GEOMORPHOLOGICAL PRINCIPLES FOR 'NATURALIZING' STREAMS AND RIVERS IN ILLINOIS

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INTRODUCTION

Over the last 200 years, land cover throughout the Illinois River watershed has been transformed from prairie with scattered forest to agricultural fields with scattered towns and cities. In the fifty counties contained wholly or partly within the Illinois River watershed, an estimated 5.9 million hectares of native prairie essentially have been eradicated; today, less than 1000 hectares of prairie remain in this portion of the state (IDENR, 1994). The presettlement appearance of the landscape, described vividly by pioneers and settlers as an ocean of grass (Winsor, 1987), today can only be imagined.

Human alteration of land cover undoubtedly has impacted, both directly and indirectly, the form and dynamics of stream channels in the Illinois River basin. Direct impacts have been greatest in headwater areas; in some subbasins of the Illinois River watershed as much as 100% of the total length of headwater streams is channelized (Mattingly et al. 1993). Indirect effects are most severe downstream, accounting in large part for high rates of sedimentation in the Illinois River and the backwater lakes and riparian wetlands on its floodplain. Concern about indirect and direct effects of human activity on stream channels is embodied in recommendations 9 and 10 of the Integrated Management Plan for the Illinois River Watershed (IMPIRW). Recommendation 9 encourages incentives for selective dechannelization of tributaries on a voluntary basis, whereas recommendation 10 calls for stabilization of unstable streams in rural and urban areas. Together, these recommendations are directed toward efforts to improve the environmental quality of streams and rivers in the watershed.

This paper defines an important role for fluvial geomorphology in the process of integrated environmental management of the Illinois River watershed. It illustrates how geomorphological analysis and information can contribute substantively to various stages of the management process. The paper also describes the concept of naturalization, which is recommended as a viable strategy for achieving environmentally based, sustainable stream management in the Illinois River basin. Naturalization is broadly consistent with the vision statement contained in the IMPIRW, but extends this vision by emphasizing the importance of fluvial geomorphology in stream management and by explicitly acknowledging that human social and economic activities are components of the contemporary natural environment.

THE CONCEPT OF NATURALIZATION

All efforts to manage environmental resources are, by necessity, guided by objectives, even in cases where these objectives are not defined explicitly. At a national level, the National

Research Council (NRC) (1992) has identified three environmental-management objectives for aquatic ecosystems: restoration - the complete structural and functional return of an ecosystem to a pristine, predisturbance state; rehabilitation - partial structural and functional return of a system to a predisturbance state, and enhancement - any structural or functional improvement. All three of these objectives retain the pristine, predisturbance state as the frame of reference for assessing environmental-quality benefits. The definition of enhancement, i.e. any improvement, is tautological and does not identify an objective that is useful in any practical sense; however, the NRC position clearly implies that improvement involves the re-establishment of pristine elements in an otherwise disturbed system. Effective restoration, rehabilitation, or enhancement requires a sound body of scientific information on the structural and functional characteristics of the pristine, predisturbance system. Without such information, attempts to reproduce or approximate the pristine state may be fundamentally misconceived or misguided.

Although some historical scientific information is available on the hydrology and ecology of the Illinois River prior to dam construction and major changes in land use (IDENR, 1994), the pristine, geomorphological character of the river is difficult to ascertain, at least in detail. For headwater areas, scientific data are even more limited. The fishes of Champaign County studies began in the late 1800s (IDENR, 1994), during the period of major channelization, but corresponding historical information on the chemical, hydrological, and geomorphological characteristics of headwater streams is meager at best. Undoubtedly, transformation of headwater streams has been as dramatic as transformation of the botanic landscape; however, in most cases, the exact nature of change in fluvial environments is unknown.

The lack of scientific information on the pristine state of many streams in the Illinois River basin calls into question the appropriateness of stream restoration, rehabilitation, or enhancement as defined by the NRC. Even if fragments of information were available, attempts to direct stream systems toward the pristine state would be challenged by two factors: 1) environmental conditions throughout the watershed, especially land cover, are now dramatically different than those that existed under predisturbance conditions and 2) environmental restoration of land cover characteristics at the watershed scale is economically impractical. These limiting factors imply that the pristine geomorphological character of stream systems, even if it could be accurately determined, probably has little relevance for the development of sustainable management strategies in the contemporary environmental setting.

Naturalization is an alternative to restoration that specifies an environmental-management goal appropriate for watersheds characterized by intensive, ongoing human utilization of biophysical resources (Rhoads and Herricks, 1996). In particular, naturalization promotes the establishment of sustainable, morphologically and hydraulically varied, yet dynamically stable fluvial systems that are capable of supporting healthy, genetically diverse aquatic ecosystems. The term sustainability, as used in this context, refers to *system insurance sustainability* (Gale and Cordray, 1994), in which management is directed toward human economic and social concerns as well as toward preservation of existing biophysical diversity or enhancement of this diversity. It embraces the notion that recurring human interaction with biophysical components of fluvial systems is part of the contemporary and future natural environment in resource-rich settings, but seeks ways to take advantage of this interaction to sustain or enhance morphological diversity and dynamic stability. Thus, system states other than the pristine one are valued and system dynamics may be actively "managed" through recurring human intervention. Where human manipulation of the environment has occurred in the past, but is not expected to recur in the future, naturalization may rely on duplication of the present condition of a comparable undisturbed or recovered part of a fluvial system. Although naturalization does not actively seek to direct fluvial systems toward the pristine, predisturbance state, it sanctions re-establishment of documented pristine characteristics within the contemporary setting if it can be determined that such characteristics are sustainable and will contribute to the general goals of morphological diversity and dynamic stability.

FLUVIAL GEOMORPHOLOGY AND STREAM MANAGEMENT

Environmental management generally involves four distinct phases: planning, design, implementation, and monitoring/appraisal. The discussion below focuses on how fluvial geomorphology can contribute to the four phases of stream management for the Illinois River watershed. The emphasis is on the types of geomorphological information needed to develop naturalized management strategies at the watershed and reach scales.

Planning Phase

Effective management of fluvial systems must be based on information concerning the geomorphological dynamics of these systems, including the role of human activity in these dynamics. Failure to base environmental-management strategies on such information will result largely in uninformed, trial-and-error approaches that may prove costly and that most likely will accomplish little in relation to management objectives. Geomorphological information ensures that management strategies are consistent with the fluvial dynamics of specific streams and rivers.

Perhaps the most important aspect of examining the dynamics of stream systems is to evaluate the degree to which they are stable or unstable. As noted in the Technical Report for the Integrated Management Plan for the Illinois River Watershed, the distinction between "stable" and "unstable" streams varies among disciplines. From an engineering perspective, an unstable stream channel has a rate or magnitude of erosion great enough to generate public concern (Brice, 1982). From a geomorphological perspective, an unstable stream is one that exhibits abrupt, episodic, or progressive changes in location, geometry, gradient, or pattern *because of environmental or human-induced changes in water or sediment inputs from the surrounding watershed and/or spatial imbalances between sediment inputs and outputs* (Rhoads, 1995). The geomorphological view recognizes that streams are dynamic systems that change through time, *even when environmental conditions are constant.* Only when change in a stream channel is systematic and can be tied definitively to human-induced disturbances or to sustained environmental change should this channel change be viewed as instability. Progressive enlargement or infilling of a stream or river through time, such as the sedimentation occurring in the Illinois River, is a hallmark of instability. On the other hand, lateral or down-valley migration of channel bends is part of the natural dynamics of meandering rivers and should not automatically be viewed as a sign of instability. All meandering streams erode their banks to some extent. The key is to identify rates of erosion that are increasing systematically through time, especially in conjunction with progressive human-induced changes in watershed conditions. Also, a rate of migration for a meandering reach that is far in excess of rates for other meandering reaches in a watershed may, but will not always, reflect disturbance-induced instability.

At the watershed scale, the primary focus of stability assessment involves historical analysis of changes in stream-channel characteristics. This type of analysis is useful for identifying systematic patterns of channel change and for relating this change to land-use changes or to human manipulation of stream channels (Kondolf and Larson, 1995). A variety of information sources can be used to try to establish the geomorphological character of streams in Illinois prior to widespread development of agriculture, including pioneer and settler accounts; newspapers and journals; U.S. General Land Office Survey Records; nineteenth century railroad surveys; early U.S. Geological Survey topographic maps and stream-gaging records; U.S. Army Corps of Engineer navigation surveys and flood damage reports; U.S. Department of Agriculture soil surveys; and documents/photographs in county historical societies, county courthouses, and state museums or libraries (Trimble and Cooke, 1991; Rhoads and Herricks, 1996).

Perhaps the most valuable information on stream-channel changes over the past 60 years is historical aerial photography. The University of Illinois Map and Geography Library has photographic coverage ranging from the late 1930s to 1993-1994 for most portions of Illinois. Analysis of historical aerial photography involves digitizing stream-channel positions for each year of photographic coverage into a Geographic Information System (GIS) database. The data handling, analysis, and display capabilities of the GIS can be used to: 1) register each data set to a common scale and projection using control points identified on planimetric base maps, 2) assess image to map rectification error as well as digitization error, 3) determine systematic trends in channel change through time and space, 4) evaluate the extent to which detected changes are the result of human manipulation of the stream or of natural processes, and 5) relate changes in channel position to potential controlling factors, such as variations in stream power, material properties, land use, and stream management (Rhoads and Urban, 1997). Another advantage of GIS-based analysis is that it provides a framework for integrating data on streams and rivers with a wide variety of other types of environmental information, especially ecological data (Montgomery et al., 1995).

A complement to historical analysis of stream-channel change is field-reconnaissance assessments of current stream-channel conditions (e.g. Simon and Downs, 1995). Such assessments should be conducted by a trained fluvial geomorphologist who is familiar with the dynamics of the fluvial system of interest. The goal is to characterize and classify various channel types in the watershed. An effective classification scheme will be based not only on current characteristics of the channels, but also on historical information concerning channel dynamics (Kondolf, 1995). Although a variety of generic classification schemes for rivers have been developed (e.g. Rosgen, 1994; Downs, 1995), such schemes are most useful when they are tailored to the watershed of interest (Kondolf and Downs, 1996). No geomorphological classification system currently exists for the Illinois River watershed, but a scheme developed for streams in east-central Illinois provides a starting point for classification of streams in the Illinois River system (see Rhoads and Herricks, 1996).

Once an appropriate scheme is developed, classification can proceed based on stereoscopic analysis of recent aerial photography and on additional field evaluations of reaches that are difficult to classify accurately using aerial photography. Information on classified reaches can be entered into the GIS to produce a map showing the spatial extent of various channel types throughout the watershed. From an ecological perspective, this information is useful for determining the spatial heterogeneity, interconnectedness, and temporal stability of physical habitat conditions within the stream system. Because the classification scheme includes information on channel history and dynamics, maps of reach types are valuable for identifying portions of drainage net requiring channel stabilization or naturalization and for evaluating whether specific naturalization strategies will be sustainable at particular stream locations.

After potential sites have been identified for implementation of stabilization or naturalization strategies, detailed geomorphological investigations should be conducted to generate site-specific information on the fluvial dynamics of target reaches. Data collection activities performed in these investigations should include surveys of channel morphology, sampling and analysis of bed and bank materials, monitoring of water-level fluctuations, and measurements of flow structure, sediment transport, and bed and bank erosion at several different flow stages. Detailed field studies provide an in-depth understanding of the processes that maintain or actively change the geomorphological character of a particular reach of stream (e.g. Rhoads, 1996) and also yield information that can be used to calibrate analytical or numerical models of river dynamics developed by engineers. At sites deemed unstable, detailed field studies can help pinpoint the exact cause of instability, thereby improving the effectiveness of mitigation strategies. At sites being considered for naturalization, reaches nearby that are considered representative of desired conditions can be investigated to generate pertinent information on process-based interactions between morphological structure and hydrodynamic properties. This information can serve as the basis for developing sustainable naturalization designs for the target reach and for assessing the success of the design following implementation.

Design Phase

Recommendation (9) in the Integrated Management Plan for the Illinois River watershed endorses selective dechannelization of tributaries on a voluntary basis. The desire for dechannelization of streams is a recent development in stream management. To those unfamiliar with the complexity of natural rivers, this new task may seem easy to accomplish. A logical approach is to simply let streams recover naturally from channelization. This approach suffers from two limitations. First, many streams in Illinois are low-energy systems that take decades or even centuries to re-establish a suite of forms and processes characteristic of undisturbed streams (Rhoads and Urban, 1997). Thus, realization of geomorphological goals, and attendant ecological benefits, may be greatly delayed. Second, naturalization emphasizes that natural recovery is not possible in all circumstances due to socioeconomic constraints, but that controlled reconfiguration of the system nonetheless may be desirable. These two limitations provide justification for the development of new stream-management technology consisting of codified design criteria for dechannelizing human-modified streams. At first glance, the development of this new technology may be seen as a variant of river engineering. However, reproduction of the complex dynamics of natural rivers, including the geomorphological and ecological functions of these systems, lies outside the domain of standard engineering practice, which traditionally has focused on how to change rivers into controllable, artificial forms that have predictable hydraulic characteristics.

The desire for dechannelization has created an opportunity for fluvial geomorphologists to contribute to the development of design technology to support this type of stream management. At present, most attempts at dechannelization or naturalization are guided partly by general principles, but also include substantial expert-judgement or trial-and-error components. Existing restoration principles consist of a poorly integrated mix of traditional engineering analysis and empirical geomorphological relations (see Brookes and Sear, 1996 for a state-of-the-art review). Engineering formulae are precise, but emphasize static stability of the channel boundary, whereas rivers are dynamic systems with erodible beds and banks. On the other hand, geomorphological relations implicitly incorporate dynamic adjustment, but lack precision and often are specific to the set of data from which they were derived. Engineers, ecologists, and geomorphologists must work together to develop new technology for naturalizing streams and rivers in specific environmental settings. The IMPIRW provides an opportunity for cooperative interaction among various technical experts to produce a set of naturalization guidelines for streams in the Illinois River basin.

It is beyond the scope of this paper to present specific suggestions concerning design criteria for naturalization of streams in Illinois; however, some general suggestions are offered. First, the development of design criteria should be based on a sound body of scientific information developed specifically for the Illinois River system. Existing information on the geomorphology of this system is insufficient to support holistic strategies aimed at naturalizing and stabilizing streams throughout the entire Illinois River basin. Second, the establishment of riparian corridors is a vital component of any effort to naturalize streams. From a hydrological perspective, riparian corridors act as storage areas for floodwaters, thereby decreasing the rate of delivery of water to downstream areas in the watershed. They also help to filter sediment and nutrients from field runoff before it reaches the stream channels. Geomorphologically, these corridors provide space for natural recovery or for post-project adjustment of naturalized streams. A riparian corridor eliminates the need for straight channels and allows alternative channel configurations to be developed that are morphologically varied and dynamically stable. Where riparian corridors are present there is less need for artificial levees. Thus, floodplain-main channel interaction can be restored B a process that is important ecologically both for riparian vegetation and aquatic organisms (IDENR, 1994). Third, stream geomorphology is the physical framework within which aquatic ecosystems develop. In particular, geomorphological conditions determine in large part the heterogeneity and volume of physical habitat (Schlosser, 1987). Recent evaluations of fish populations in Illinois suggest that a deficiency of physical habitat is the most critical limiting factor for stream ecosystems, especially in headwater environments (Terhaar and Herricks, 1989; IDENR, 1994). Many attempts to create or enhance physical habitat involve the use of habitat-enhancement techniques that do not adequately duplicate either the three-dimensional structure of reach-scale geomorphological features (e.g. riffles, pools) or the role of these features in the fluvial dynamics of the stream system (Brookes et al., 1996). Future efforts to naturalize streams in Illinois will require better integration of fluvial geomorphology and stream ecology.

Implementation Phase

Once a general watershed-scale plan for naturalization has been developed, and designs have been formulated for specific stream locations, implementation of naturalization projects can begin. As noted in recommendation 9 of the IMPIRW, demonstration projects first should be initiated on public land to refine naturalization technology and to illustrate to private stakeholders the benefits of adopting this new technology. Fluvial geomorphologists can play an important role in this phase by conducting on-site visits to ensure that the project is constructed as designed. On-site inspection is critically important because implementation of naturalized designs will involve unconventional construction practices that contractors may perceive as unnecessary.

Appraisal Phase

Post-project evaluation of implemented naturalization strategies is a vital, but often neglected part of the stream-management process. Without effective post-project assessments, the degree to which specific designs achieve management objectives is difficult to ascertain. Appraisal also provides the basis for adaptive refinement of management prescriptions. Geomorphological methods can contribute to post-project assessments at a variety of temporal and spatial scales (Kondolf and Micheli, 1995). Field-based measurement programs initiated at target sites during the planning phase should be continued following project implementation so that comparisons can be made between pre-project and post-project data. Such comparisons provide an objective basis for assessing the immediate success of the project. It is especially important to survey the channel morphology, sample the substrate material, and measure flow conditions in the project reach immediately after construction has been completed. Repeated surveys, sampling, and measurements should be conducted at regular intervals for several years following construction and immediately after all large floods. Of course, geomorphological field monitoring should be coordinated with field-based biological monitoring to determine the relation between physical and ecological conditions.

GIS analysis of aerial photographs is valuable for evaluating long-term sustainability. Currently, the Illinois Department of Transportation conducts complete aerial surveys of the state every 5 to 6 years. If possible, this photography should be supplemented by large-scale aerial photographs that allow details of channel form to be measured photogrammetrically. Over time spans of decades GIS and photogrammetric analyses of project sites can be supplemented by occasional field investigations. Repeat ground-based photography and video recordings also can provide a valuable visual record of changes at each site over a period of years or decades. Together these sources of information can be used to evaluate the need for periodic site maintenance.

CONCLUSION

Fluvial geomorphology, the sub-field of earth science that focuses on the dynamics of rivers, has an important role to play in environmental management of the Illinois River watershed. The geomorphological structure and dynamics of streams constitute the physical framework within which aquatic ecosystems develop and are sustained. The dependency of aquatic ecosystems on geomorphological conditions necessitates that any management strategy that seeks to alter the structure and function of existing aquatic ecosystems must be based on a sound understanding of fluvial forms and processes, both at the watershed scale and at the reach scale.

This paper has demonstrated how various types of geomorphological analyses can contribute to a comprehensive understanding of the fluvial dynamics of the Illinois River system. It has also argued that naturalization, not restoration or its variants, is the most appropriate management goal for this system. Naturalization seeks to establish morphologically and hydraulically varied, but dynamically stable fluvial systems capable of supporting healthy, genetically diverse aquatic ecosystems. Because human resource utilization must be seen as a component of the contemporary and future natural landscape in the Illinois River watershed, the predisturbance, pristine geomorphological state, which is largely unknown in any case, is not an appropriate standard against which to assess environmental benefits.

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REFERENCES

Brice, J.C. 1982. Stream channel stability assessment. U.S. Department of Transportation, FHWA/RD-821021.

Brookes, A. and D.A. Sear. 1996. Geomorphological principles for restoring channels. In River Channel Restoration, ed. A. Brookes and D.F. Shields, Jr., pp. 75-101. Chichester, UK, Wiley.

Brookes, A., S. S. Knight, and F.D. Shields, Jr. 1996. Habitat enhancement. In River Channel Restoration, ed. A. Brookes and D. F. Shields, Jr., pp.103-126. Chichester, UK, Wiley.

Downs, P.W. 1995. River channel classification for channel management purposes. In Changing River Channels, ed. A. Gurnell and G.E. Petts, pp. 347-365. Chichester, UK, Wiley.

Gale, R.P. and S.M. Cordray. 1994. Making sense of sustainability: nine answers to "what should be sustained?" Rural Sociology 59: 311-332.

IDENR. 1994. The Changing Illinois Environment: Critical Trends. Technical Report of the Critical Trends Assessment Project Volume 3: Ecological Resources. Illinois Department of Energy and Natural Resources, Springfield, IL, USA, 167 pp.

Kondolf, G.M. 1995. Geomorphological stream classification in aquatic habitat restoration: uses and limitations. Aquatic Conservation: Marine and Freshwater Ecosystems 5: 127-141.

Kondolf, G.M. and M. Larson. 1995. Historical channel analysis: techniques for application to riparian and aquatic habitat restoration. Aquatic Conservation: Marine and Freshwater Ecosystems 5: 109-126.

Kondolf, G.M. and E.R. Micheli. 1995. Evaluating stream restoration projects. Environmental Management 19: 1-15.

Kondolf, G.M. and P.W. Downs. 1996. Catchment approach to planning channel restoration. In River Channel Restoration, ed. A. Brookes and D. F. Shields, Jr., pp.129-148. Chichester, UK, Wiley.

Mattingly, R.L., E.E. Herricks, and D.M. Johnston. 1993. Channelization and levee construction in Illinois: review and implications for management. Environmental Management 17: 781-795.

Montgomery, D.R., G.E. Grant, and K. Sullivan. 1995. Watershed analysis as a framework for implementing ecosystem management. Water Resources Bulletin 31: 369-386.

National Research Council. 1992. Restoration of Aquatic Ecosystems. National Academy Press, Washington, D.C., USA, 552 pp.

Rhoads, B.L. 1995. Stream power: a unifying theme for urban fluvial geomorphology. In Stormwater Runoff and Receiving Systems, ed. E.E. Herricks, pp. 65-75. Boca Raton, Florida: Lewis Publishers.

Rhoads, B.L. 1996. Mean structure of transport-effective flows at an asymmetrical confluence when the main stream is dominant. In Coherent Flow Structures in Open Channels, ed. P.J. Ashworth, S.J. Bennett, J.L. Best, and S.J. McLelland, pp. 491-517. Chichester, UK, Wiley.

Rhoads, B.L. and E.E. Herricks. 1996. Naturalization of headwater streams in Illinois. In River Channel Restoration, ed. A. Brookes and D. F. Shields, Jr., pp.331-367. Chichester, UK, Wiley.

Rhoads, B.L. and M.A. Urban. 1997. Human-induced change in low-energy agricultural streams: an example from east-central Illinois. In Management of Landscapes Disturbed by Channel Incision, ed. S.S.Y. Wang, E.J Langendoen, And F.D. Shields, Jr., pp. 968-973. Oxford, MS: University of Mississippi.

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22: 169-199.

Schlosser, I.J. 1987. A conceptual framework for fish community structure in small warmwater streams. In Community and Evolutionary Ecology of North American Stream Fishes, ed. W.J. Matthews and D.C. Heins, pp. 17-24. Norman, OK, Oklahoma University Press.

Simon, A. and P.W. Downs. 1995. An interdisciplinary approach to evaluation of potential instability in alluvial channels. Geomorphology 12: 215-232.

Terhaar, M.J. and E.E. Herricks. 1989. Management and Development of Aquatic Habitat in Agricultural Drainage Systems. Water Resources Center Research Report No. 212, University of Illinois, Urbana, Illinois, USA, 145 pp.

Trimble, S.W. and R.U. Cooke. 1991. Historical sources for geomorphological research in the United States. The Professional Geographer 43: 212-227.

Winsor, R.A. 1987. Environmental imagery of the Wet Prairie of East Central Illinois. Journal of Historical Geography 4: 375-397.

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