

A GIS Tool for Fish Habitat Modeling

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An ArcGIS fish habitat modeling tool is developed to model the extent of fish habitat under different flow conditions. The study of the impact of change in flow on availability of fish habitat in river channels involves biological sampling, river surveying and hydraulic modeling. Biological sampling seeks to associate fish species with the hydraulic habitat they utilize and the habitat conditions are defined in terms of depth and velocity. The velocity and water depth for different flow rates are obtained by using a two-dimensional hydraulic model. The fish habitat modeling tool combines the results of the hydraulic model and the biological sampling statistics to determine the spatial extent of available hydraulic mesohabitat and the available hydraulic habitat for individual fish species at each of a number of different flow rates. The application of the habitat modeling tool is demonstrated by applying it to a short reach of the lower Brazos River in Texas.

Introduction

Instream flow is defined as the flow regime necessary to maintain an ecologically sound environment in river channels and riparian areas. Maintaining an ecologically sound environment includes maintenance of the diversity and productivity of aquatic species. In 2001, the 77th session of the Texas Legislature passed Senate Bill 2, which established the Instream Flow Program for Texas Rivers. Senate Bill 2 directed the Texas Water Development Board (TWDB), the Texas Parks and Wildlife Department (TPWD) and the Texas Commission on Environmental Quality (TCEQ) to perform engineering and scientific studies to determine suitable flow conditions for maintaining an ecologically sound environment for Texas Rivers, while also allowing for water use by municipal, industrial, agricultural, navigational and recreational users (Texas Instream Flow Studies, 2002).

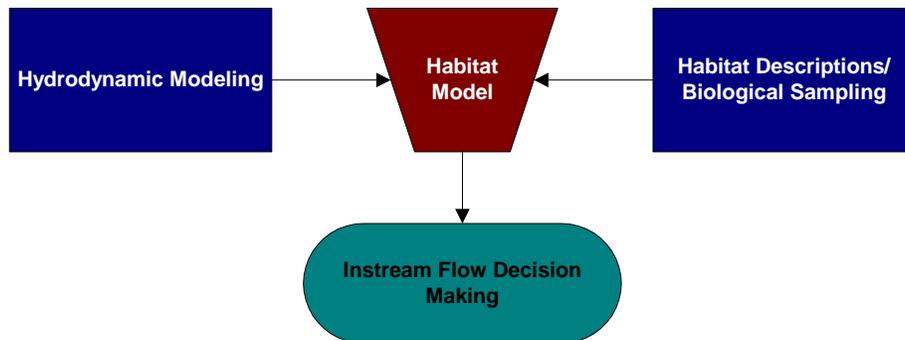


Figure 1: Instream flow studies components

Three components of a typical instream flow study considered when making a flow regime recommendation are the habitat descriptions and biological sampling, hydraulic modeling, and habitat modeling (Figure 1). The first component, habitat descriptions and biological sampling, includes identifying different types of aquatic habitat and fish species, and the conditions under which they live. These conditions include substrate type, water depth and velocity, temperature, etc. The hydraulic modeling component includes modeling of spatial and temporal variations in depth and velocity currents for different flow conditions. A habitat model combines the results of the hydraulic model and biological sampling to determine the spatial extent of the habitat for different fish species under varying flow conditions. The objective of this paper is to describe the development of a GIS tool for the habitat-modeling component of instream flow studies. The application of the GIS tool is demonstrated by using a small reach of the Brazos River in Texas as an example. The GIS tool described in this paper is an improvement over the previous work done by Austin and Wentzel (2001).

Study Area

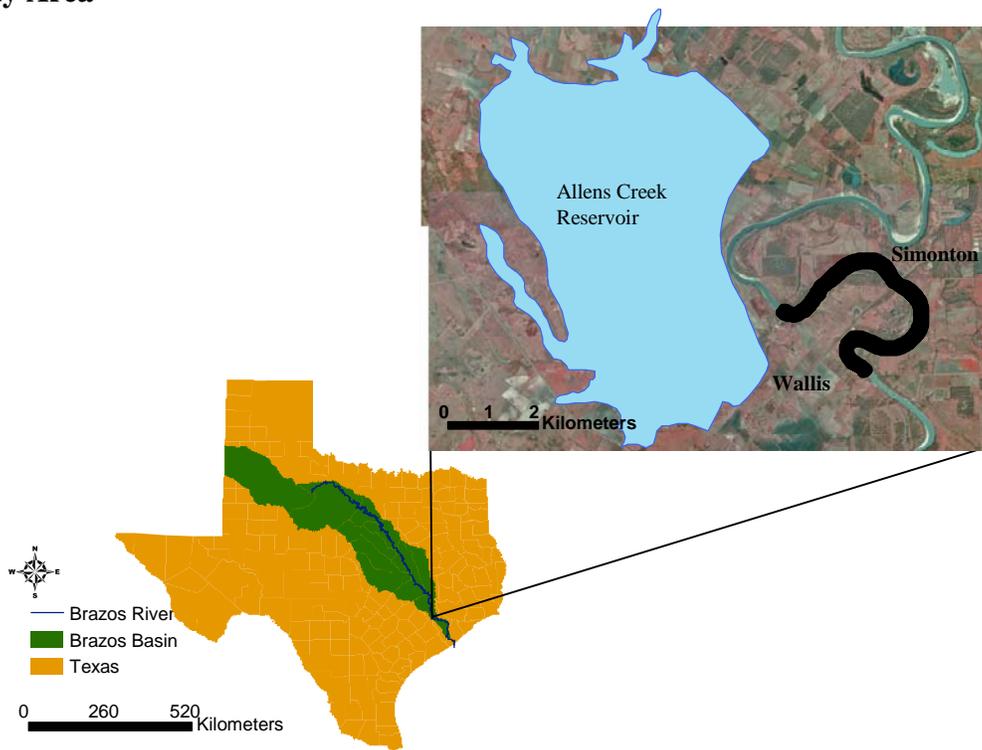


Figure 2: Study area (Brazos River in Texas)

The study area is a 6.9 km reach of Brazos River located just downstream of the proposed Allens Creek Reservoir (Figure 2), an off channel project located due NE of the town of Wallis, TX on FM 1093, near the town of Simonton, TX. The Brazos River in the vicinity of study area is about 100m wide, and is deeply incised with frequent meander bends and an abundance of riparian habitat. In one section of the study area, riparian habitat has been altered by placement of rock and concrete rip-rap for bank stabilization.

Biological Data Collection

Biological data, specifically fish habitat utilization data, for the study area were collected by the Texas A&M university (Gelwick and Li, 2002) using seines, gillnets, and a boat-mounted electrofisher. Based upon velocity currents, water depth, river morphology, presence of large woody debris, and substrate type, eleven mesohabitat sites were identified: five runs, four pools, one riffle, and a tributary confluence. At each mesohabitat site, fish-habitat samplings were performed to cover a range of different flows: three in the summer season and three in the winter season. In addition, at each sampling site, depth, velocity, dissolved oxygen, conductivity, and water temperature information was collected.

Based upon a statistical analysis of the biological data collected, mesohabitat criteria are developed as shown in Table 1 (Austin et al. 2003).

Mesohabitat Criteria	Depth (m)		Velocity (m/s)	
	Low	High	Low	High
Backwater	0	1.00	< 0.05	0.05
Shallow Margin	0	1.00	0.05	0.35
Shallow Margin with structure	0	1.00	0.05	0.35
Riffle	0	0.75	0.35	> 0.35
Riffle with structure	0	0.75	0.35	> 0.35
Deep Margin	1.00	> 1	< 0.35	0.35
Deep Margin with structure	1.00	> 1	< 0.35	0.35
Mid-Channel	0.75	> 0.75	0.35	> 0.35
Mid-Channel with structure	0.75	> 0.75	0.35	> 0.35

Table 1: Mesohabitat criteria

In Table 1, a structure means large woody debris (LWD) or any object resulting from anthropogenic actions (for example, a pile of trees). The biological data collected for the study area are not enough to develop individual habitat criteria for all the species that are available in the study area. However, hydraulic habitat utilization data collected for Western Mosquitofish is sufficient to create an example criteria table as shown in Table 2. If sufficient habitat data for individual fish species are collected, a table similar to Table 2 can be developed for all individual species of interest.

Percentile flow	Depth (cm)		Velocity (cm/s)	
	Low	High	Low	High
Winter 50	12.50	23.50	-3.50	18.17
Winter 30	30.83	37.50	-3.50	5.17
Winter 15	30.83	35.83	0.17	5.17
Summer 50	18.83	70.17	-3.17	43.50
Summer 30	35.83	40.83	4.83	9.83
Summer 15	11.50	41.83	-4.83	2.50

Table 2: Habitat criteria for Western Mosquitofish

Hydrologic and Bathymetry Data Collection

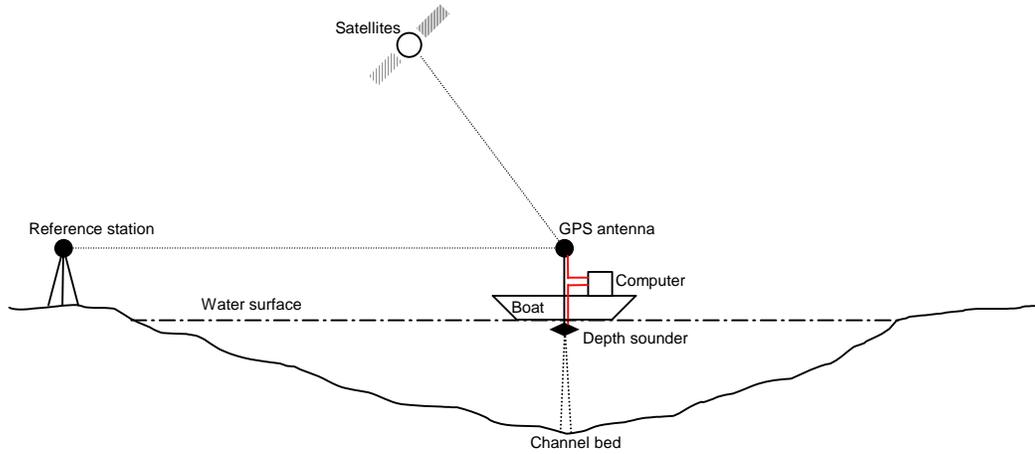


Figure 3: Bathymetry data collection using depth sounder and GPS

Hydrologic and bathymetry data were collected by the Texas Water Development Board (Austin et al., 2003). Hydrologic data include flow measurements and water surface elevations. The bathymetry data were collected using a boat-mounted acoustic depth sounder which was coupled to a GPS unit (Figure 3). The GPS unit was equipped with an antenna capable of receiving Differential GPS (DGPS) corrections. The depth sounder provides the water depth, and the GPS provides the latitude and longitude. The water depth can be subtracted from water surface elevation to get the elevation of the channel bed. Therefore, the whole set-up outputs a set of points with location (x,y) and elevation (z) attributes. Figure 4 shows a sample of the bathymetry data along the study area.

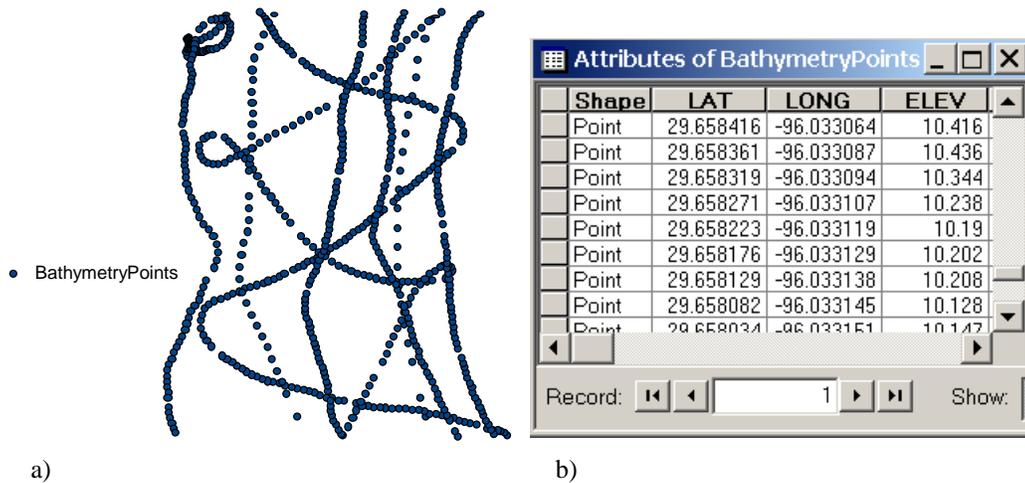


Figure 4: a) Bathymetry data as point features in GIS; b) Attribute table linked to the data

Hydraulic Simulations

RMA-2 (Donnell, 2001), a two-dimensional depth-averaged finite element hydrodynamic model is used to compute the spatial distribution of velocity currents and water depths under different steady-state flow conditions. The surface water modeling system (SMS) interface developed at Brigham Young University is used to execute the RMA-2 model. The SMS interface also provides tools for generating and editing a finite element mesh for RMA-2. The major model inputs to RMA2 are channel bathymetry data, upstream flow rate, and downstream water surface elevation. The model is calibrated by adjusting the eddy viscosity and the roughness as quantified by Manning's n, and is verified by using observed velocity measurements.

GIS Habitat Modeling Tool

The GIS habitat tool uses the hydraulic model output (spatial distribution of depth and velocity) in conjunction with the habitat criteria to determine the spatial extent of fish habitat for a given flow rate. The habitat-modeling tool is developed using Visual Basic and ArcObjects for the ArcGIS 8.x environment.

Input Data

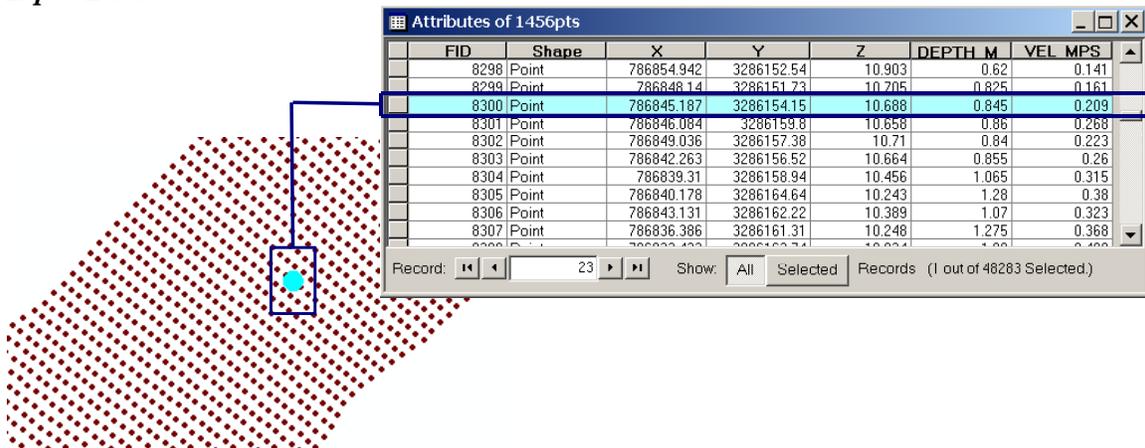


Figure 5: Input GIS data to habitat modeling tool

The input data for the GIS habitat tool include a set of points (point feature layer), the channel boundary (polygon feature layer), and two separate tables specifying the habitat criteria for mesohabitats and microhabitats. The input points are generally the finite element nodes from the hydraulic model with water depth and velocity stored as attributes (Figure 5). The point feature layer can have depth and velocity attributes for a single flow or for different flows stored in different fields. The channel boundary is a polygon feature specifying the extent of the study area. The first habitat table includes mesohabitat types and their habitat criteria described in terms of depth and velocity range as shown in Table 1. The second habitat table includes microhabitat types and their habitat criteria described in terms of depth and velocity. The microhabitat table has to be developed by using the tables similar to Table 2 for different species.

Habitat Tool Application



Figure 6: Habitat modeling toolbar

As shown in Figure 6, the habitat toolbar has two components: raster analysis and habitat modeling. Each component is described separately in the following sections.

Raster Analysis

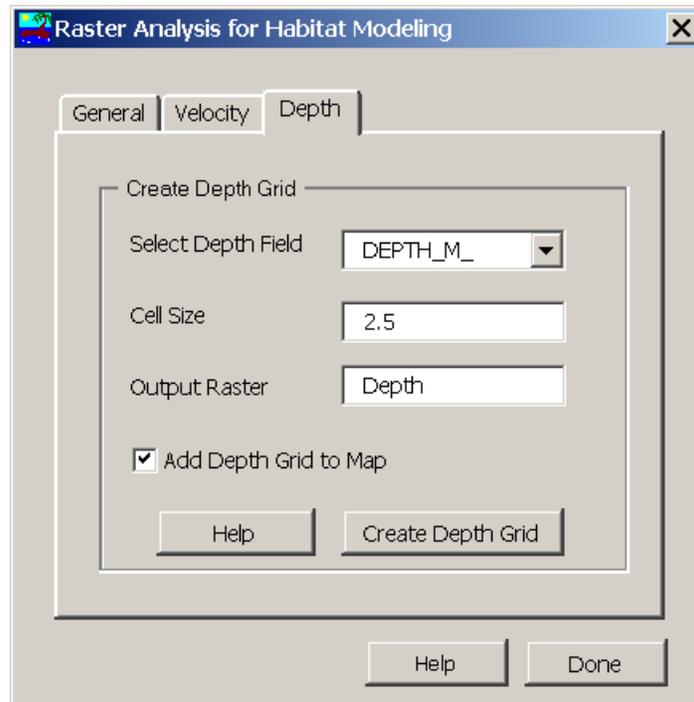


Figure 7: Raster analysis interface for habitat modeling

The raster analysis interface (Figure 7) provides pre-processing of the input data for habitat modeling. The raster analysis component uses the inverse distance weighting interpolation scheme available with the spatial analyst extension in ArcGIS to interpolate the input feature layer to create depth and velocity grids. The extent of spatial

interpolation is defined by the input boundary polygon. Figure 8 shows depth and velocity grids for a small section corresponding to a flow of 41.22 m³/s (1456 cfs).

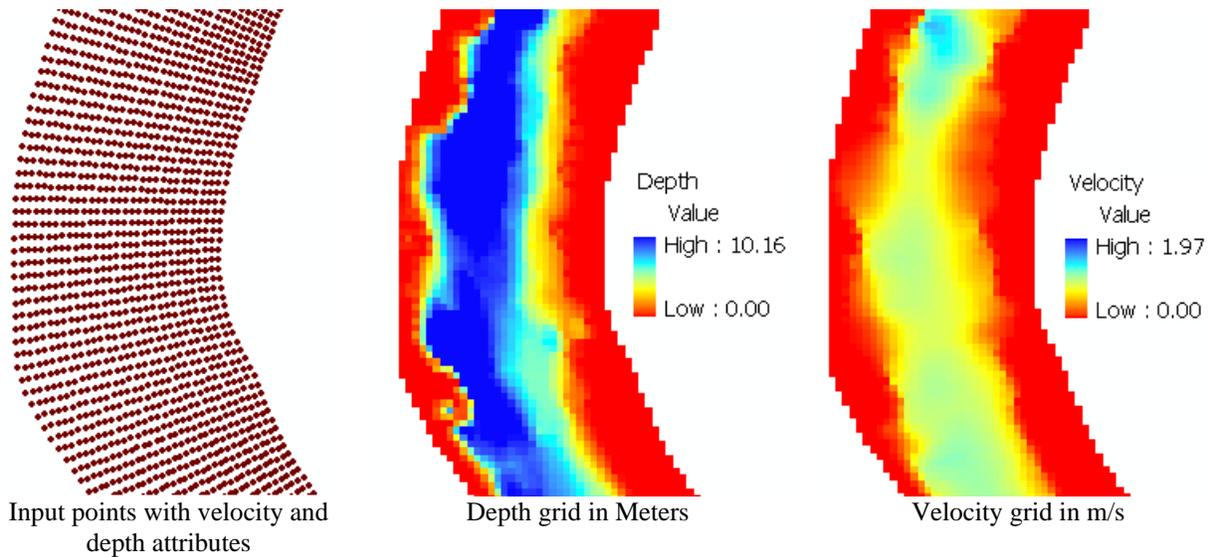


Figure 8: Depth and velocity grids

Habitat Modeling

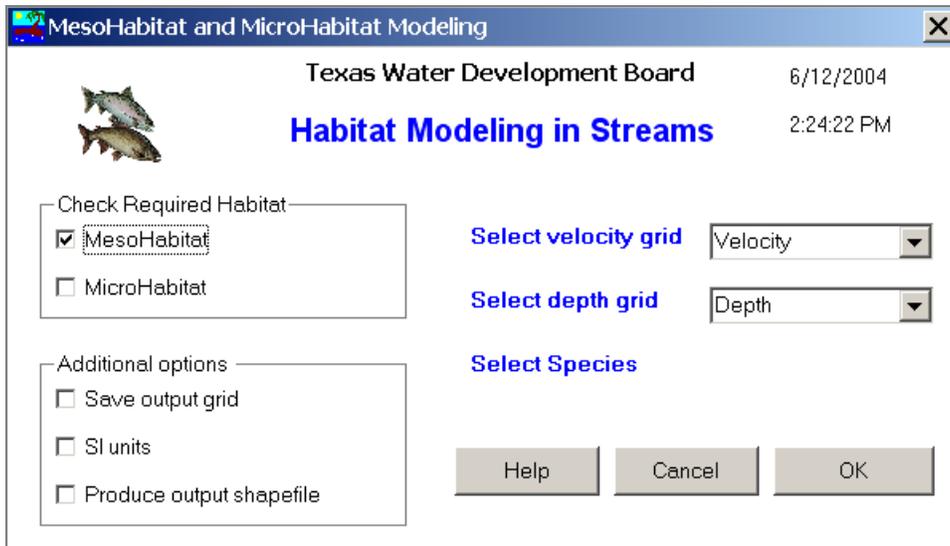


Figure 9: Habitat modeling interface

The habitat modeling interface (Figure 9) uses the velocity and depth grids produced by raster analysis interface in conjunction with the habitat criteria table (Tables 1 and 2) to map the spatial extent of fish habitat. The habitat modeling interface uses the Raster Calculator of the spatial analyst extension through the IRasterModel interface in ArcObjects. The habitat modeling interface can be used to identify both mesohabitats and microhabitats. The default analysis environment is in English units, but an option to use

SI units is also available. The default output format from the habitat model is a raster, but an option to save the output as a shapefile is also available. The shapefile option copies the input mesh points, and for each point saves the output habitat type as an attribute.

Mesohabitat Analysis

For mesohabitat analysis, the mesohabitat option is checked (Figure 9), and the velocity and depth grids are selected. The output is a raster surface with each cell having an integer value corresponding to a particular habitat type. The mesohabitat types in Table 1 are assigned integer values ranging from one for Backwater to ten for mid-channel w/structure. Finally, based on the value of each cell, the raster surface is symbolized to show each habitat type with a different color. Figure 10 shows a sample mesohabitat output corresponding to a flow of 41.22 m³/s (1,456 cfs).

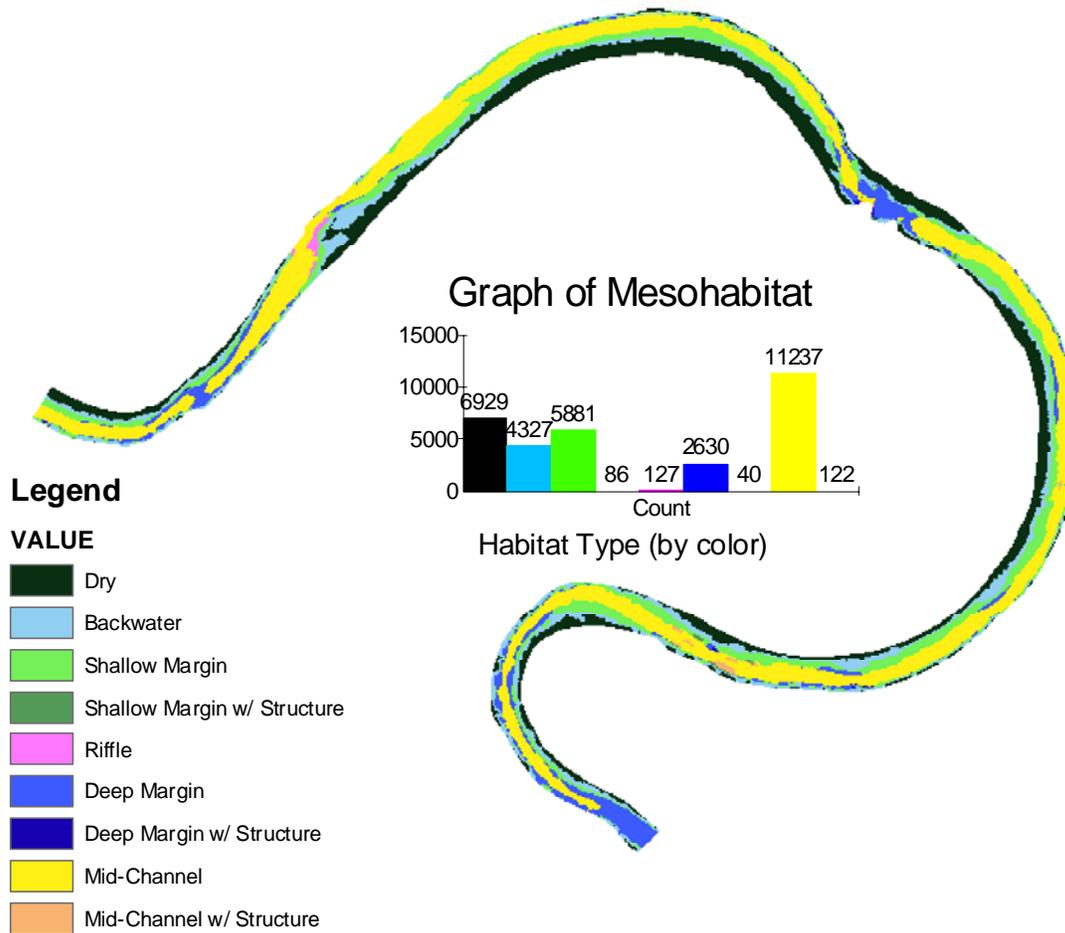


Figure 10: Mesohabitat results for 41.22 m³/s (1,456 cfs)

Microhabitat analysis

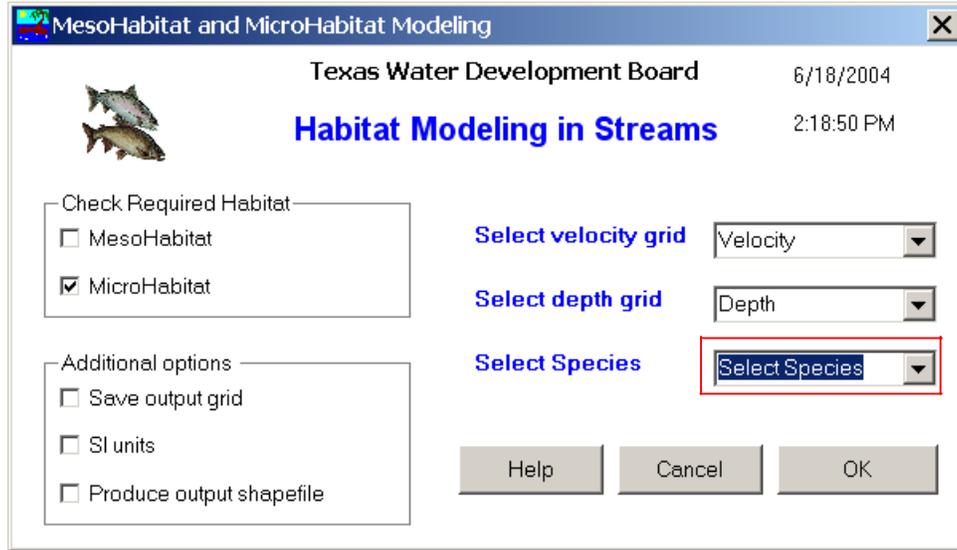


Figure 11: Microhabitat analysis

For microhabitat analysis, the microhabitat option is checked (Figure 11), and the velocity and depth grids are specified. When the microhabitat option is checked, the type of species also has to be specified. This option is not required, and is therefore not available with mesohabitat analysis (Figure 9). Figure 12 shows a microhabitat output (Western Mosquitofish) corresponding to a flow of 116.09 m³/s (4,100 cfs). Only 77,425 m² (10 %) of suitable area is available for the Western Mosquitofish at 116.09 m³/s flow.

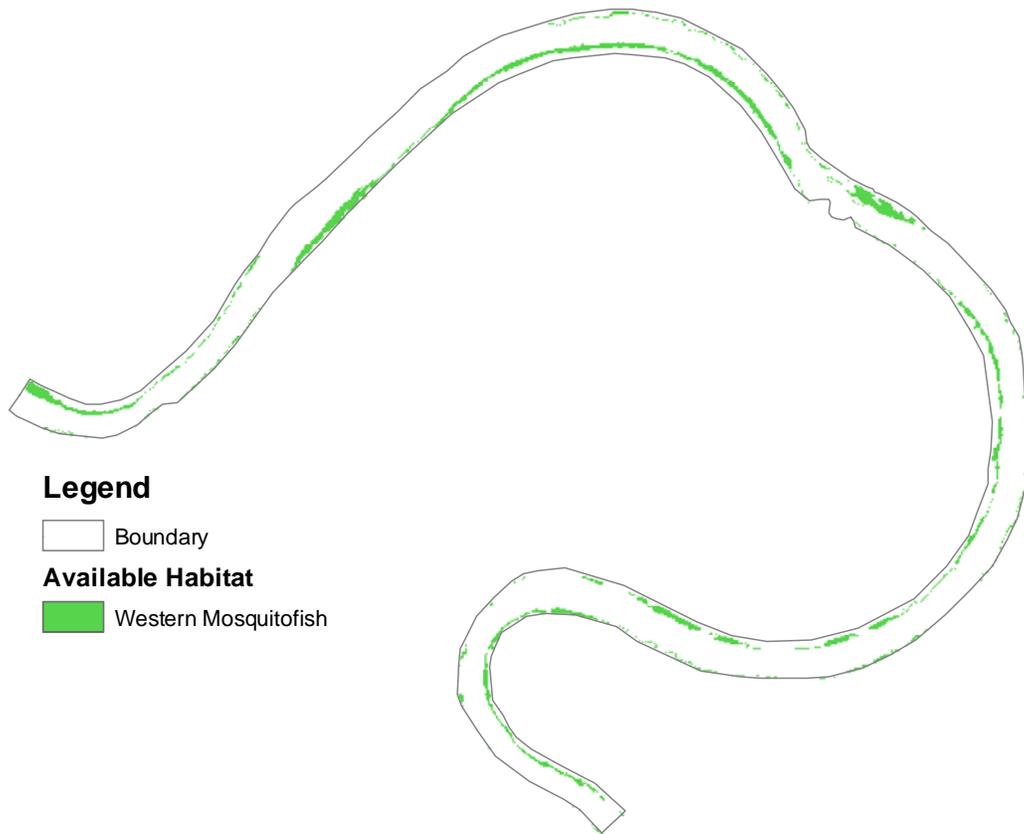


Figure 12: Microhabitat analysis results for the Western Mosquitofish for 116.09 m³/s (4,100 cfs)

The GIS habitat tool can then be used to determine the spatial extent of habitat types for several flow-rates to produce a flow versus habitat area relationship (Figure 13) which can be used for decision-making purposes.

Mesohabitat Area
Absolute Area at each Flow Rate
Brazos River, Site 1 (Total Area = 784,475 sq. m)

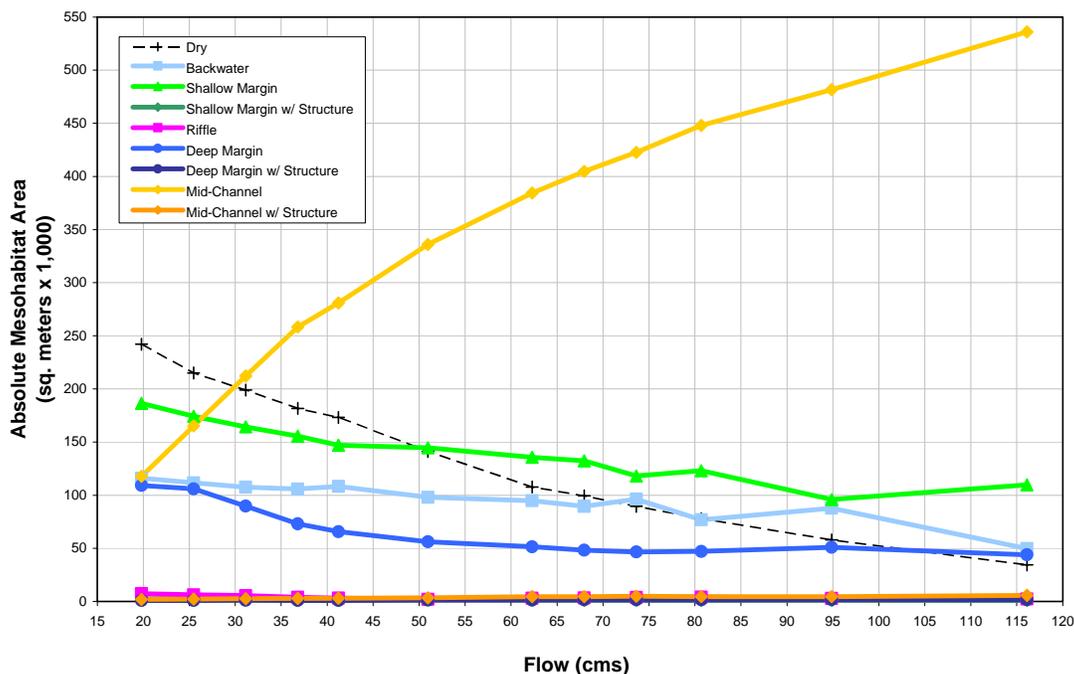


Figure 13: Habitat area versus flow

Summary

A GIS habitat modeling tool is developed that uses the velocity and depth grid in conjunction with habitat criteria to determine the spatial extent of habitat for the different fish species at each of a number of different flow rates. Although the tool is developed for instream flow studies in Texas, it can be used in other areas that use the velocity and depth criteria for fish habitat modeling.

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< <http://www.twdb.state.tx.us/InstreamFlows/index.html>>

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