APPLICATION OF NEW APPROACHES TO INSTREAM FLOW: USE OF TWO-DIMENSIONAL MODELING AND HABITAT-USE GUILDS IN A SOUTHEASTERN STREAM

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Abstract. Recent advances in the field of instream flow were applied to address the site-specific challenges encountered while conducting a study on Swift Creek, North Carolina. A two-dimensional hydraulic model was used to simulate the complex hydraulic features of the stream. A habitat modeling procedure was used to calculate usable aquatic habitat at varying stream flows by relating hydraulic simulations and substrate/cover data to guild-based habitat suitability criteria. Guild-based habitat suitability criteria representing groups of species that utilize similar habitats were developed in consultation with resource agencies to more fully represent the range of habitats important to Swift Creek's diverse fish and macroinvertebrate assemblage. Results of the study will be used to evaluate the effect of alternative aquatic base flow regimes on the biota and instream habitats of Swift Creek.

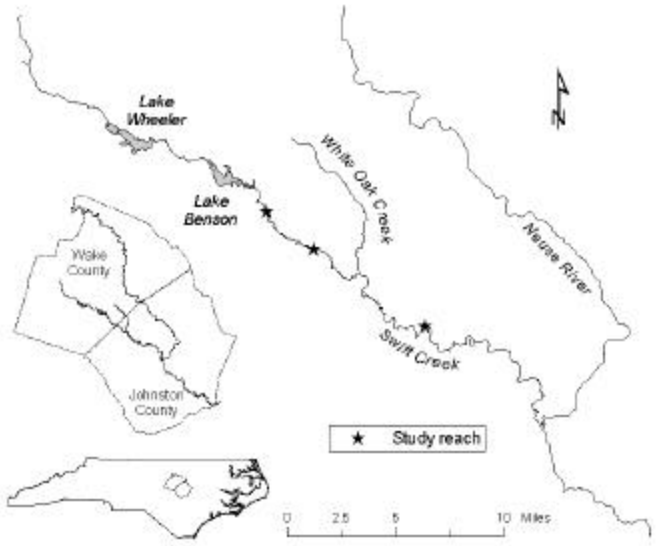

Figure 1. Swift Creek study reach locations in Wake and Johnston Counties, North Carolina.

INTRODUCTION

Increased and competing water demands have placed a strain on stream flow and instream habitats throughout the southeastern United States. In response, regulations governing water withdrawals and diversions have become increasingly stringent. Rather than rely on standard setting methods such as $7Q_{10}$, many regulatory agencies now require completion of a site-specific field study to assess differing flow management alternatives and ensure aquatic resource protection.

A variety of instream flow assessment tools and methodologies are available, each with their own strengths and weaknesses. In selecting an assessment tool, project applicants and resource managers should consider the site-specific constraints associated with individual projects.

Two recent advances in the field of instream flow assessment, two-dimensional modeling and guild-based habitat suitability criteria, were used in the current study to address challenges encountered in Swift Creek, which is characterized by a hydraulically complex stream channel and a diverse fish and mussel fauna. Because these constraints are commonly encountered in streams across the southeastern United States, discussion of the application of these assessment tools should be of interest and value to project applicants and resource managers.

BACKGROUND

The City of Raleigh (City), North Carolina is pursuing reactivation of Lake Benson as a raw water source. Lake Benson is located downstream of Lake Wheeler on Swift Creek, a tributary of the Neuse River (Figure 1). Both reservoirs served as a raw water source for the City from 1953 to 1983. Construction of a new water treatment plant at Lake Benson will increase the reliability of the City's water system and

Table 1. Guild-based habitat suitability criteria evaluated and the species/groups that they were selected to represent

Guild-based criteria	Represented species/group
Shallow, fast, coarse	Spawning cyprinids, adult darters, and some macroinvertebrates, including multiple mussel species
Shallow, fast	Adult cyprinids and darters inhabiting sand bed riffles
Shallow, slow, fine	Spawning centrarchids
Shallow, slow, cover	Cyprinid and catostomid young-of-year
Shallow, slow	Adult cyprinids and the young-of-year of multiple species
Deep, fast, cover	Some adult catostomids and some macroinvertebrates
Deep, fast	Adult catostomids and cyprinids
Deep, slow, cover	Adult centrarchids and other cover-dependent species
Deep, slow	Some adult centrarchids and ictalurids
Deep, stream margin, root mats	Some mussel species including dwarf wedgemussel

provide a net increase in the City's total raw water supply.

The North Carolina 1995 Dam Safety Rules (15A NCAC 2K.0502) stipulate that an instream flow study must be conducted to establish minimum flows below non-power producing dams in streams that support either good aquatic habitat or are designated as special case streams. Special case streams include those streams classified as Outstanding Resource Waters and streams that support either self-sustaining populations of wild trout, exceptional non-game or fishery resources, or populations of aquatic species listed as threatened or endangered by the U.S. Fish and Wildlife Service or the North Carolina Wildlife Resources Commission. Swift Creek meets several of these criteria, including having populations of the federally endangered dwarf wedge mussel (*Alasmidonta heterodon*).

GUILD-BASED HABITAT SUITABILITY CRITERIA

Habitat suitability criteria (HSC) are used to depict the microhabitat requirements of aquatic organisms and are most typically developed for individual species. HSC graphically depict the optimum and usable ranges of depth, velocity, substrate, and cover ranging between 0.0 and 1.0, where 0.0 represents unsuitable conditions and 1.0 represents completely suitable conditions (Figure 2). Selection of appropriate habitat suitability criteria can be problematic in streams with diverse faunal assemblages. Species-specific HSC are often unavailable for many non-game species, and practical considerations place limits on the numbers of HSC that may be assessed in any given study.

Selection of appropriate HSC may be simplified by considering HSC that represent groups, or guilds, of species that utilize similar habitats (Aadland 1993; Bain 1995). Additionally, evaluation of guild-based HSC provides the opportunity to evaluate the effect of stream flow changes on the entire aquatic community, rather than individual target species. Guild-based HSC have been developed or proposed in many studies, and their use is now widely accepted (Aadland 1993; Bain 1995; Leonard and Orth 1988).

Guild-based HSC were used in the current study to more fully represent the range of habitats important to Swift Creek's diverse fish and macroinvertebrate assemblage, which includes over 40 species of fish and eight special status mussel species. To select the HSC used in the study, the life stages of the various species inhabiting the stream were first assigned to habitat-use guilds based on life history and habitat preference data identified in the literature and input from resource managers familiar with Swift Creek's biota (Table 1). Next, species-specific HSC developed in other studies and guild-based HSC available in the literature (Aadland 1993; Bain 1995) were collected and evaluated. Finally, HSC representing each of the various habitat-use guilds identified in Swift Creek were developed by modifying existing HSC in

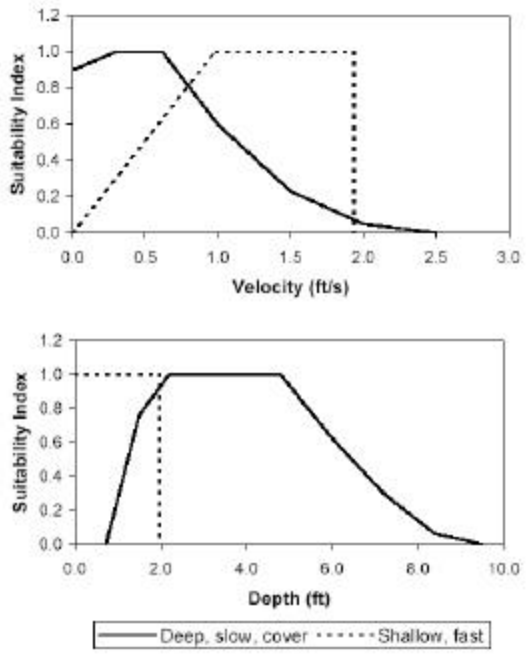

Figure 2. Example velocity and depth habitat suitability criteria developed to represent the range of habitats preferred by two differing habitat-use guilds in Swift Creek, North Carolina.

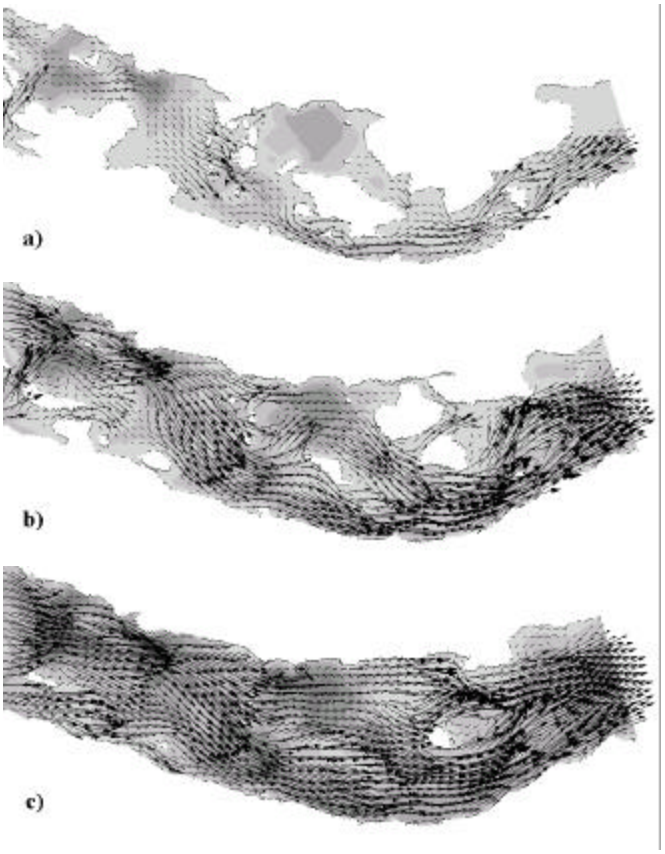

Figure 3. Water depth and velocity vectors predicted by the two-dimensional model at stream flows of 2.5 (a), 10 (b), and 40 ft^3/sec (c). Relative magnitude of velocities are indicated by arrow size.

consultation with participating resource agencies to better describe the range of habitats utilized in Swift Creek. Sufficient numbers of existing HSC were evaluated to be confident that the HSC developed during the study adequately described the habitat requirements of the various guilds that were identified.

TWO-DIMENSIONAL HYDRAULIC MODELING

The traditional, transect-based, one-dimensional hydraulic models of the Physical Habitat Simulation System (PHABSIM; Milhous et al. 1989) provide poor simulations of diverging and converging flow, eddies, intermittent backwaters, and split flows around islands (Waddle et al. 2000). Two-dimensional hydraulic models provide superior resolution of these types of hydraulically complex features and thereby provide a better prediction of instream habitat conditions in complex channels (Leclerc et al. 1995; Waddle et al. 2000).

Because Swift Creek contains complex flow fields such as eddies, split channels, transverse flow, and secondary channels around islands, a two-dimensional hydraulic model was used to simulate hydraulic conditions. The two-dimensional hydraulic model (STAGR) used in the Swift Creek study is a finite volume model developed by Jonathan Nelson, U.S. Geological Survey, and further refined at Utah State University. The two major elements of the hydraulic simulation model are the prediction of water surface elevations and mean column velocities and vectors for the entire habitat reach over a range of flows of interest (Figure 3).

TWO-DIMENSIONAL HABITAT MODELING

Hydraulic simulation results were converted into a measure of habitat for each habitat-use guild evaluated in the study using WINHAB2D, a two-dimensional habitat model developed at Utah State University that parallels the application of PHABSIM modeling. The habitat modeling procedure consisted of combining the hydraulic simulation results with substrate and cover data collected in the field and predicting habitat values for each habitat-use guild, based on their HSC.

The output of the two-dimensional habitat model describes the relationship between stream flow and habitat availability for the habitat-use guild of interest in terms of weighted usable area, which is the wetted area of a stream weighted by its suitability. The model can be used to create flow versus weighted usable area curves (Figure 4), which are also produced by traditional PHABSIM modeling approaches. However, the major advance of two-dimensional habitat modeling over traditional PHABSIM output is the ability to

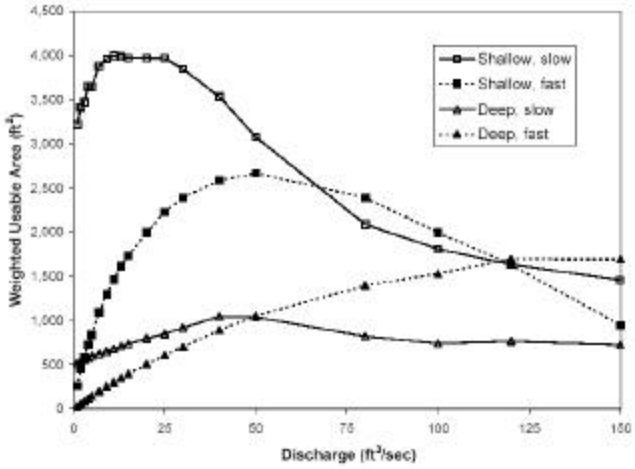

Figure 4. Example weighted usable area versus flow relationships developed for four of the habitat-use guilds evaluated in the study.

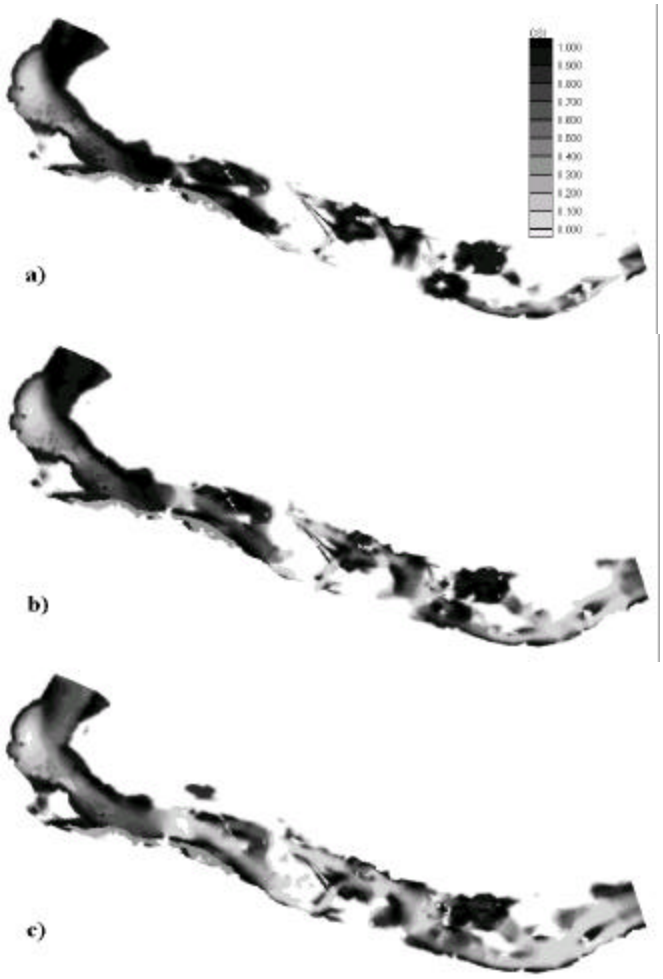

Figure 5. Spatial shift and relative quality (indicated by scale) of shallow, slow, fine habitats at stream flows of 5 (a), 11 (b), and 20 ft^3/sec (c).

produce graphic representations of the relative quality and spatial distribution of suitable habitats at varying stream flows (Figure 5).

DISCUSSION

Data generated during the current study are still being assessed at this time. However, it is clear that the technological advances used in this study, two-dimensional modeling and guild-based HSC, have resulted in a more accurate and robust representation of the relationship between stream flow and instream habitats than would otherwise have been possible. Two-dimensional hydraulic models enable simulation of hydraulically complex habitats that traditional, one-dimensional models are unable to adequately describe. Two-dimensional habitat models provide increased comprehension of the relationship between stream flow and instream habitat by allowing visualization of the quality and spatial distribution of those habitats (Figure 5). This tool will prove useful in assessing the effects of changing stream flow on critical habitats. Guild-based HSC afford the opportunity to represent the habitat requirements of diverse faunal assemblages, thereby providing a more robust, community based assessment of alternative stream flows, rather than one based on a few target species of interest.

It is likely that other instream flow studies conducted in streams in the southeastern United States will face site-specific constraints similar to those encountered in Swift Creek, complex hydraulic habitats and a diverse fish and macroinvertebrate assemblage. These studies should also benefit from the application of two-dimensional modeling and guild-based habitat suitability criteria.

ACKNOWLEDGEMENTS

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