COASTAL RESTORATION

Urban Stream Naturalization - A Systems Context for Practice Implementation

Final Report

Objectives

The overall objective of the research is to develop methods to integrate ecological, geomorphological and hydrological/hydraulic information at reach to watershed scales to support selection and placement of in stream BMPs for stream naturalization based on ecological performance criteria for these BMPs. Specific objectives of the research include: 1) to identify and classify hydraulic habitat units; 2) to relate hydraulic habitat units to various management practices and extant stream geomorphology; 3) a) at a local scale to relate hydraulic habitat with specific BMPs, channel geomorphology and aquatic communities and develop measures of ecological performance at the reach scale and b) using geomorphological and ecological processes required for the development of sustainable aquatic ecosystems at a watershed scale, to develop measures of ecological performance at the watershed scale; and 4) to evaluate research findings to provide guidance for BMP design and placement to achieve watershed management goals established by local agencies and stakeholders along Southern Lake Michigan.

We have identified four tasks for this research, 1 & 2 to be completed in year one activities, 3 & 4 to be completed in year two:

- Develop a method to define in stream hydraulic habitat (fluvial habitat unit - FHU);
- Map two FHU elements in the target watersheds: 1) low-flow stage FHUs and determine the spatial distribution and connectivity among these units and 2) high stage floodplain and main-channel connectivity to define the spatial distribution and connectivity among high-stage refugia associated with extant stream conditions;
- Use dynamic mapping in the target watersheds: 1) to relate low flow stage FHUs with BMPs, channel geomorphology to develop structure specific ecological performance measures based on aquatic community needs; 2) to determine the availability of high-stage refuge habitat at a watershed scale; and 3) to complete a watershed specific ecosystem potential analysis that considers organism sources, system connectivity, and both low and high stage habitat to assess system capacity for the development of sustainable aquatic ecosystems.
- Evaluate research findings to provide guidance for BMP design and placement to achieve watershed management goals established by local agencies and stakeholders along Southern Lake Michigan.

Research Completed

Year one research completed to date has included development of a method to define the FHU, and initiation of mapping on the target watersheds.

Definition of a Fish Hydraulic Habitat Unit (FHU)

Habitat is described by a combination of physical, chemical, and biological conditions, in which organisms can live. Habitat is spatially heterogeneous and temporally variable. In flowing water ecosystems, habitat is primarily dependent on the flow stage and channel geomorphology. In any reach of channel, features of importance to aquatic organisms can be, and usually are, delineated as a mosaic of habitat units, where a habitat unit is defined in terms of the specific environmental needs of an organism and related to features of

the environment. The identification of habitat units can be species specific recognizing that the inherent spatial heterogeneity and dynamics over time related to changes in flow or stage in a channel will produce a range of habitat units in any reach of stream. The diversity, spatial extent, and juxtaposition of the habitat units in streams can be used to develop a means to describe how habitat units are related to the distribution and composition of aquatic communities.

In historical delineation of aquatic habitats, velocity, depth, substrate, and cover are widely used; and depth, velocity, and substrate are considered to be the most important factors in the microhabitat specialization of stream fishes (Trautman, 1957; Cross, 1967; Pfleiger, 1971). Many habitat classification schemes developed by fisheries biologists focus on bed topography elements, which we will term channel geomorphic units (CGUs), with riffle and pool delineation among the most widely used CGUs (Schwartz, 2002). However, few delineation studies have connected complex hydraulic characteristics with CGUs, although some researchers have taken turbulence and Froude number into their classification of habitat units (Hawkins et al., 1993, Jowett, 1993). Schwartz (2002) has defined a scheme of habitat units characterized by the three-dimensional geomorphologic complexity and related to hydraulic characteristics. Although it is not directly based on hydraulic conditions, it is a good starting point for a FHU development.

We have developed an approach to characterizing hydraulic conditions in relation to channel planform and flow obstructions to develop and define hydraulic habitat units. These units are based on hydraulic conditions, and scaled to encompass hydraulic feature size that can be associated with fish presence. The resulting FHU is based on the following

- Life in a fluid flow is characterized by both fluid movement and the capacity of an organism to sustain fitness in that environment. In streams the fluid is water and movement is related to both downstream velocity and the range of three-dimensional velocity vectors associated with water flow in the channel. Thus the definition of simple hydraulic characteristics such as mean velocity in the downstream direction in inadequate characterize the full range of fluid movement in a FHU. Complex hydraulic characteristics such as turbulence, acceleration, and deceleration need to be considered. The movement of the organism in the fluid medium is also an important consideration. In the moving fluid, even maintaining position requires energy where an energy budget is determined by a number of factors associated with the environment and the organism (Statzner et al, 1988). In assessing a FHU, hydraulic conditions are important to metabolism, feeding, and behavior of aquatic organisms.\
- Hydraulic conditions are the result of the force of flow, planform of the channel, and substrate and bed forms. Hydraulic conditions are sensitive to changes of both flow and the shape and size of substrate materials. Habitat delineation from hydraulic perspective should first differentiate major geomorphologic forms, for example riffles and pools, where riffles usually have supercritical flow with turbulent surface and pools usually have subcritical flow with smooth surface. Next habitat within each of these major forms can be defined in greater detail, for example it is possible to differentiate riffles with standing wave and broken wave, and it is possible to characterize different hydraulic conditions associated with different parts of a single hydraulic form (e.g. depth and velocity changes after an obstruction).
- It is common where defined technologies do not exist to achieve a specified performance that management will depend on practices that have a proven value although performance may be variable or poorly defined. Choosing the best of these practices has resulted in the identification of Best Management Practices (BMPs) available to address management needs.
- It is possible to develop hydraulic conditions that are stage specific. We will term the creation of desired hydraulics as a Best Management Practice (BMP) for aquatic ecosystem enhancement. The objective of FHU BMPs is in enhancing in stream habitat conditions and associated ecological performance of the fish community. Many in stream BMPs are implemented with the goal of

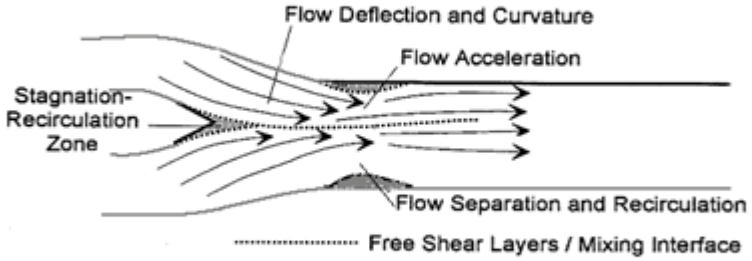
enhancing habitat by creating specific habitat conditions. Past work by the PLs on habitat enhancement in the Chicago metro area suggests that the availability of habitat diversity is dependent on hydraulic conditions and the habitat defined on the basis of hydraulics does enhance fish community characteristics locally. Hydraulic aspects of habitat have a marked influence on fish-community quality, even in the face of other factors that can affect habitat quality, such as large ranges of variation in water temperature, turbidity, and chemical water quality. Thus far, however, there have been no systematic attempts to characterize hydraulic conditions associated with specific BMPs. There is only limited evidence to relate fish community diversity to channel hydraulics. Moreover, most attempts to characterize habitat hydraulics by ecologists are based on fairly rudimentary types of hydraulic properties, such as mean depth or mean velocity. As discussed before, these simple hydraulic properties are not enough to explain the physical conditions completely. Work by the PLs indicates that such measurements cannot adequately capture the spatial structure of hydraulic conditions of relevance to fish at the scale of individual BMPs. The capacity of a BMP to generate specific hydraulic conditions such as flow convergence and divergence, flow acceleration and deceleration, flow separation (either horizontally across the stream or vertically within the flow column), transitions from supercritical to subcritical flow, and turbulent wakes or jets are of vital importance to habitat requirements of fish.

The purpose of the research is to develop a reach-scale, hydraulics-based classification of fish habitat that explicitly accommodates the spatial structure of the reach-scale hydraulic environment for specific BMPs and extant stream conditions. A FHU has two components. The first is a characterization of flow related hydraulic features associated with channel structures. The second is suitability of those hydraulic features to an organism - in this research a fish species. In this report we will define the first component and in the future work this characterization will be combined with biota preference based on the autecology information.

The development of FHUs is based on flow hydraulics. The delineation of habitat will occur as smaller scale FHUs are consolidated into a reach habitat characterization where the reach habitat units would be on meso- to micro-habitat scale considering the scale and movement of fishes. The characterization of an FHUs and reach hydraulic habitat units is based on visible hydraulic characteristics (termed surface signatures of hydraulic conditions), known relationships of flow and obstructions, and expert opinion. The classification scheme will focus on the spatial structure of hydraulic conditions for low-moderate flow stages when spatial complexity of this environment is greatest, and is expected to be robust under different flow stages. By adding an evaluation of flow convergence and divergence, flow acceleration and deceleration, flow separation (either horizontally across the stream or vertically within the flow column), transitions from supercritical to subcritical flow, and turbulent wakes or jets to the traditional measures of habitat (depth, velocity and substrate), it will be possible to more effectively characterize the range of hydraulic habitat elements associated with BMPs and stream structure.

Stream flow is highly three-dimensional thus the definition of the FHUs, although primarily related to downstream flow, will include both the lateral and vertical hydraulic properties of flow and will be based on the surface signature of related hydraulic conditions. In the lateral direction, the flow could be straight, meandering, convergent, divergent, or recirculating. Convergence and divergence of flow are usually associated with acceleration and deceleration of flow and a the presence of micro hydraulic zones such as the stagnation zone, deflection zone, and separation and recirculation zone etc. Figure 1 shows the hydraulic conditions associated with flow convergence. The recirculation provides fish with special transverse flow, velocity gradient, and vorticity, which may be favored by some species for feeding, resting, spawning, and refuge from high flows. And the recirculation is usually produced by implementing BMPs into streams.

Figure 1. Hydraulic zones associated with convergences.



In the vertical direction, Froude number (Fr) is one of the important parameters that can characterize the vertical flow profiles. Froude number could be understood as the ratio between the turbulence force and the gravitational force. When Fr>1, the turbulence force is greater than the gravitational force and the flow is supercritical, which could be reflected by the presence of waves on the water surface; when Fr<1the gravitational force is greater and the flow is subcritical, where the water surface conditions are tranquil. At the transitions from subcritical to supercritical or from supercritical to subcritical flows, hydraulic jumps and hydraulic drops will happen respectively (Figure 2). Thus it is possible by identifying surface signatures to infer specific hydraulic conditions in the water column. The preliminary definition of hydraulic habitat units is listed below in Table 1.

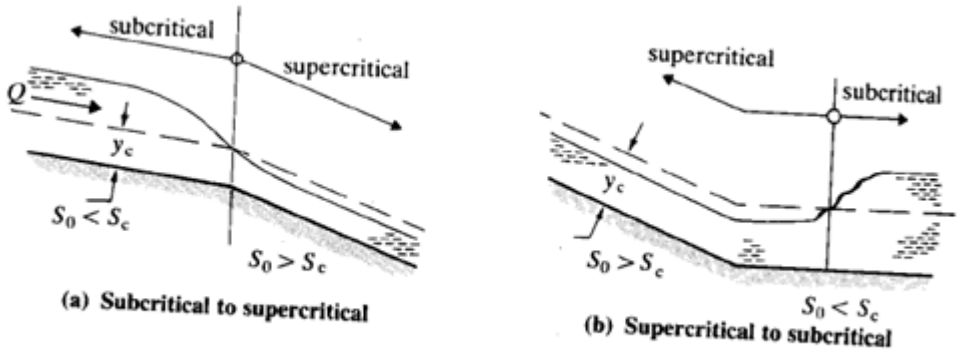


Figure 2. Hydraulic drop & hydraulic jump

Table 1. Preliminary definition of Hydraulic Habitat Units

Lateral flowline	Vertical profile	Water surface	Momentum/ gradient	Hydraulic Habitat Units	Notes
None				**Backwater**	Little or no current; happens before or after obstructs.
Straight/ Meandering	Gradually varied flow	Smooth (subcritical)	Low	**Slow smooth flow**	Subcritical flow; have relatively tranquil water surface; for low and high momentum usually happen in pool/glide and run/raceway respectively.
			High	**Fast smooth flow**	
		Turbulent but unbroken (supercritical)		**Standing wave**	Supercritical flow; turbulent water surface; generally shallower and faster than subcritical flows; usually happen in riffle/rapid.
		Broken (supercritical)		**Breaking wave**	
	Rapidly varied flow	Subcritical to supercritical	Low	**Hydraulic drop**	Hydraulic condition from subcritical to supercritical; depth decrease and flow accelerates; turbulence increases.
			High	**Cascade**	
		Rapidly varied/broken (supercritical to subcritical)		**Hydraulic jump**	Hydraulic condition from supercritical to subcritical; a rapidly varied and broken water surface happen; the flow becomes deeper and slower downstream.
Convergent				**Micro convergence**	Have a micro hydraulic complexity such as the stagnation recirculation zone, scour pool etc. (Figure 1); flow accelerates.
Divergent				**Micro divergence**	Flow decelerates; have corresponding hydraulic complexity.
Recirculate				**Recirculation**	Eddies and transverse flow happen; relatively high vorticity and velocity gradient; happen downstream of obstructs or point bars.

After development of the scheme of the FHSs, the characterization of the diversity, frequency of occurrence, spatial extent, and juxtaposition of these units would be completed in relation to existing channel conditions or specific BMPs and extant in stream geomorphologic conditions. The characterization will be based in part on field observations of hydraulic conditions during low- to moderate-stage flows at a variety of locations in the North Branch and Waukegan watersheds, but will also draw heavily upon results of numerical modeling and analysis of field data derived from published and unpublished studies by the PLs and others, and the input by experts who have completed hydraulic analyses of habitat structures. The spatial extant of the units relative to the fish size and movement would be a critical problem when relating hydraulic habitat units to fishes preference. One proposed approach is to divide the hydraulic habitat units into several size categories according to the scale of fishes, and then characterize the properties such as frequency of occurrence and spatial extent for units in each category.

Mapping FHUs

The research approach for year 1 also includes a mapping component. Specifically, activities have included involve mapping of extant floodplain-channel characteristics along the Waukegan River and the West Fork of the North Branch of the Chicago River as well as mapping of historical changes in these characteristics. The timing of funding has resulted in the implementation of initial mapping activities in the Spring of 2006. Mapping will be performed using recent and historical aerial photographs of the watersheds and will be conducted using ARCGIS 9.0 software. Images will be rectified to a common coordinate system and floodplain and channel conditions will be mapped through visual inspection of the imagery and classification of features into distinct hydraulic-habitat categories derived from geomorphological characterizations. This analysis is focused on the identification of the existing structure of planform-scale features that contribute to habitat diversity for fish within the target watersheds, historical changes in the structure of physical habitat, and the potential for management of floodplain-channel characteristics to enhance physical habitat. Mapping procedures have been developed and will occur during the summer 2005 and will be conducted by Inci Guneralp, a senior PhD student in Geography with considerable expertise in mapping and analysis of channel geomorphology using aerial photography. Some site visits to the watersheds will be conducted to ground truth the mapping and ensure accuracy in categorization of floodplain-channel geomorphological conditions.

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Research Information

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- **Completion Date**:February 28, 2006
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