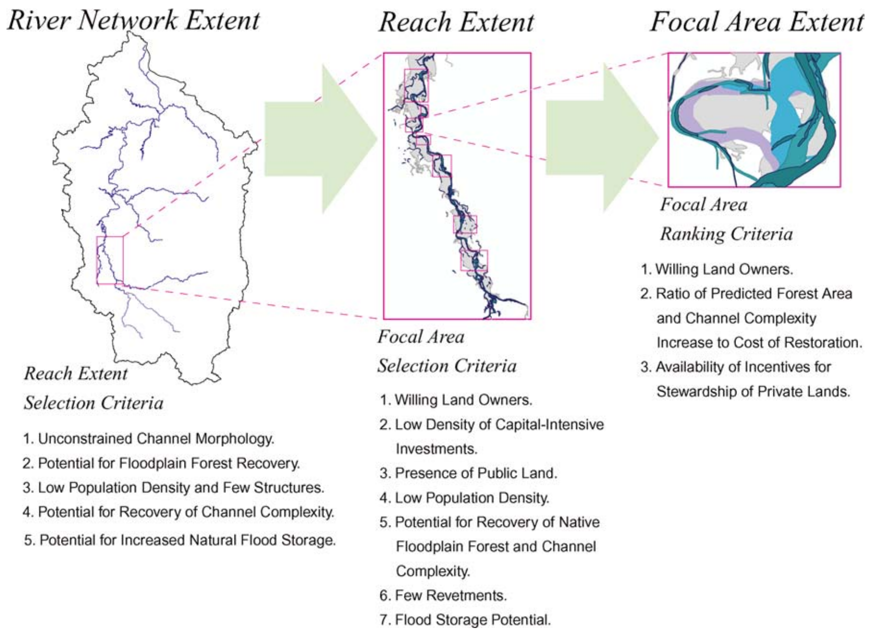

Figure 2. Three spatial extents and related prioritization criteria at which the framework is applied.

constraints or low potential for increased ecological value with few constraints. Lands in these categories have mixed qualities, some arguing for, some against restoration in this approach. In these areas, decision makers can focus on alternative policies or practices that might move a site into the lower right quadrant. Policy changes and incentives tend to modify demographic and economic constraints rather than change the biophysical potential for ecological benefits. Examples would be changes in lending rules or interest rates, federal farm assistance requirements, or the purchase of private lands by public interests. Other possibilities would be the use of land zoning restrictions or taxation policies that would have minimal economic consequences but major ecological benefits.

Low restoration potential

Areas that combine low potential for increased ecological response with high demographic and economic costs are likely to be poor choices for restoration. These areas fall in the upper left quadrant of figure 1. These sites provide little ecological benefit, are located in areas where pressures for future modification are high, and investments in restoration may be costlier than other areas because of property values. In contrast to lands described above, these areas are more suited for intensive use because their conversion will achieve less ecological response per unit of investment.

Before rejecting lands in the low restoration potential category, however, the following questions should be asked. First, are critical habitats or at-risk species present? If so, restoration outcomes may warrant heroic efforts even in the face of large socioeconomic obstacles. Second, do these lands present opportunities to learn about the values of and approaches to conservation and ecological restoration? Particularly in urban areas, these places are where people live and work. As we pass these habitats every day and use them for recreation, such landscapes provide a tangible link between people and the natural processes upon which we depend.

Landscape modeling approach

In this analysis of the Willamette River and its floodplain, the floodplain provides the most constant and quantifiable spatial framework for comparing physical, biological, demographic, and economic characteristics of the river corridor (Gregory *et al.*, 1998, 2002a). Channel position, forests, and land use may change, but the floodplain (the area historically inundated by floods) is relatively constant. We employ a spatial framework for floodplain assessment by mapping one-km "slices" of the Willamette River floodplain at right angles to the floodplain's center axis (figure 3). The longitudinal width of the slices needs to be long enough to represent landform components (e.g., pools, riffles, islands) and human land uses (e.g., crop fields, residences, buildings) but short enough to describe the variance in biophysical and social features along the length of the river. If the slice length is too long, it will homogenize and obscure relevant features, but if it is too short it will make interpretation and application difficult. For example, 5-km slices in the Willamette would have contained many land uses and more than 10 pools and riffles, but 100-m slices would have included only parts of pools or riffles and sections of agricultural fields, farm buildings, or residential structures and lots.

Within each of the 228 one-km slices, numbered from 0 (zero) starting at the confluence of the Willamette and Columbia Rivers at Portland to 227 at the confluence of the Middle and Coast Forks of the Willamette near Eugene, we measured characteristics of channel complexity, floodplain forests, human systems, and economic patterns. Information sources

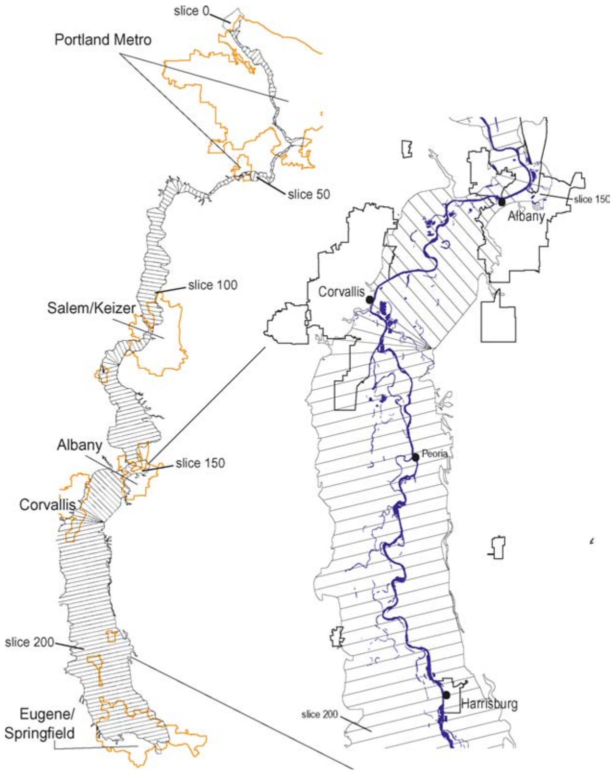

Figure 3. Spatial framework for prioritizing locations for river restoration using historical floodplain and one-km "slices" perpendicular to floodplain axis.

for these measurements included historic and contemporary river channel maps (1850, 1995, 1932, 1995) (Gregory *et al.*, 2002a), General Land Office Survey records for historic vegetation (ca. 1850) (Gregory *et al.*, 2002b), satellite data for land cover, census, road and county taxlot data for land use (all ca. 1990) (Enright *et al.*, 2002). The longitudinal display of these features creates a linear illustration of the characteristics of the Willamette River and allows consistent and simultaneous analysis of a floodplain river and the human systems along its course. Additionally, it creates a spatial context based on the natural processes that shape river channels and create their floodplains.

We then used this spatial framework for each slice to compare the presence and amount of several key factors that influence restoration planning. Implicit throughout this work is the conviction that there are important advantages to allowing natural processes (e.g., floods) to assist in accomplishing restoration goals. It is also imperative that these processes be allowed to operate in ways that minimize risk to human life and property. Next, we briefly introduce the two broad categories of biophysical and social factors that are used in the restoration prioritization approach.

Characteristics addressed in landscape modeling

Channels, floodplains, and hydrology create the physical setting for the development of the ecological properties of a river system. The primary role of these physical processes is recognized in fundamental ecological ideas, such as the river continuum concept (Vannote *et al.*, 1980) and the flood pulse concept (Junk *et al.*, 1989). We use the inundated floodplain as our spatial boundaries for that portion of the landscape formed by fluvial processes of deposition and erosion. The floodplain is the area where water is transported and detained during floods. The friction of the shallower floodplain margins and roughness of intact floodplain forests slow the floodwaters, providing refuge for aquatic organisms during these disturbances and dissipating the force of the flood. The heterogeneity of the channel creates complex habitats, thus we use the length of thalweg per km slice of floodplain as a measure of the channel complexity. Channel complexity and non-structural floodplain storage increase the diversity of habitats and the natural refuges of a floodplain river (Junk *et al.*, 1989).

Restoration is a process of change, and channel features prone to frequent change (e.g., river tributary junctions, multiple channel reaches) have greater potential for rapid restoration. Yet, when people attempt to stabilize these dynamic reaches, enormous investments are required by agencies and local communities to confine channels. Historical patterns of river channels offer useful contexts for determining potential responses to restoration in the future.

Diversity and extent of floodplain forests are closely linked to channel structure and dynamics of flooding. River reaches with high geomorphic complexity and frequent channel changes are characterized by high vegetative species diversity of riparian patches and related diversity within those stands. Tributary junctions and multiple channel reaches exhibit complex mosaics of riparian forests, and single channel reaches contain simpler patterns of floodplain vegetation. The stability of the single channel reaches can support older forests because the vegetation is not exposed to the effects of floods as frequently as more complex channel reaches.

Patterns of recent and current human land use create a context for considering potential future ecosystem patterns and locations for restoration efforts. Efforts to limit the impacts of development along the major rivers in the Pacific Northwest region have intensified as measures to limit development in floodplains and minimize impervious surface area are being applied in rapidly urbanizing lands (Booth, 1991). Major urban development in river floodplains is largely irreversible over the near future, while adjacent agricultural and forestlands at the urban fringes offer much greater potential for change.

Economic production influences landowner's decisions about the use of lands along the Willamette River. Prices of goods and services derived from riparian lands provide an indication of the likelihood of landowner participation in restoration efforts. Regulatory processes also influence landowners' decisions, and the longevity of governmental policies may be sources of uncertainty for landowners. Patterns of land productivity strongly influence the feasibility of restoration and must be evaluated along with patterns of river modification and ecological condition.

Restoration prioritization process used in landscape modeling

Although land acquisition and regulation are powerful tools in ecosystem restoration, there will never be enough money, political support, or willing sellers to protect ecosystem values in landscapes dominated by private ownership. Regardless of the strengths and weaknesses of a restoration approach, the pace of human-caused landscape change often leads to situations where the need for restoration outstrips the resources available to restore lost ecological functions (Dale *et al.*, 2000). Restoration of ecologically-significant patterns and processes in places where human population density and land use intensity are high may require reversal of long standing investments in land form and water course alteration. If ecological restoration of floodplains and the benefits of built environments are in opposition then the conceptual model described previously expresses the nature of the prioritization task: at the river network extent find those reaches where two conditions exist, investment in constructed conditions is low and the potential for increased ecological benefit is high. If potential ecological gain is high but the existing structural investment is also high, then future net gain is interpreted as small, as is the likelihood of community acceptance of large-scale restoration projects. While we illustrate here this particular conception of restoration priorities, it is important to note that there are many other valid sets of restoration priorities. We argue that the key issue is that decision-making processes used to geographically prioritize restoration locations must be consistent with *both* the biophysical and socioeconomic dynamics of the systems being managed. Otherwise these gains in ecosystem restoration will not endure, no matter how sophisticated their methods or laudable their goals.

Figures 4 and 5 show two examples of how to make the proposed conceptual model quantitative and spatially explicit (Hulse *et al.*, 2002). Beginning with river kilometer zero at the confluence of the Willamette and Columbia Rivers, we use the spatial framework explained previously to quantify the key factors affecting both opportunities and constraints for restoration. These two approaches are not mutually exclusive, but may be used in concert by individuals or groups interested in choosing among available options for restoring riverine and floodplain ecosystems. Again, note that either of these approaches may be applied with restoration priorities other than those we illustrate, given the necessary data for the relevant factors.

One approach for prioritizing locations for restoration is graphical inspection of multiple factors in a river network. Applying this approach does not require access to sophisticated tools or computationally intensive techniques, and thus any group could employ it with access to the kinds of graphs shown. Potential users of this approach might be newly-formed watershed councils or lay person monitoring efforts seeking to localize their efforts in the places best suited to their aims. In figure 4, a single value is recorded for each factor for each river slice and the resulting single-factor linear graphs are stacked atop one another so that you may read the values for both opportunities and constraints for a chosen slice by visually scanning up or down the figure. In this graphical inspection approach, constraints on restoration are low where two factors, 1990 population density and 1990 number of structures per slice, are low. Conversely, opportunity for restoration efforts to succeed ecologically is expressed in terms of change in channel complexity and in area of floodplain forest since pre-European-American settlement occurred. This approach assumes

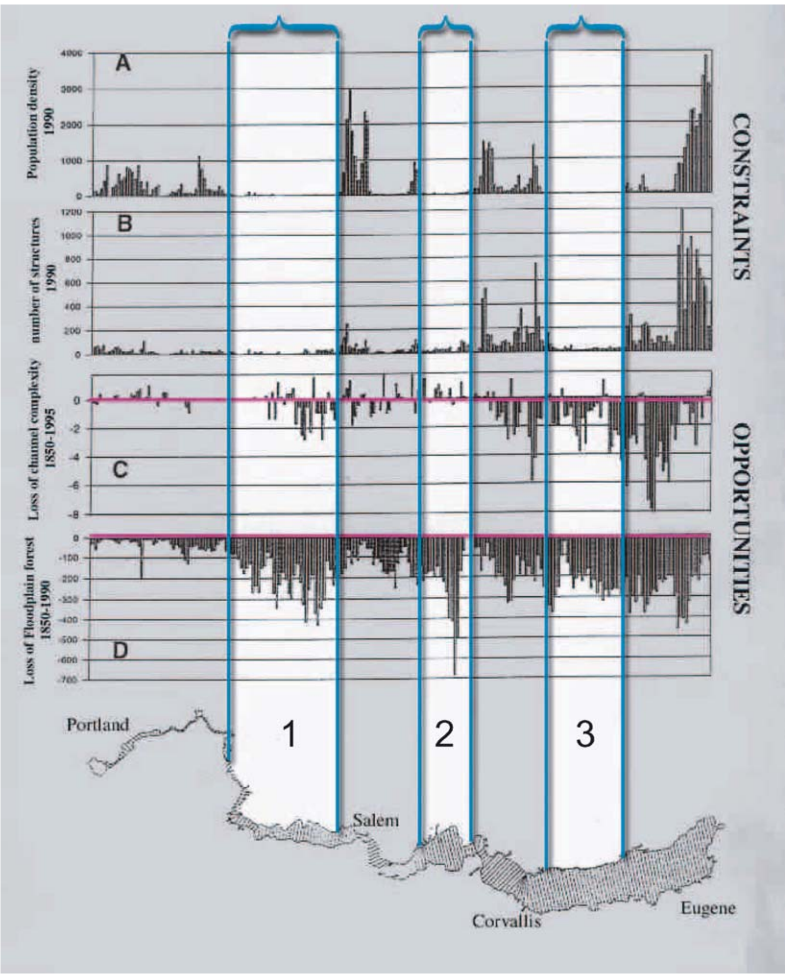

Figure 4. Graphical example of river reaches with coincident low constraint and high opportunity to restore channel complexity and native floodplain forest.

that restoration potential is high where there has been a large loss of channel complexity and area of floodplain forest since settlement. Thus these slices have the biophysical potential to recover what has been lost by employing natural processes as a restoration aid.

Highlighted vertical bands labeled 1 through 3 (outlined in blue in figure 4) indicate reaches of the river where *both* desired conditions exist: constraint measures are low and opportunity measures are high. This example puts constraint in the controlling position (i.e., only look for opportunities where you know constraints are low) and shows the degree to which opportunity, as represented in figure 4 by just two indicators, may also be available in these zones. This graphical inspection approach is a simple way to use the longitudinal pattern data previously described to prioritize river reaches for restoration.

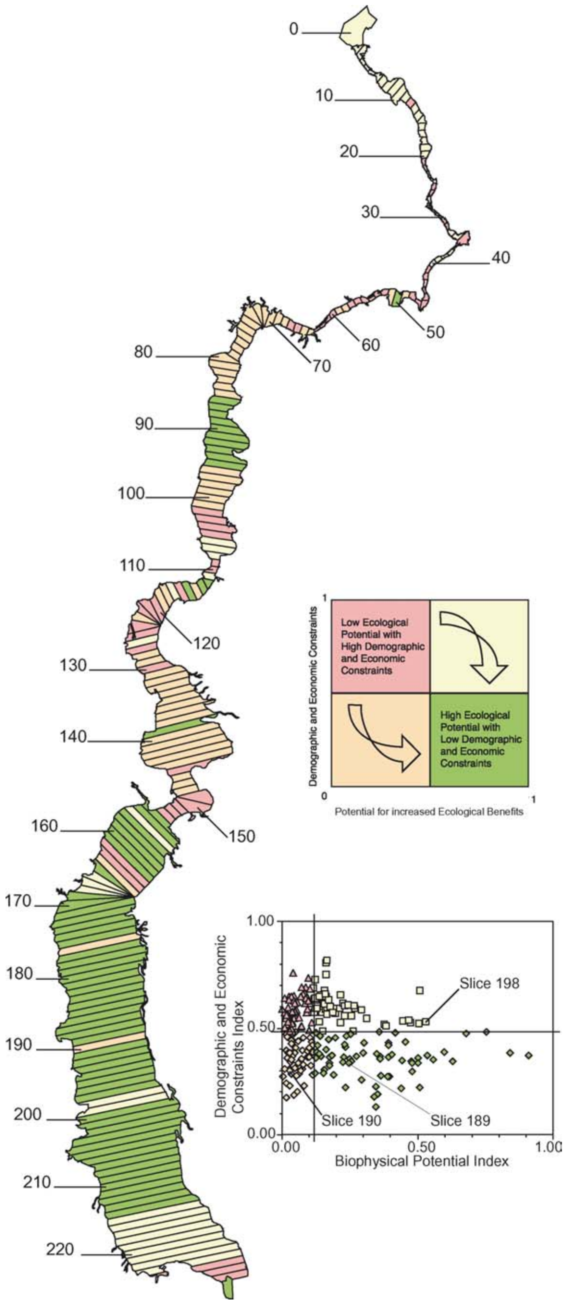

Figure 5. Illustration of possible restoration priorities using the purposes of (1) increase channel complexity, (2) increase area of floodplain forest, (3) increase non-structural flood storage. Other purpose may alter priority locations.

A more quantitatively and functionally detailed example of how data on longitudinal patterns can be used to identify areas with relatively high restoration potential is illustrated in figure 5. Potential users of this more complex approach include resource managers, professional planners and staff advising elected officials charged with natural resource conservation and development decision-making. In the example, restoration objectives are to increase channel complexity, floodplain forest area, and non-structural flood storage. The potential ecological benefits of restoration are represented by three biophysical factors and the social constraints are represented by five different demographic and economic factors:

Human factors and hypothetical relative weightings (constraints)

1. 1990 pop. density/slice	0.11
2. 1990 bldg. density/slice	0.11
3. 1990 road density/slice	0.22
4. 1990 area of private land/slice	0.22
5. 1990 percent of slice worth more than [1]$6200/hectare.	0.34

Biophysical factors and hypothetical relative weightings (opportunities)

1. change in length of forest/slice 1850–1990	0.4
2. change in length of channel/slice 1850–1995	0.4
3. percent of channel length in revetment 1995	0.2

These factors, and their weightings are then used to quantitatively rank each slice using two independent indices describing (a) social constraints and (b) biophysical opportunities. The former consists of five factors: population, structure, road, private land ownership, and higher price taxlot areal densities within each slice. Biophysical opportunities are then described by three factors: change in length of riverbank woody vegetation, change in length of channel complexity, and percent of bank revetted per slice. Empirical studies demonstrated that the richness of fish and riparian plant communities was significantly related to each of these biophysical factors (Baker *et al.* 2002). The weightings were based simply on the greater importance of both channel complexity and floodplain forests, with recognition that removal of revetments could enhance the recovery of both of these features.

Each factor is assigned a number between 0 and 1, using a linear relationship between the minimum value (or, in the case of forest change and channel length change, a threshold) and the maximum value. Then, a weighted sum of these normalized components is computed to form each composite index. A restoration potential value is then defined for each slice using these two indices, and the median value of each index is used to divide the space into quadrants. Each slice falls into a single quadrant (figure 5).

The color-coded map and scatter plot of slices in figure 5 shows the priority locations that emerge from these restoration purposes and their corresponding factors and weightings.

Note the contiguous green slices, especially where such slices are adjacent to pale orange slices (e.g., slices 188, 189 and 190). These are locations where high potential for increased ecological benefit (green) occurs next to places that are already functioning relatively well ecologically and have less likelihood of future pressure for development (pale orange). The concept of connectivity is especially important in riparian systems, and thus a lower ranked slice takes on higher priority when it is in close proximity to higher ranked slices.

Development of weighting values for human factors and biophysical factors could be based on (1) empirical data or simulation models, (2) professional judgment, (3) concepts from scientific and social literature, (4) political and landscape planning policies, or (5) local values of citizens. The weightings could be adjusted to reflect priorities of local communities and stakeholder groups. Differences between outcomes with different weighting systems could serve as a basis for discussion of alternatives for future landscape conditions and local decisions.

Results

Analyses such as these provide a coarse-grained prioritization of candidate river reaches at the whole-river network extent. Such analyses are only the first step in a multiscale process for prioritizing reaches and focal areas for restoration. The choice of project focal areas requires more detailed study of local conditions. This includes the willingness of local landowners to consider restoration actions, the proximity of population centers, the percentage of public land ownership, the presence of transportation infrastructure, the degree to which remnant channel features are present, the type and extent of revetments, historic channel dynamics, flood storage capacity, and finer-grained analysis of historical floodplain vegetation.

Here we illustrate how this can be approached using a hierarchy of selection factors at differing spatial scales as diagrammed in figure 2. In the example shown, the chosen restoration purposes are (1) increase channel complexity, (2) increase area of native floodplain forest, and (3) increase non-structural storage of floodwater. With slice priorities mapped at the full river network extent in figure 5, a reach is chosen that meets the criteria listed under "Reach Extent Selection Criteria" in figure 2 and which had a large number of contiguous green slices in figure 5. The chosen reach is shown in figure 6. Note the slice numbers in black at the western edge of the historical floodplain, and that slice 190 is pale orange, indicating low constraint and comparatively low increases in ecological potential given measurements of revetments, channel complexity and vegetation in this slice. Slice 189, Harkens Lake, which is immediately downstream of slice 190, has more than twice as much revetment, and has experienced significant historical declines in channel complexity and woody vegetation along the bank. Thus it is a high priority focal area within this reach for restoration. As figure 6 shows, Harkens Lake is not the only potential focal area, but is used here to illustrate how the approach may lead to restoration on the ground. Harkens Lake was chosen for this illustration based on rankings among criteria listed in figure 2 under "Focal Area Selection Criteria" and "Focal Area Ranking Criteria" that support the purposes listed above. Coincidence between areas of high flood storage potential, ratio of predicted increase in channel complexity and forest area to cost of restoration actions, and strategic public land

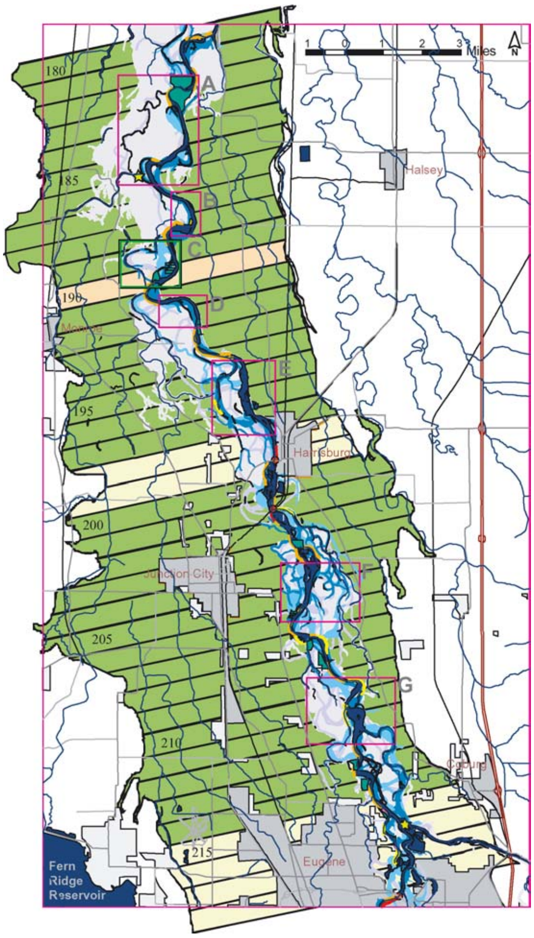

Figure 6. Candidate focal areas in the Willamette River reach downstream of Eugene, Oregon. Slice colors correspond to those used in figure 5. In the map above, blues in the mainstem river corridor represent river channel locations at different times, orange and yellow are revetments, red dots are bridges, and yellow stars are major confluences.

ownership is emphasized. This too employs a constraints and opportunities approach, but through flood storage, adds protection of downstream life and property as an objective of fluvial process restoration.

Discussion

A growing body of reports on the state of the environment in the United States and other nations paint a compelling picture of the need to better track environmental change (Risser *et al.*, 2000, Heinz Center, 2002). One reason to do so is to better understand the biophysical resilience of human-dominated ecosystems. A recent report on the state of Oregon's environment called explicitly for regular, recurring use of land use and land cover (LULC) data to track landscape change. Information sets having adequate spatial and classificatory detail and length of record in time to complete such a task are few and, in most locations, literally far between. The expense and complexity of gathering and updating on-the-ground information for large areas with so many important environmental processes has simply been too great. Yet we now find ourselves at a point where the absence of such information constrains our ability to answer important questions, questions such as "is this critical ecological process functioning within historic ranges of variability?"... or ... "is this key resource improving or getting worse over time?". Without answers to such questions, ecological values will most often lose out to those values for which markets, laws, local controls and culture provide measures in comparable currencies through systems of interaction and accountability.

The advent of satellite and other sources of information about the earth's surface has significantly improved the ability to track environmental change over time. LULC data form the foundation of the restoration prioritization approach outlined previously, and such approaches rely principally, although not solely, on remotely sensed land cover data. Remotely sensed digital land use and land cover data have been available since 1972. Once properly processed and ground checked, they can be used to map the landscape in a cost effective manner with known degrees of certainty (Cohen *et al.*, 1995, 1998, 2001; Lattin and Peneston, 1999; Mooij and DeAngelis, 1999; National Research Council, 2000). These remotely sensed images of landscape patterns can also be correlated with ground-level changes to critical ecological processes and updated with finer-grain data as these become available. Scientific studies have established linkages between LULC change and important resources such as fish and wildlife habitat, urban stormwater runoff, soil productivity, forest condition, air quality, and biological diversity (Karieva and Wennergren, 1995; Li *et al.*, 2001; Oetter *et al.*, 2001). However, to adequately represent human-dominated portions of the land, they must be augmented to provide the necessary information about culturally driven landscape change.

Any representational model of land and water conditions is subject to constraints, i.e., it is necessarily an abstraction. An information set that is adequate to characterize both biophysical and social factors must represent both land use and land cover, but it must do so at a level of detail fine enough to capture key features too small or narrow for certain satellite sensors to detect. This is especially true for those characteristics that pertain specifically to the intended human *use* of land, in addition to the *cover* types detectable and classifiable through conventional remote sensing techniques.

Linking the LULC classification and restoration prioritization approach to evolving environmental governance systems

The comprehensive set of laws, programs, policies and institutions at work in a landscape can be conceived as a governance system. There is a continuum of such governance systems currently employed to manage land and water resources, each with varying characteristics, suited to different needs. Previous work has identified five distinct approaches to environmental governance systems and raised questions about the ability of each to respond to the inherent dynamism of human/riverine landscapes (Hulse *et al.*, 2001).

These questions are most sharply focused on issues of how far environmental governance systems should permit human-dominated landscapes to deviate from historical ranges of key resource variability and the extent to which governance systems can anticipate the effects on resources of human actions that are difficult or impossible to reverse (Johnson and Herring, 1999). These questions are central to any pragmatic approach to increasing resilience and they are answered in operational terms through a variety of regulatory (e.g., Endangered Species Act, Clean Water Act) and administrative mandates and through accepted cultural practices (e.g., bank lending rules, zoning codes, interest rates, incentive programs) that bear, especially in privately owned lands, on landowner's choices about how to manage their lands. This study found that certain biophysical resources had declined during the past 150 years in the Willamette River floodplain (figure 4) and that those slices where resources had declined the most were, in many cases, the places best suited to restoring those same resources (Jerrick *et al.*, 2001; Holling and Gunderson, 2002).

Determining the amount, pattern, and distribution of key ecological resources in the past and present are tasks that are information-intensive. LULC data are commonly used to provide this information. While such data are necessary to engage these issues, we found that alone they are insufficient. Our experience convinces us that anticipating the effects of human choices about future land and water use requires regular interaction and clear, unambiguous communication with policy-making and policy-shaping groups from all the regulatory, administrative and cultural groups mentioned above. Further, it requires that these groups have at their disposal anticipatory tools capable of providing scientifically-defensible answers *in terms relevant to each group's purposes* to questions about the trade-offs inherent in future conservation and restoration options (Hulse *et al.*, 2000). A principal challenge to any land use/land cover classification scheme is that it be sufficiently adaptable to the demands of these various purposes.

Conclusions regarding prioritization, visualization and citizen involvement

Because the social and biophysical dynamics of the systems in question are so inherently complex in both space and time, we argue that data visualization tools are a central ingredient in any successful approach to establishing and maintaining lines of communication, especially when the ultimate aim is to bring about constructive change on the ground in how land is used and managed. This is especially true for communications between the creators of restoration prioritization approaches and the policy-makers faced with the task of applying them in making the necessary trade-offs, regardless of whether these policy makers are elected officials, agency directors, planning staff, watershed councils, or simply interested private landowners.

As geospatial data and GIS have become accepted parts of land and water management, the cartographic challenges of representing *processes* as well as *patterns* have become apparent. Any static representation (e.g., maps, aerial perspectives, graphs, and charts) is, by definition, limited in its ability to depict dynamic processes.

One key characteristic of the techniques we have developed and refined in response to these challenges involves the application of videographic animations of quality-assured geospatial data as a means of accurately helping lay citizen and policy-making groups

Pre-EuroAmerican Scenario (PESVEG) ca. 1851

Land Use / Land Cover (LULC) ca. 1990

Plan Trend 2050

Development 2050

Conservation 2050

Figure 7. Videographic simulations of alternative land and water uses in the southern Willamette River Basin. Note differences in extent of floodplain forest and urban area.

understand complex social and biophysical processes (Hulse *et al.*, 2000). These techniques begin with classified GIS data on LULC and employ broadcast video and computer rendering techniques to objectively depict future conditions under a range of citizen-defined alternative future land and water use scenarios. In our visualization work to date, citizen groups have interacted with these in mostly passive ways, being able to view them and comment on them through hand-held electronic voting devices in large audience formats. An excerpt from a recent video is shown in figure 7. The visualizations have also been incorporated into federal agency training materials (McKay, 2001; Heard et al., 2004; U.S. EPA, 2000) and used in regional television productions on natural resource management in the Pacific Northwest (KGW-TV, 1998).

While these approaches are in the early stages of refinement, and are not yet in-grained in the decision-making processes that motivate land and water use, they are promising. Their application requires careful attention to ecological and institutional particularities of place, but as approaches they are adaptable to the ways these particularities vary from one location to another. They have the capacity to deal with plural and conflicting interests, and to connect values of very general and long range importance to immediate and practical actions at local site extents. As such, they enable broader constituencies to participate in evaluating the qualities of state and process together, as they vary over a moderate span of time.

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Note

1. $6200 per hectare is the contemporary market value of unimproved agricultural land. Market values above this amount indicate investments in the land in the form of infrastructure, buildings, water systems, etc.

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