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INTEGRATING SCIENCE AND TECHNOLOGY TO SUPPORT STREAM NATURALIZATION NEAR CHICAGO, ILLINOIS[1]

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ABSTRACT: Many urban and suburban communities in the Midwest are seeking to establish sustainable, morphologically and hydraulically varied, yet dynamically stable fluvial systems that are capable of supporting healthy, biologically diverse aquatic ecosystems – a process known as stream naturalization. This paper describes an integrated research program that seeks to develop a scientific and technological framework to support two stream naturalization projects near Chicago, Illinois. The research program integrates theory and methods in fluvial geomorphology, aquatic ecology, hydraulic engineering and social theory. Both the conceptual and the practical challenges of that integration are discussed. Scientific and technical support emphasize the development of predictive tools to evaluate the performance of possible naturalization designs at scales most appropriate to community based projects. Social analysis focuses on place based evaluations of how communities formulate an environmental vision and then, through decision making, translate this vision into specific stream naturalization strategies. Integration of scientific and technical with social components occurs in the context of community based decision making as the predictive tools are employed by project scientists to help local communities translate their environmental visions into concrete environmental designs. Social analysis of this decision making process reveals how the interplay between the community's vision of what they want the watershed to become, and the scientific perspective on what the watershed can become to achieve the community's environmental goals, leads to the implementation of specific stream naturalization practices.
(KEY TERMS: watershed management; community based decision making; hydraulic modeling; stream naturalization; fish ecology.)

INTRODUCTION

Recent initiatives by US Federal agencies, including the Environmental Protection Agency (EPA) and the Natural Resources Conservation Service, have supported a move toward integrated watershed management that emphasizes community driven decision making based on sound science. The concept of stream naturalization, which seeks to establish sustainable, morphologically and hydraulically varied, yet dynamically stable fluvial systems that are capable of supporting healthy, biologically diverse aquatic ecosystems, is consistent with this new perspective. Naturalization integrates biological, physical and social science within a local decision making context over multiple temporal and spatial scales (Rhoads *et al.,* 1999; Frothingham *et al.,* 2002).

Demand for naturalization of stream channels is growing, especially in urban environments where past channelization has degraded the environmental quality of many fluvial systems. From a science and engineering perspective, the development of a knowledge base to support stream naturalization has occurred mainly in a bottom-up, trial-and-error manner because existing scientific information lacks the specificity required to produce reliable, predictable outcomes. A critical need exists for the development of a theoretically informed, systems approach to stream naturalization that integrates multiple geomorphological, ecological and engineering factors (erosion control, sustainability, habitat enhancement, sediment transfer, aesthetic elements) at multiple scales within a dynamic analytical framework. The development of such an approach will help to establish realistic levels of certainty for predicting environmental responses of

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streams to specific naturalization practices (Naiman *et al.,* 1995; Rhoads and Herricks, 1996; Rhoads and Monahan, 2000).

A critical need also exists for social investigations that examine interaction between scientists and stakeholders in the decision making process underlying stream naturalization. Even if adequate naturalization tools were available, the extent to which these tools would be incorporated into community based decision making is uncertain. Not only are the social dynamics of naturalization poorly understood, but they essentially have been ignored – a critical omission given that naturalization ultimately is instituted within the social context of community based decision making. The summary chapter in a recent volume on sustainable stream management projects identifies integration of scientific knowledge and community based decision making as the most critical issue in need of further investigation (Brookes and Shields, 1996). Only by understanding the interplay between science and decision making can science be responsive to place based visions of environmental quality. Social investigations of this process are vital to translate environmental preferences into concrete stream naturalization strategies based on the mutual consideration of environmental values, local knowledge, and scientific information (Rhoads *et al.,* 1999). Acquiring an understanding of the social processes of stream naturalization is also a critical first step in developing improved mechanisms of information exchange between scientists and local communities.

This paper describes a research program that seeks to develop an integrated scientific and technological framework for stream naturalization. Empirical and modeling aspects of the research are focusing on two stream naturalization projects in the Chicago metropolitan area. These projects highlight the scientific and technological challenges associated with naturalized stream channel designs as well as the vital role of social interaction and community perceptions in the naturalization process.

RESEARCH OBJECTIVES

Specific objectives of the research program are to: (1) develop and test a set of dynamic, process based, multi-scale analysis and modeling methods that integrate ecological, geomorphological, and engineering information to effectively predict fluvial and habitat dynamics of human modified stream systems; (2) examine the social processes that define the content of a community's environmental vision and that influence the effective incorporation of scientific and technical information into community based decision making; (3) determine the extent to which specific stream naturalization strategies that fulfill the environmental objectives of a local community are also sustainable given the fluvial and ecological conditions of the watershed; and (4) explore how community based environmental preferences shape and, in turn, are shaped by science and technology as preferences emerge and then are translated into specific environmental designs.

RESEARCH DESIGN AND METHODOLOGICAL INTEGRATION

The research design combines social analysis, both of community based environmental visions and of decision making about stream naturalization, with a scientific and technical analyses aimed at generating a predictive understanding of, and technical basis for, stream naturalization. The social methodology includes analysis of the historical development of the environmental vision within each community, and case study investigations of current components of this vision and the role of scientific information in sustaining this vision. Scientific and technical research is developing and integrating engineering-based modeling of stream dynamics with geomorphological analysis of stream processes and ecological analysis of physical habitat and fish community characteristics. Specific tasks include: (1) the development of predictive engineering models to meet community based needs for stream naturalization; (2) geomorphological and ecological assessments of streams in the two target watersheds where naturalization projects are underway; (3) testing and application of scientific and technical tools in the context of community based decisions; (4) historical analysis of archival material on community attitudes towards water and watersheds; (5) open ended interviews of local actors and agents engaged in stream naturalization; and (6) participant observation of interaction between scientific and technical experts and community representatives in the decision making process about naturalization.

STUDY SITES

The two study sites for this project are the West Fork of the North Branch of the Chicago River, Northbrook, Illinois, and Poplar Creek, Elgin, Illinois. Naturalization goals and expectations differ between the two sites due to contrasting possibilities and limitations associated with their environmental settings.

The primary goal for the North Branch of the Chicago River in downtown Northbrook, Illinois is to naturalize in-stream conditions by enhancing hydraulic, morphologic and biological diversity without compromising stream channel stability or conveyance, and by improving stream aesthetics in an economically viable manner. The watershed is situated within a highly urbanized landscape at the northern edge of the Chicago metropolitan area and the river has been channelized several times over the last 100 years (Jim Reynolds, Director of Public Works, Village of Northbrook. personal comm.). The existing stream channel is straight and trapezoidal with a flat uniform bed (Figure 1). Channel banks are covered with a dense array of adventitious tree species and locally a variety of ad hoc bank treatments, including boards and concrete rubble have been used to try to prevent bank erosion. Channel stability is a major concern because at many locations, parking lots and alleys extend to within two to three meters of the tops of banks.

Naturalization of the river represents the first step in an attempt to revitalize downtown Northbrook. Because the proximity of urban infrastructure to the river precludes channel realignment, naturalization involves bank treatments and enhancement of in-channel geomorphological structure, with the latter of these two components serving as the focus of the research team's contribution to the project.

At the Poplar Creek study site, the environmental setting is less constraining than at Northbrook, allowing for a more comprehensive approach to stream naturalization. While the North Branch is flanked by urban development, Poplar Creek flows through a broad undeveloped floodplain. Consequently, the goals of naturalization at this study site extend beyond the in-channel environment. In the early 1900s, an approximately 350 meter reach of the creek just south of Elgin, Illinois, near the confluence with the Fox River was artificially straightened. Immediately upstream from this reach is a 600 meter section of the creek that was not channelized and has a meandering planform (Figure 2). A specific goal of naturalization is to dechannelize the straightened section of Poplar Creek and reestablish a dynamic meandering stream system with diverse in-stream habitats and a naturally functioning floodplain ecosystem. The naturalization project is a coordinated effort that includes The Illinois Chapter of the Nature Conservancy, the Fox Valley Land Association, the Illinois Nature Preserves Commission, the Kane County Soil and Water Conservation District, and the U.S. Army Corps of Engineers (USACOE). As part of the project, 33 acres of land containing the straightened and meandering reaches of Poplar Creek and the adjacent floodplain were purchased to provide a buffer to protect Bluff Springs Fen, which lies immediately to the east of the meandering reach of the creek and is one of the few remaining fen wetlands in Illinois. The community group responsible for the management of this fen, the Friends of Bluff Springs Fen, is a primary driving force behind the effort to naturalize Poplar Creek. This group has expressed a desire to return Poplar Creek and its floodplain to pre-European settlement conditions. Design plans for naturalization of Poplar Creek have been developed in collaboration with the

Figure 1. Naturalization Efforts on the West Fork of the North Branch of the Chicago River Are Highly Constrained Due to Local Land-Use. Parking lots and alleys extend to within 2 to 3 meters of the channel.

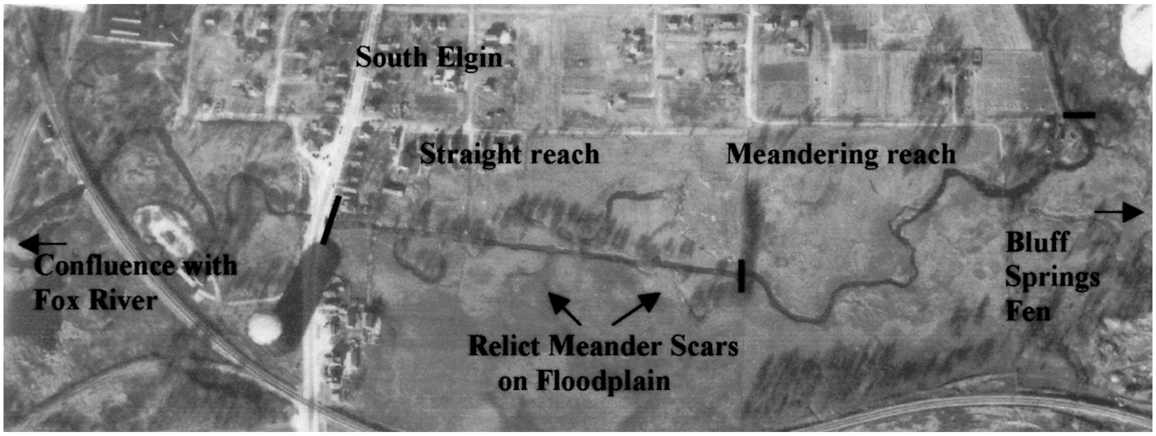

Figure 2. Air Photo of Poplar Creek, Elgin, Illinois (taken 1938) Close to Its Confluence With the Fox River. Bluff Springs Fen: A protected wetland fen is shown to the east (right) and the two study reaches – straight and meandering.

USACOE, which will be responsible for construction of the project.

The North Branch and Poplar Creek projects serve as contrasting examples of stream naturalization opportunities. Restoration in the classic sense of a return to predisturbance conditions is clearly not viable to any extent in the highly constrained urban setting of Northbrook, whereas predisturbance conditions may have some relevance to naturalization of Poplar Creek.

INTEGRATED RESEARCH TO SUPPORT STREAM NATURALIZATION NEAR CHICAGO

North Branch of the Chicago River

The planning phase of the naturalization project for the North Branch was already in an advanced phase when the research team became involved in project design. A concept plan developed by the consulting engineers called for the implementation of several artificial riffles, or rock weirs, within this low gradient urban channel. Preliminary field studies were undertaken to evaluate the suitability of such structures from a geomorphological and ecological perspective. This field effort included surveying the longitudinal profile of a 900-m long section of the stream (Figure 3), sampling particles on existing riffles composed of concrete rubble (Figure 4), and evaluating ecological conditions using EPA's Rapid Bioassessment Protocols for wadeable streams and rivers (Barbour *et al.,* 1999). This analysis suggested that the weir-like riffles being considered by local officials were unsuitable because: (1) weir structures serve as small check dams that retain sediment, thereby decreasing habitat quality by covering substrate and lowering water quality through the accumulation of sediments that have the potential for reducing oxygen levels in the upstream pools; and (2) the total change in stream elevation over the reach is not great enough to construct a sufficient number of rock weirs to improve habitat. Based on this analysis, the research team recommended an alternative design that draws upon principles from geomorphology, ecology, and engineering. Interaction between the researchers and the stakeholders was vital in this stage of the process. A mutual understanding of stakeholder desires and technical realities by all parties was vital to achieve effective naturalization. Some of the key factors contributing to the final design shall now be considered.

Geomorphology. Geomorphological principles provided the basis for an initial pool-riffle design for the straightened Northbrook channel. This design was then modified based on ecological and engineering considerations. An initial design was developed from the bar unit concept (Dietrich, 1987; Frothingham e*t al.,* 2002), which proposes that bar units are the fundamental bed forms in meandering and straight stream channels. In straight channels, bar units alternate on either side of the channel in the downstream direction and include pools, riffles, and alternate bars as bar elements. In meandering channels, the bar units wrap around meander bends and include pools, riffles, and point bars as bar elements. Bar units have been implicated in the process of meandering through the bar bend theory of meander initiation (e.g., Rhoads and Welford, 1991).

Because a primary goal of naturalization at the North Branch site is to maintain a stable channel planform, alternating bar units are considered

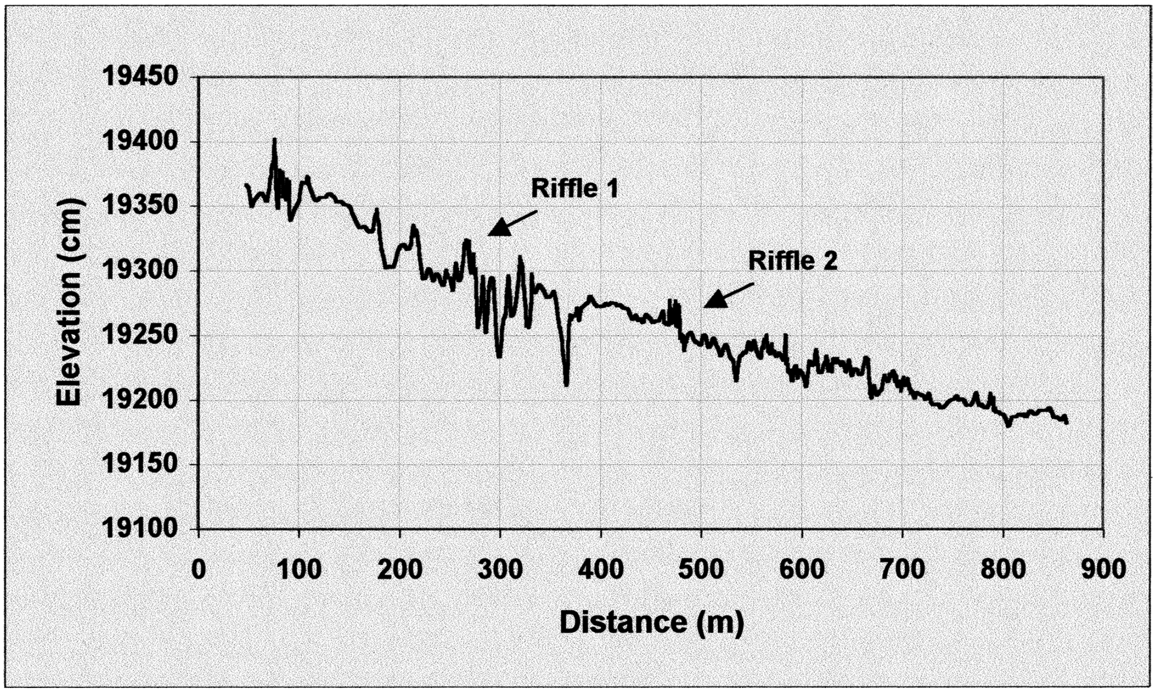

Figure 3. Longitudinal Profile of the Study Reach at Northbrook, Illinois.
Existing riffle positions are indicated (Riffle 2 is shown in Figure 4).

Figure 4. Photograph of Riffle 2 at Northbrook Prior to Naturalization Work (location of riffle is shown in Figure 3).
The riffle material consists in part of concrete slabs rather than indigenous materials.

inappropriate because deflection of the flow toward the channel banks by the alternating bar structure could trigger bank erosion and channel meandering. Instead, a design was developed to mimic the influence of bar units on spatial variation in hydraulic conditions, but to avoid deflection of flow toward the channel banks (Figure 5). The design is similar to a Parshall flume in that flow converges in the center of the channel in narrow, deep pools and diverges over wide, elevated riffles. Other geomorphological considerations draw upon knowledge of pool-riffle sequences found in nature. The most important of these characteristics include: (1) periodic spacing at five to seven times the channel width; (2) smooth transition areas between pools and riffles; (3) coarse material on the riffle and fine sediment in the pools; (4) highest velocity over the riffles and lowest velocity in the pools at low stage; and (5) convergence of mean flow velocity in riffles and pools with increasing flow stage. Ten pool riffle units resulted from the criteria of fitting the maximum number of units into the study reach while maintaining a minimum distance of one unit length between road bridges and the closest pool-riffle structure. These units are distributed among three reaches separated by bridge crossings.

Ecology. Ecological considerations dictate that the pool riffle structure should provide a robust habitat characterized by physical complexity to meet the diverse needs of aquatic life (Schwartz *et al.,* 2001). To determine existing ecological conditions at the site, an integrated effort that included a habitat survey and biological monitoring, conducted in conjunction with the geomorphological field survey, was completed at the Northbrook site during June 1999. A habitat survey along a 900 meter section of stream provided data on channel unit type (pool, glide, and riffle) and dimensions, substrate composition, coarse woody debris, shade cover, bank physical and vegetation characteristics. Survey results showed that glides constitute 51 percent of the total stream reach, whereas shallow pools encompass only 22 percent of the reach length. Pools were located only near existing urban structures that promote bed scour, such as bridge abutments and storm sewer outfalls. Biological monitoring included fish and macroinvertebrate sampling. For the macroinvertebrate samples, five locations were sampled within the proposed naturalization site. At each location, two sub-samples were taken at fast and slow flow areas. Species diversity of macroinvertebrates was low, in which over 90 percent of the sample abundance consisted of isopod species and Chironomids. Electrofishing using a backpack shocker at four 60 meter sample reaches yielded green sunfish, bluegill and white sucker. Fish densities in reaches with shallow habitat units ranged from 0.008 to 0.014 fish/m^2. The highest density, 0.036 fish/m^2, occurred in a pool greater than 1 meter deep. Fish biomass followed the same pattern with the greatest biomass occurring in the deepest pools. These findings remained consistent over two additional sampling periods in 2000 and 2001 (Figure 6).

Results from the habitat survey and biomonitoring indicated that increasing the availability of deep pool habitat is a critical element for enhancement of biological diversity. Thus, it was recommended that pools have a depth of 1 meter and that two or more pool-riffle units be placed sequentially in each section of the reach to promote a continuum of habitat structures. This design emulates the hydrodynamic function of natural pool-riffle sequences, especially at low flow when depth, combined with channel form, provides a diversity of hydraulic habitats within each pool-riffle unit. Deep low velocity flow should be

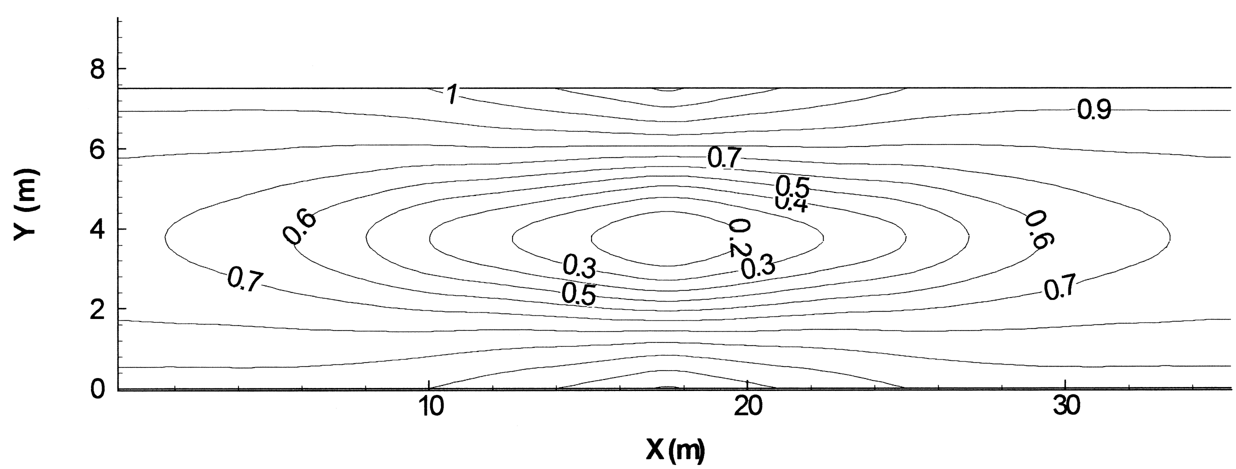

Figure 5. Contour Plot of the Pool-Riffle Unit. The Y-axis represents the cross-sectional distance in meters, and the X-axis represents the downstream distance in meters.

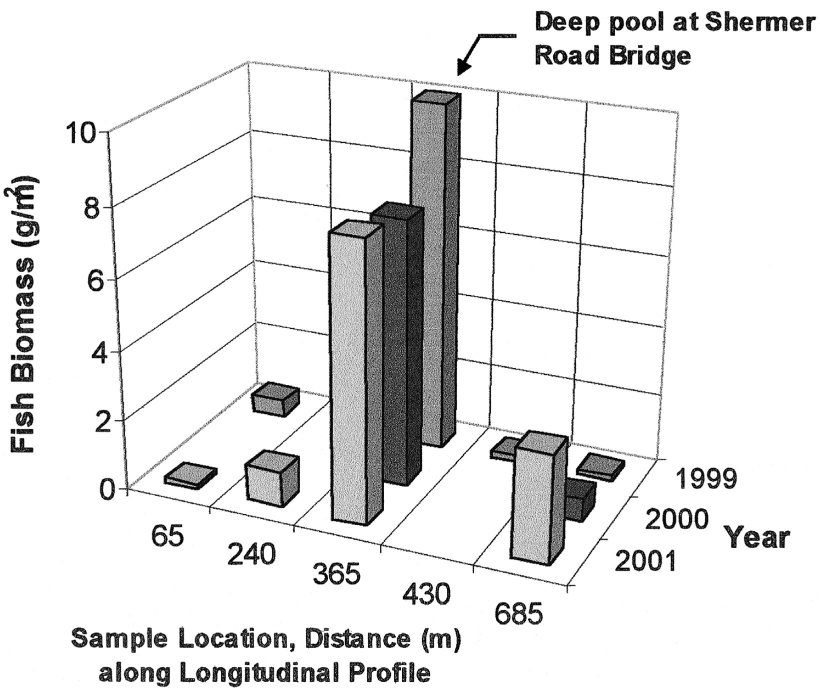

Figure 6. Fish Biomass in g/m^2 for Five Sample Locations Along Longitudinal Profile (Figure 3) of the North Branch of the Chicago River Surveyed at the Northbrook, Illinois Site.

present in the pools and shallow, high velocity flow should exist over riffles. The placement of multiple units also meets aesthetic criteria to enhance visual diversity and to produce audible effects of babbling flow over shallow riffles. The riffles also should improve water quality by increasing oxygenation of water as it enters the downstream pool.

Hydraulic Engineering. Engineering considerations focused on the proper hydraulic functioning of the structure to promote self-sustaining morphological units within the naturalized channel while providing suitable habitat. Verification of several aspects of the hydrodynamic performance was necessary. To ensure stability of structure it is imperative that the resistive force of the material is larger, at any given spatial location, than the tractive force exerted by the flow over a wide range of flow conditions. Slopes of the channel bed must also be less than the angle of repose of the corresponding material. The velocities in the pool need to be large enough so that silting is prevented and a self-scouring, self-sustaining pool riffle morphology is maintained over time and over varying flow regimes. Finally, the pool-riffle structure should not raise the water stages above the existing levels during high flows (i.e., flood risk should not be increased by the addition of the new structures).

To evaluate the hydrodynamic performance of the pool-riffle structures, numerical simulations were conducted using FLOW-3D – a powerful three-dimensional numerical model for solving computational fluid dynamics (CFD) problems, developed by Flow Science, Inc., New Mexico (FLOW-3D® User's Manual, 1998). This model provides a design aid to support geomorphological and ecological assessments. Flow 3-D solves the fully-3D transient Navier-Stokes equations by a finite volume approximation. It uses the volume-of-fluid (VOF) method by which it performs a volume tracking, allowing for the robust and efficient treatment of the free surface. Obstacles are defined independently from the mesh by a solid modeler. FLOW-3D determines solid volume fractions in each cell, which is supplemented with area fractions in each of the three coordinate directions. This allows for an accurate representation of the solid boundaries. Turbulent closure can be achieved through one of several advanced and widely accepted schemes.

To obtain a representative description of the flow in a pool and riffle unit, a sequence of three units was simulated with FLOW-3D. The simulated computational domain corresponded to a reach 140 meter long, 7.5 meter wide and 2.6 meter deep. The mesh contained 190 cells in the stream wise direction and 40 in the transverse and vertical directions. Fifty percent of the vertical cells were included in the top 35 percent of the computational domain to simulate accurately the variations in the water surface. The large eddy simulation (LES) option was used to obtain turbulence closure. Three simulations were performed, corresponding to different stages: low, medium, and high water levels.

The simulations indicate that at low flow the highest near surface velocities occur over the riffle with the flow decelerating as it enters the pool (Figures 7a and 7b). Recirculation of the near-bottom flow is evident at the upstream end of the pool and high near bed velocities occur at the downstream end of the pool (Figure 7c). This morphological feature, therefore, provides considerable hydrodynamic variability over a small spatial scale. Flow within the pool exhibits strong secondary circulation with two surface convergent cells producing downwelling over the center of the pool and divergence of flow near the bed (Figure 8). This pattern of fluid motion is similar to that found in natural pools and should promote self-scouring of the pool. The model predicts counter rotating surface divergent cells over the riffle; a result that is consistent with geomorphological field studies of flow structure over riffles.

To evaluate model predictions, a physical model of three successive pool riffle sequences was constructed in the Hydrosystems Laboratory at the University of Illinois. Three-dimensional velocity measurements of flow through these sequences were obtained for three stages corresponding to the low, medium and high water levels in the numerical modeling. Measured velocities in these experiments generally conformed to model predictions (Belby, 2001).

North Branch Pool-Riffle Design. Based on the geomorphological, ecological and engineering analyses, a three-dimensional pool riffle structure was proposed with a longitudinal profile at the centerline defined by a sinusoidal curve with longitudinal slopes at the entrance to and exit from the pool of 1:10 (Figure 9). Transverse slopes in the pool area are 1:3.

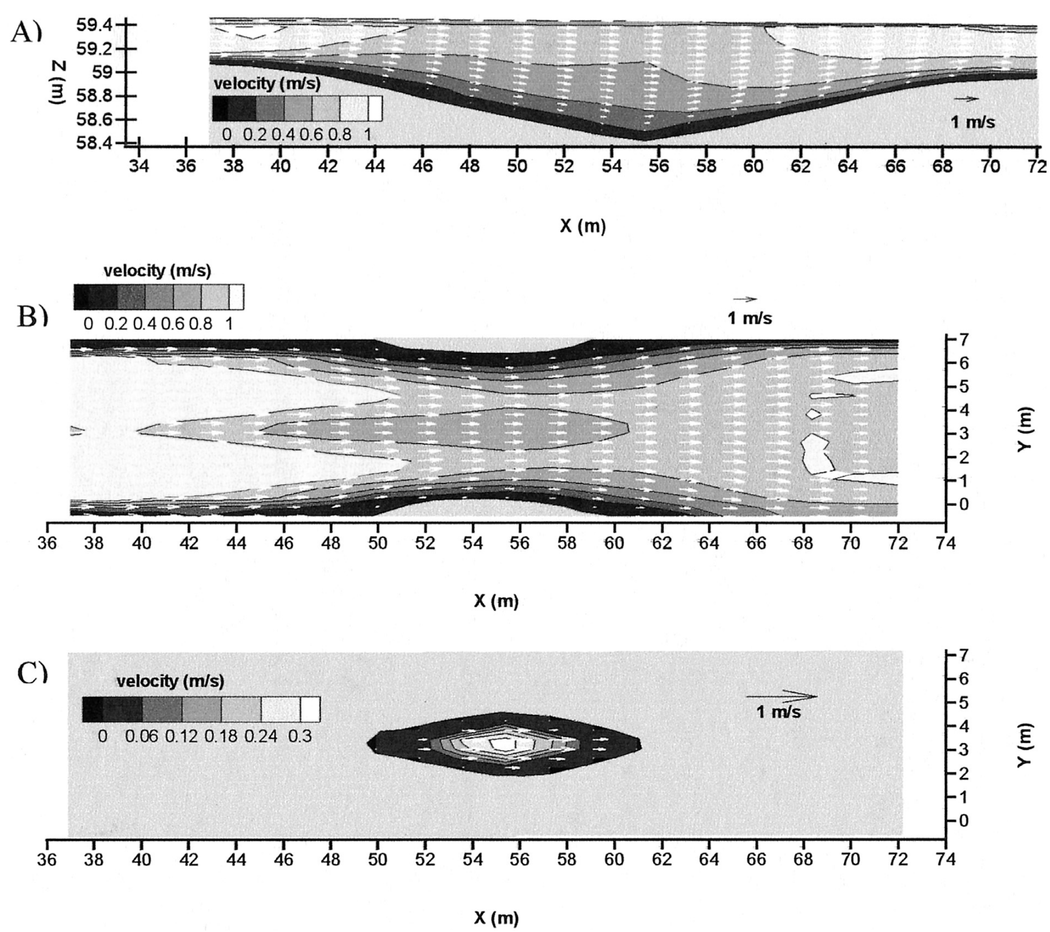

Figure 7. Velocity Fields and Vectors Representing Results of the Numerical Modeling of Flow Through the Pool Riffle Unit. Distance is represented in meters and velocities (indicated by the key at the top of each figure) are in ms^{-1}. A) Side view of the velocity field along the centerline of the pool-riffle unit. Velocities are highest near the surface and over the riffle, decelerating in the pool section. B) Top view of the velocity field near the water surface. C). Top view of the velocity field near the bottom of the pool.

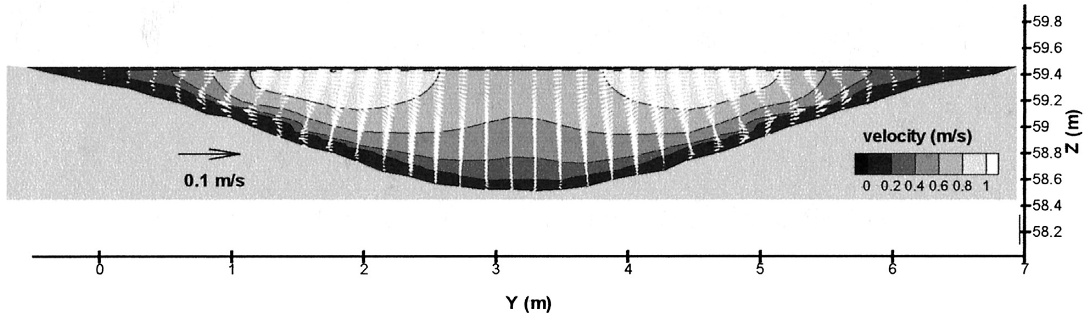

Figure 8. Cross Section Showing Simulated Velocities in the Pool.
Distance is represented in meters and velocities are in ms^{-1}.

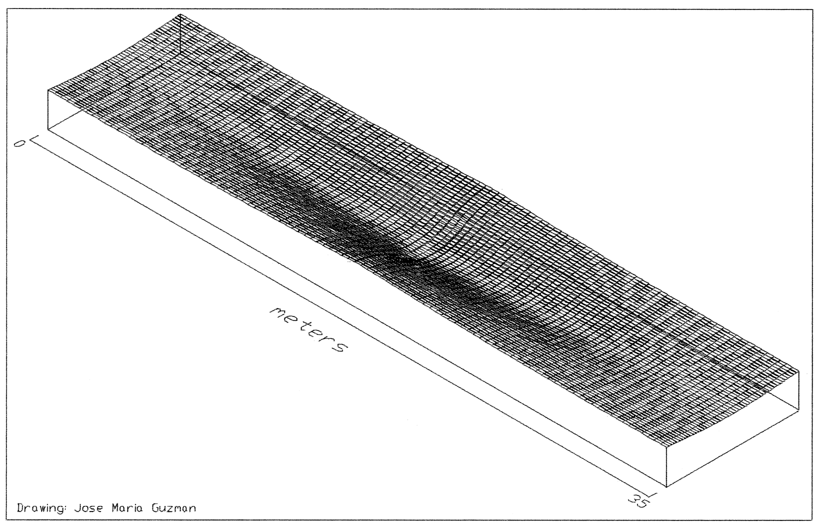

Figure 9. Isometric Plot of a Single Pool Riffle Unit as Designed for Implementation at the Northbrook Stream Restoration Project. [Scale properties of the diagram are; 1:1:1 (x:y:z), total length of the unit is 35 meters.]

Additionally, based on the numerical model results and on field observations of the stability of existing particles within the stream, a suitable combination of bed materials were recommended as follows: for the pool region (from x = 8.75 m to x = 26.25 m) excavation of into underlying glacial till, and for the riffle region (from x = 0 m to x = 8.75 m; and from x = 26.25 m to x = 35 m) a surface layer of medium gravel (1.25 to 5 cm diameter) capped with imbricated flat stones (0.25 to 0.5 m diameter).

Social Analysis. Social analysis at Northbrook has a double headed approach focusing both on practical interaction between scientists, engineers and stakeholders throughout the planning and design process as well as on ideological aspects of river based redevelopment. Initial social analysis at the North Branch site involved compiling a chronological database on the history of the North Branch of the Chicago River and previous attempts by the community of Northbrook to restructure it. Information was drawn from local library sources, detailed content analysis of local newspapers (*Northbrook Star, Chicago Tribune*), and technical documents provided by local consulting firms and government. These historical documents suggest that the redevelopment goal at Northbrook is to enhance community prestige by creating a greater sense of place. Beautification of the river is seen as one of the primary means to achieve this objective.

Interviews with local officials and other stakeholders supplement the historic compilation with detailed contemporary data. Interviews have sought to explore stakeholder values and interests as political participants in the river restructuring process. One component of the research examines how various stakeholders in the community of Northbrook have assigned ideological meanings to the river and have used these meanings within the local political arena to advance specific redevelopment objectives. Meanings vary with the diverse political orientations of stakeholders as representatives of personal, constituent, and community interests. Within the local political arena these contrasting meanings translate into diverse ideologies concerning appropriate management of the river and policy for river naturalization. Results of this part of the social analysis highlight some tensions associated with the implementation of the concept of naturalization. These tensions stem from the dichotomy between stakeholder values and desires and "expert" sense of best usage and vision. These findings reveal a common problem in implementing any planning process, even those based on bottom-up planning strategies. Planners and technical experts do not easily lose their sense of technical prowess and expertise, even when they recognize that they have to acknowledge the importance of local understandings and values (Darier *et al.,* 1999).

Observations also have been made of the interaction between natural scientists and engineers on the research team and local stakeholders, such as the Northbrook public officials and representatives of the Friends of the Chicago River. Much of this interaction has occurred in the context of meetings between the two groups in Northbrook or at the University of Illinois. Local officials have welcomed the involvement of members of the research team, who are viewed as contributing substantial "value added" components to the project. The research team has made a conscientious effort to supply information and recommendations to local stakeholders, but to defer to and incorporate elements desired by these stakeholders into the stream naturalization project. The research team has also emphasized the innovative nature of the project and that, although the design is based on sound science, the implementation of any innovative design entails some uncertainty.

A key outcome of interaction has been the evolution of project design. Local officials and representatives of the Friends of the Chicago River see the value of the proposed pool-riffle structures for meeting project objectives relative to the rock-weir riffles initially proposed by the FOCR. The research team also has incorporated aesthetic elements into the design, such as the introduction of coarse rock on riffles to produce water aeration and audible effects ("babbling brook") that were desired by local officials and the FOCR. Translation of the pool riffle concept into specific construction plans by the project engineers involved several rounds of interaction between the research team and these engineers, but this interaction proceeded smoothly with the engineers expressing a willingness to alter details of the design prior to finalization of the plans. Construction of the pool riffle sequences began in November 2001 and project engineers invited the research team to the site to assist the contractor in building the structures according design specifications. The research team plans to monitor the site after construction to assess the performance of the pool riffle structures relative to the results of experimental and numerical testing.

Poplar Creek

As the research team became involved in the stream naturalization at Poplar Creek, initial emphasis was placed on the need to understand the dominant processes operating in the system to effectively remeander the channelized section of the creek. The meandering reach upstream of the channelized reach currently contains abundant large woody debris (LWD), and this material is believed to be a major factor influencing the dynamics of Poplar Creek (Figure 10). The effects of the LWD on fluvial and ecological processes must be ascertained at a level consistent with theory based predictive models of channel dynamics being developed as part of this research project. In recent years local volunteer groups who participate in controlled burns and brush clearance activities once or twice per year at the site have removed LWD from the system. The rationale behind these activities (as stated by the organizers) is the perception that LWD in the system contributes to flooding and decreases habitat quality and that brush removal through burning encourages establishment of fen plant species rather than brushy undergrowth.

Field investigations at the site have focused on the role of LWD in the geomorphology and ecology of Poplar Creek, whereas engineering analysis has been conducted to evaluate channel stability following remeandering. As in the Northbrook case study, social analysis is examining interaction between the research team and local stakeholders as well as the ideologies underlying the concern about stream naturalization along Poplar Creek.

Geomorphology. Geomorphological field research has focused on investigating the pattern and movement of large woody debris in the stream system and on characterizing the influence of this material on patterns of three-dimensional flow and channel erosion and deposition in meander bends.

Woody debris pieces within the study section have been mapped in relation to the coordinate system and each LWD piece has been associated with the geomorphologic conditions in its immediate surroundings (e.g., on point bar, on riffle, outside of meander bend, etc.) In addition, 150 pieces of LWD have been tagged using round aluminum tree tags attached with nails.

Figure 10. Large Woody Debris (LWD) in One of the Meander Bends at Poplar Creek. LWD is a major factor influencing the flow dynamics and hydraulic habitat at this site.

To provide detailed hydrologic data, a water stage recorder, consisting of a pressure transducer connected to a data logger, has been set up within the study section of Poplar Creek to record water levels on an hourly basis. The distance of movement of tagged woody debris pieces is currently being compared with hydrologic data recorded during a 12-month sampling period. These data will be used to document the pattern of LWD movement in relation to channel morphology and the occurrence of different types of hydrologic events. Preliminary results indicate that at high stages, LWD is very mobile in this system.

Detailed measurements of three-dimensional velocities have been conducted in three meander bends containing LWD obstructions. At each meander bend, intensive surveying has been performed to establish a topographic map of the local channel morphology. Based on these maps, ten monumented cross sections, each oriented perpendicular to the local channel direction, have been established from the entrance to the exit of each meander bend. Two sets of flow measurements, one at low flow conditions and one near bankfull flow conditions have been collected for seven to nine cross sections at each meander bend. In addition, the LWD present in one of the study meander bends has been physically removed to eliminate its influence on the flow dynamics of the bend. Flow measurements have been collected at both low and high flow stages in the cleared bend to determine three-dimensional flow patterns in the absence of the LWD. In addition to the velocity measurements, the ten cross-sections at each bend have been surveyed on a regular basis to document patterns of channel erosion and deposition. Preliminary results suggest that the presence of LWD substantially alters both the spatial patterns of downstream velocity within the bends and also disrupts the helical motion typical of flow through unobstructed bends. Current analysis is focusing on the influence of altered flow characteristics on patterns of erosion and deposition in bends containing LWD.

Ecology. Fisheries sampling was completed at two geomorphic scales to characterize community structure between channel segments with different planform characteristics (i.e., the meandering and straight reaches), and to specifically investigate the ecological significance of LWD and associated hydraulic conditions under different flow regimes. Community level fisheries sampling was completed in the summer of 2000. Fish samples showed that both reaches contain game species, including largemouth and smallmouth bass, walleye, bluegill, green sunfish, and channel catfish, confirming impressions by local residents based on their fishing experience in Poplar Creek. Fish density and diversity was greater in the meandering reach compared to the straight reach, but fish biomass was greater in straight reach (Table 1). Fish biomass in the straight reach was dominated by large carp, which comprised approximately three-fourths of the total biomass in the reach. Biomass in the meandering reach was more evenly distributed among different species. In the spring and summer of 2000, sampling focused on fish in eddies formed downstream of LWD and sampling of habitat areas in other portions of the stream during high and low flow conditions. These sampling efforts were carried out immediately prior to the collection of geomorphological data at the three meander bends in the meandering reach to correlate fish presence and relative abundance with three-dimensional flow measurements obtained by the geomorphology team. During flows approximately one-half bankfull, no fish were collected from noneddy habitat units, whereas 71 percent of the eddy habitat units contained fish. During low flow conditions, 33 percent of the noneddy habitat units and 71 percent of habitat units near LWD contained fish. These results suggest that LWD provides hydraulic refuge for fish during high flows and habitat cover during low flow. Overall, the presence of pool riffle sequences and the abundant LWD in the meandering reach appear to contribute to habitat complexity and associated biological diversity.

TABLE 1. Fish Metrics Between Meandering and Straight Reaches for a Summer 2000 Sample on Poplar Creek, Elgin, Illinois.

Fish Metric	Meandering Reach	Straight Reach
Total Number of Species	17	12
Diversity Index	3.27	2.75
Fish Density (fish/m^2)	24.0	16.5
Fish Biomass (g/m^2)	943.4	2,057.5
Fish Biomass w/o carp (g/m^2)	925.4	570.8

In addition to fisheries sampling, a benthic invertebrate sampling campaign has been in place at the site since early spring of 2000. Several artificial substrates have been introduced into Poplar Creek both in the meandering and straight reaches. Preliminary data indicate that Poplar Creek has the potential to support a diverse macroinvertebrate community, but that the presence of a diverse array of organisms depends on the availability of coarse gravel substrate, which is present on riffles in the meandering reach but absent entirely within the straight reach. Thus, remeandering of the straight reach should enhance the diversity of macroinvertebrates in this section of Poplar Creek through the development and maintenance of riffles.

Engineering. Engineering analysis has focused on the development of numerical models of meandering streams to allow prediction of channel dynamics for various remeandering scenarios. Two existing numerical hydrodynamic models provide a foundation for the development of an integrated channel dynamics model that also accounts for sediment transport and bank erosion. The first model, Meander, is a one-dimensional model valid for erodible streams. The second, FLOW-3D, is a fully three-dimensional, state-of-the-art, computational fluid dynamics (CFD) model (FLOW-3D® User's Manual, 1998). The scale of the problem examined here is in the overlapping region of applicability of the two models. Meander is an engineering tool; it generates results relating only to the channel planform and migration of that form, but can be applied easily to large spatial domains. FLOW-3D generates a complete and detailed picture of the flow field, but requires considerable computational resources.

As a first stage in model development, the two models have been applied to a meandering reach of the Embarras River, Illinois (Rodríguez and Garcia, 2000) where a detailed set of 3-D velocity measurements is available for comparison (Frothingham, 2000). Results of the numerical simulations show that the 3-D model accurately predicts the main characteristics of the measured velocity field (Rodríguez *et al.,* 2000). Results of FLOW-3D are accurate and demonstrate the capability of the code to successfully capture the three-dimensional secondary-flow patterns. A critical component of the modeling effort will be to define the role that LWD plays in channel dynamics.

Prior to numerical modeling, historical evidence of channel stability was determined through analysis of air photos taken sequentially since the 1930s. Georectification and digitization of the straight and meandering channel sections showed that this system has remained in a stable planform configuration for many decades. This stability can be attributed firstly to the very low gradient of the system with the slope of the straight section being 0.000958, and secondly to the low stream power values. Stream power at bankfull stage is approximately 5 to 10 watts per square meter (W/m^{-2}) based on field measurements of near bankfull discharge at the site and estimates of bankfull discharge derived from a USGS gaging station several kilometers upstream from the site. Brookes (1988) cites a threshold of 35 W/m^{-2} below which straightened channels will not exhibit bed and bank instability and will not adjust their channel shape by means of erosion. These factors collectively describe a system with insufficient power to promote self-adjustment to a meandering planform. For the same reason it seems reasonable to expect that attempts to remeander this section may have considerable success in that the new channel alignment will remain stable. This assumption was supported by numerical simulations of channel migration derived from the Meander model for four different remeandering scenarios. The degree of stability predicted by the model was very high even with maximum migration rates for the four alternatives ranging from 2.7 to 6.4 meters over a simulation interval of 100 years.

Social Analysis. Social analysis for Poplar Creek employs the same double-pronged approach used for the Northbrook case study, but for this location the ideological component focuses on discourses of environmental resource provision. Central to the discourse surrounding the naturalization work at Poplar Creek is the importance of Bluff Springs Fen, a protected natural area encompassing a wet sedge meadow and the land and the water along Poplar Creek. Local stakeholders have represented these natural resources as environmental provisions for community use. Social analysis is examining the values, ideologies and languages that influence the provisioning of these resources.

Open ended interviews have been carried out with watershed residents, city officials, local planners, and the main resource providers (e.g., the Nature Conservancy, Illinois Nature Preserves Commission) that are the primary stakeholders responsible for resource provision. The interviews suggest that provision of resources may not be addressing the needs and wants of the majority populous of the area; instead it is addressing the visions of a minority who are interested and invested in the local environment. In particular, the project site is located within a Hispanic neighborhood and this segment of the local population has not been included in planning for naturalization of the site.

Interaction between the research team and the local stakeholders has occurred since the inception of the naturalization project in 1998. These stakeholders have inherent respect for the collective expertise of the research team and have appreciated the contribution of time, information and analysis in support of the project. The research team has tried not to actively steer the naturalization plan toward a particular outcome; however, the provision of information by the team has led to debate when this information has conflicted with naturalization criteria and desired outcomes of the local stakeholders. One criterion held by stakeholders is that floodplain vegetation should be restored to a pre-European settlement condition. The perception was that this condition probably consisted of wedge sedge meadow based on the proximity of the floodplain to a fen. Thus, establishment of wet sedge meadow on the floodplain became an early goal of the project. However, historical research based on General Land Office survey records indicated that the area surrounding the creek consisted of lowland deciduous woodland in the early 1800s. In the light of this information stakeholders abandoned their criterion, rather than change their goal. Their rationale is that wedge sedge meadow provides a compatible riparian landscape with the nearby fen. This example shows how the process of naturalization is intimately linked with human value systems, even when the goals of naturalization are founded in environmental concerns. A similar debate arose when the research team demonstrated empirically the value to stream organisms of leaving LWD within the river system, rather than clearing it from the creek on an annual basis. Because the introduction of LWD to stream is related to what local stakeholders perceive as “weedy” tree species covering the floodplain, which they hoped to remove, these stakeholders find it difficult to acknowledge the ecological value of the trees.

Implementation of the remeandering project at Poplar Creek has been delayed by protracted negotiations regarding land acquisition and by the extended process of obtaining funding for construction through the USACOE. It is anticipated that remeandering of the stream may take place in the spring or summer of 2003.

SUMMARY AND CONCLUSIONS

Over the last two decades, many communities in the Midwest have, through grass roots social processes, developed an increased concern about and control over the environmental management of streams and rivers. Thus far, most efforts to improve environmental quality have focused primarily on mitigation of impaired water quality and altered hydrologic regimes. These communities now, however, are also recognizing the need to address concerns about the physical form and dynamics of streams and the importance of physical factors in determining ecological conditions. This paper has described a research program aimed at generating an integrated framework to support stream naturalization at two contrasting urban locations in the Chicago metropolitan area. Scientific and technical support for stream naturalization involves the integration of geomorphological, ecological, and engineering analyses to guide the development and evaluation of specific naturalization designs within the context of interaction between project scientists and local stakeholders. Social analysis focuses on investigation of the role of this interaction in shaping naturalization outcomes and examination of the ideological foundations of stakeholder attitudes toward the stream resources in their communities. The two case studies examined here illustrate the importance of tailoring technical aspects of stream naturalization to extant environmental constraints and to the environmental vision of stakeholders. It also shows that scientific and technical input can clash with this vision and that scientists and technical experts therefore need to be careful to separate their information from their opinions when participating in the naturalization process (Rhoads *et al.,* 1999). The social analysis also reveals that even at the local level an environmental vision often reflects the wants and desires of an empowered few, rather than of the community at large.

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