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DEVELOPMENTS IN RIVER AND WATERSHED MANAGEMENT FROM ECOSYSTEM PERSPECTIVES

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The natural forms and processes of river and riparian systems throughout the world have been greatly modified by human actions. The objectives leading to these modifications have been quite varied, including navigation, flood and erosion control, cattle grazing, and agricultural and urban development. Despite these different purposes, the results of river modification have been remarkably similar--straighter, simpler channel geometry; less complex aquatic habitat; elimination or simplification of riparian vegetation.

Interest in managing rivers, watersheds, and forests based on ecological principles has grown world wide in recent years for many different reasons. Generally, our past emphasis on intensive management for single purposes, such as commodity production or flood protection, has led to undesired consequences. In some cases there has been increased recognition of the benefits of natural processes in maintaining ecological processes and productivity. In other cases past management has been found illegal, such as in the case where threatened species are put at risk of extinction. Also, in many countries public interest in a clean, natural environment has grown and there has been some decline in emphasis on strict engineering solutions to environmental problems. Scientists and engineers in many countries and in many institutions are now looking to natural ecosystems for insights for better managing rivers, watersheds, and forests. Attention to the importance of restoration of river and other wetland systems is coming at the highest levels of government (National Research Council 1992).

The objectives of this paper are to outline some of the current thinking in the United States about how watersheds function geomorphically and ecologically and about how understanding of watershed function can be used to restore watersheds where past land use has modified the system. I also briefly summarize some of the different approaches to watershed restoration underway in the United States and describe an approach to planning restoration actions.

I will speak from the point of view of a geologist with 25 years experience working in an interdisciplinary team of forest and stream ecologists studying how forest, mountain watersheds function under natural and managed conditions. I am not an engineer and, therefore, will not try to offer specific engineering solutions to problems.

II. Geomorphology and ecology watersheds.

Research into the structure and function of river networks and watersheds has followed several paths relevant to management--hierarchical classification, linkages among system components, effects of disturbances on ecological systems, and assessment of management effects. A critical consideration is that certain phenomena, such as streamflow and landslide processes, pass through the watershed from hillslopes to small, steep channels to larger, low-gradient main channels.

Geomorphic classification systems for stream systems have been developed in the U.S. for use in stream surveys and in stream restoration (Frissell et al. 1986, Rosgen 1988). The hierarchical aspect of such classification systems, describing channel and valley floor structures at various scales, is important because it aids understanding of watershed function at multiple scales. A key to application of classification systems is to bring general understanding of the origin and operation of river systems into planning the future management of sites. This is important where the management objective is to maintain native species and natural processes and habitats.

Over the past few decades studies of stream and riparian ecosystems have focused on the importance of connections among different parts of watersheds and ecosystems. These connections include 1. connections between upstream and downstream areas; 2. links between hillslopes and channels; 3. forest-stream interactions; 4. exchange between surface and subsurface waters; and 5. interactions of main channel and floodplain areas during floods. Upstream-downstream connections involve movement of waters, sediment, organic material, food resources, and fish and other organisms which use different parts of a stream system for various parts of their life histories (Vannote et al. 1980). Hillslope-channel interactions occur, for example, where various types of landslides or other erosion processes may affect channel structure and sediment supply (Swanson et al. 1985). Forest-stream interactions include shading, fine and coarse organic matter delivery to streams, bank protection by roots, and many other functions of streamside vegetation (Gregory et al. 1991). Consequently management of streamside vegetation can be based on management objectives for the stream itself (Gregory and Ashkenas 1997, Nakamura 1997). Recent studies have identified the zone of interaction between surface stream water and associated shallow groundwater, termed the hyporheic zone, to be important in terms of providing distinctive habitat for aquatic organisms and for nutrient cycling (Bencala 1993). Studies of large river systems have found that interactions of main channel and floodplain areas during floods are extremely important to productivity of river ecosystems (Bayley 1995).

Management actions along streams and rivers commonly cut many of these natural connections within river and riparian systems. Barriers to connections may take structural (e.g, dams, concrete lining of channels), hydraulic, water temperature, water chemistry, or other forms. Where management objectives include maintaining natural ecological conditions, efforts have focused on maintaining these connections. Restoration practices are aimed at removing barriers to restore these connections. Knowledge of the strength and consequence of each type of connection can be used in setting priorities for restoration.

The destructive forces of floods and debris flows are obvious, leading to various measures to try to prevent their occurrence and impact. However, floods and debris flows are natural in many mountain landscapes and these processes can have important positive effects on aquatic habitat, such as providing boulders and large woody debris to main stream channels where such coarse material increases habitat complexity. Also, some aspects of ecological recovery of stream and riparian biota can be rapid (Lamberti et al. 1991), but other aspects, such as recovery of old stream-side forest, may be very slow. Some species have life history traits, such as processes of regeneration, that are adapted to periodic flooding or disturbance by geomorphic processes, so natural disturbance processes may help to keep them in the local ecosystem. Other species are favored by long periods without significant disturbance. Natural stream and riparian systems commonly provide a mixture of these situations--larger forest rooted away from the stream can partially cover near-stream vegetation which is kept in early successional stages by frequent disturbance. This two-level, vertical structure of riparian vegetation can help keep a broad range of forest-stream interaction processes functioning--the bigger trees carry out some functions and the smaller vegetation other functions.

From these perspectives natural disturbance by floods, debris flows, and other processes can be considered socially acceptable in landscapes managed for natural ecosystem processes. A key question then becomes: What is a desirable level of natural ecosystem disturbance processes? As in the case of fire, floods, and other disturbance processes in ecosystems, we can address this question by reference to the historic range of ecosystem conditions and disturbance processes. In government managed parks and national forests in the U.S. many land managers are trying to manage ecosystems within the range of historic disturbance processes and ecosystem conditions (Swanson et al. 1994, 1997). The underlying idea is that native species have adapted to the range of ecosystem conditions (e.g., habitat structures) and disturbance regimes (e.g., frequency, severity, and size distribution of disturbance events) that existed in the area in the past. Dramatic change in those conditions increases the risk of eliminating native species and desirable ecological processes.

Efforts to manage ecosystems within the range of historic variability are just beginning in the U.S. and the idea is being argued in the scientific community. The first step is to document the historic variability, such as streamflow frequency or the frequency and severity of forest fires. The next step is to consider the effects of events of various frequencies and magnitudes. For example, major floods or fires may remove existing vegetation, but set the stage for new vegetation to be established. Smaller floods or less severe fires may have less obvious, but important effects on vegetation development, animal populations, or the potential damage by future events of these types. In the case of fire, for example, we have found that suppression of fire in forests where it had been frequent, but of low intensity, has allowed build up of organic litter which is fuel for the next fire. So we may have converted a forest area from a high frequency/low severity fire regime to low frequency/high severity. This has changed the forest ecosystem greatly and created high fire hazards for people living in such areas.

In the U.S. we frequently hear the call for placing any restoration practices in the context of the full watershed (Kauffman et al. 1997). Because the flow of water and mass movement disturbance processes extends from hillslopes through small channels to large rivers, analysis of erosion control and restoration practices in channels should be placed in the context of potential for various events triggered in upstream and hillslope areas.

In summary, both ecological and geomorphology concepts of watershed structure and function emphasize connections among various parts of the ecological and geophysical systems. Management actions can block these connections; restoration practices can reconnect the system.

III. Examples of watershed restoration projects in the U.S.

A remarkable change in management of river systems is underway in the U.S. and elsewhere (National Research Council 1992). Past emphasis in river management was on engineering works to reduce the variation in height and extent of flooding and debris flows with the objectives of power generation, navigation, flood protection, water diversion, and others. This was successful up to a point, but, when the capacity of engineered structures was exceeded, the resulting flood problems were made worse. Also, undesired ecological and other consequences gradually developed. This has led to a great variety of restoration measures which are generally designed on ecological principles and historic patterns of ecosystem conditions. The overall intent of these projects is to find a better balance between the ecological and economic functions of river systems.

The technical path to a better balance varies greatly, depending on the local objectives, social factors, and ecosystem conditions. Approaches to river restoration include changes in streamflow and water temperature regimes, channel pattern, fish passage through dams and reservoirs, woody debris conditions in channels, and many others.

The following cases provide some examples with some common themes: 1. human activities had simplified the system, 2. undesired effects of earlier engineering practices led to major investments in restoration, 3. engineers, ecologists, and others worked together to develop the restoration plan, 4. the restoration measures involved returning the system to more natural and more variable conditions, 5. continued involvement of an interdisciplinary team to monitor the effects of restoration practices gives important information on how to change the practices to better meet management objectives.

A. Colorado River. The flow of water through the Grand Canyon in the southwestern U.S. has been regulated since Glen Canyon Dam went into operation in 1963 for purposes of power generation and other water uses. Reduction of peak flows allowed undesired change in aquatic and riparian conditions through the Grand Canyon

National Park and neighboring areas. These changes included invasion by a non-native tree species that may reduce local water availability through high transpiration rates, degraded habitat quality for some rare native fish species, and loss of sand bars used by people traveling through the Grand Canyon on boats for recreation. Periodic flooding is thought to be essential to maintaining the natural conditions and native species. Also, it is believed that flooding was important to move sand from the stream bottom up onto exposed bars along the riverbank where they could be used for recreation.

Therefore, an experimental, "artificial" flood was created by water release from an upstream dam. The pre-dam average annual peak flow was 93,400 cubic feet per second (cfs) and annual flood periods lasted for many weeks. The experimental flood was only 45,000 cfs and much shorter duration than natural flood periods. Geomorphic and ecological responses are being examined. The experimental "flood" was expensive in terms of loss of potential to generate hydroelectric power and the research effort itself, both pre- and post-flood sampling, has also been expensive. Initial ecological and geomorphological results are encouraging, including increases in extent of sand bars.

However, interactions between engineering and river systems are very complex, so many challenging issues remain. For example, Glen Canyon Dam is designed and operated in a way that produces much less variation in river water temperature in downstream areas than under natural conditions. Water temperature affects interactions among native and introduced fish species. Biologists are now arguing about how best to manage the water temperature regime of the river to benefit native fish species.

So management of the flood regime and river and riparian systems of the Colorado River is still an experiment. Additional experimental floods are planned and an interdisciplinary science team is following effects. See the website http://wwwdaztcn.wr.usgs.gov/flood.html for further information.

B. Columbia River. Over the past century a system of 18 major dams has been constructed on the Columbia River system that drains much of the northwestern U.S. These dams are used to produce power, provide for irrigation of productive dry-land agricultural areas, and permit navigation along the river system. Over this same period the major salmon runs on the river, once of high economic value, have declined greatly. Over $3,000,000,000 have been spent in efforts to improve salmon populations in the Columbia River system. the funded measures include expensive fish hatcheries, structural changes to dams to improve fish passage, and changes in reservoir management to improve salmon migration. But these expensive efforts are now judged to have been a failure because salmon populations have not recovered.

The next round of proposed actions includes reducing operations of selected fish hatcheries because hatchery fish may change genetic diversity of fish populations and lower survival, lower reservoir levels to provide more fast-flowing river, and even removing some of the large dams. As in the case of the Colorado River system, restoration of the Columbia River is a massive experiment conducted at great cost and the measures of past failures, the loss of once-great salmon runs, are front-page news in all the newspapers.

C. Management of mountain streams of the Pacific Northwest. Major issues of stream restoration in the Pacific Northwest of the U.S. concern effects of cattle grazing and removal of woody debris from streams. Cattle grazing, channel straightening, and other activities can severely damage stream banks and riparian vegetation. Kauffman et al. (1997) review how technological perspectives on how to fix degraded ecological conditions and declining salmon populations have changed through time from fish hatcheries to fish ladders and more recently to in-stream structures. They go on to argue that "the first and most critical step in ecological restoration is passive restoration, the cessation of (human) activities that are causing degradation or preventing recovery." They suggest that after passive restoration the system be given enough time (perhaps 10 years) to undergo natural recovery before using active restoration practices, such as channel and streambank reconfiguration, vegetation planting, or in-stream structures.

For many years large woody debris was removed from small streams and rivers in the Pacific Northwest to improve navigation and log movement along rivers, promote fish migration, collect valuable wood, and to meet other objectives. Research over the past 20 years has documented the historic abundance and ecological significance of large woody debris in forested streams and rivers (Harmon et al. 1986). This history, coupled with declines in salmon populations, have led to extensive programs to put large woody debris back into streams. Very few studies are monitoring effects of these practices an Kauffman et al. (1997) contend that this restoration program has had little success. One study in the Oregon Cascade Range by Dr. Stan Gregory and colleagues reveals modest increases in fish populations in areas with woody debris structures relative to areas without them. Also fish populations appeared to have higher survival through a major flood in areas of greater channel complexity provided by woody debris.

IV. Planning watershed and ecosystem restoration practices

River, watershed, and ecosystem restoration projects involve as many or more social and economic factors as biological and engineering considerations. A recently funded project in western Oregon provides an example of a technical (rather than political) approach to planning and making decisions about watershed management and restoration. An interdisciplinary approach involving ecologists and economists is attempting to identify sites where there may be greatest payoff from restoration measures in ecological terms. The leaders of this project hypothesize that channel junction areas and wide valley floors with secondary channels provide a variety of especially valuable habitat conditions. Economic values are also examined. Areas of highest economic value, such as existing developments for business, industry, and residential uses, would be most difficult and expensive to restore to increase ecological benefits.

This information is then used to identify places to emphasize in restoration efforts. The objective is to fit the restoration practices with the natural functioning of the ecosystem and to get the maximum ecological benefit for the effort and money invested. The easiest decisions to proceed with restoration efforts occur where ecological values are high and the land values for other uses are low. Restoration work is low priority where other values are extremely high and the benefits of restoration work appear to be low. The difficult decisions are where both ecological and other values are high.

V. Finding the best way

Close, long-term working relationships among engineers, scientists, managers, and the public are a critical aspect of finding a desirable balance between ecological function, economic, and other social benefits. This is important in terms of achieving common understanding between groups with very different cultures, interests, and languages, such as engineers, scientists, and general citizens. In some cases these groups work together in a long-term process, called "adaptive management" by some (Holling 1978, Walters 1986, Lee 1993), which involves using management actions, such as widespread erosion control works, as experiments. Effects of the practices are predicted, monitoring evaluates the actual effects, findings from monitoring and new studies are evaluated, and changes in future practices are modified, based on the lessons from the monitoring and other sources of information. Some key concepts in adaptive management are that 1. many effects of land and watershed management actions develop over long periods of time, so we need to learn as we go and not base future decisions on only the immediate response to a practice; 2. we learn through time, so we need mechanisms to adjust future practices, based on what we have learned; 3. the social context of management activities changes through time and this needs to be taken into account in future management.

I have had the good fortune to work in a interdisciplinary scientist-land manager group for over 20 years. This group of ecologists, hydrologists, geologists, and land managers has developed many ideas to change management of forests and rivers that have found wide application. The U.S. government has recognized the value of such interdisciplinary groups by establishing, for example, the Long-Term Ecological Research (LTER) program of the National Science Foundation throughout the country and Adaptive Management Areas in the Pacific Northwest where such research-management groups pioneer new ways to manage forests and watersheds. Other countries have done the same. Discussions are now underway concerning establishing programs like LTER in Japan.

VI. Conclusions

Many of the management principles and guidelines relevant to river restoration are outlined in Nakamura (1997) and Gregory and Ashkenas (1997 Japanese citation). Based on the U.S. situation, I summarize and amplify on the points as:

1. Use ecological principles concerning a. providing habitat for species of special

concern; b. maintaining the ecological and geophysical interactions among the upstream-downstream, forest-stream, surface-subsurface waters, river-floodplain components of the river-riparian ecosystem; c. returning the system to more natural conditions of variability.

2. Restoration designs should be based on site-specific objectives which consider ecological, social, economic, and other factors.

3. Engineers, ecologists, and others should work together to define restoration objectives and the practices to meet them.

4. Continued involvement of an interdisciplinary technical team to monitor the effects of restoration practices gives important information on how to change restoration practices to better meet management objectives.

Understanding of the physical and biological functions of small and large river systems, forests, and watersheds has increased greatly over the past few decades. Around the world we see many examples, some costing great amounts of money, to modify watershed and river management schemes to allow them to function with more natural ecological processes. This apparently global shift is especially remarkable considering the very different social, ecological, and geophysical contexts among countries. The evolution of these practices in many cases is guided by interdisciplinary teams of engineers, scientists, public, and others in an adaptive management framework. In developed parts of the world changes in management of watersheds and natural resource systems seem to be driven more by social change than new technological advances.

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