TWO-DIMENSIONAL HYDROLOGIC MODELING TO EVALUATE AQUATIC HABITAT CONDITIONS

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Abstract: We describe the modeling and mapping procedures used to examine aquatic habitat conditions and habitat suitability of a small river in north-central West Virginia where fish survival and reproduction in specific reaches are poor. The study includes: (1) surveying cross sections of streambed reaches and measuring discharges and corresponding water-surface elevations, and (2) GIS-based mapping of the streambed and hydrologic modeling of water-surface elevations under different discharges based on field data. Using flow duration curves developed from historic data, we develop maps of water depths associated with different flow durations. Cooperating biologists will use these results to examine habitat connectivity under various flow conditions and to develop correlations between water depth in different habitats with physical and biological parameters such as temperature, dissolved oxygen, and periphyton populations. The results will be applied to other reaches in the river where fish survival and reproduction also are poor.

INTRODUCTION

Stony River in north-central West Virginia begins just inside the Grant County line east of Cabin Mountain and north of Dolly Sods Wilderness. Approximately 10 miles downstream from its headwaters, the stream is dammed to provide a cooling source for Dominion Power Company's Mount Storm Power Plant. The dam is a run of the river dam, that is, releases are not controlled mechanically and outflow approximates inflow so long as the lake level behind the dam is at least as high as the spillway. Most of the river's length downstream of the dam supports some fish species, but some reaches do not support reproducing fisheries. Researchers from several universities and agencies are cooperating with Dominion Power to determine why there are no fish in these reaches.

Our work with this project entails examining physical conditions that might be contributing to the lack of fish and determining whether these factors influence other biologically relevant measurements in these reaches. Specifically, we are focusing on water connectedness during different flow regimes and associated water depths. Even if water connects various parts of the river during a given flow, fish passage might be limited because the water depth is too low for effective passage or because certain hydraulic or physical conditions impede passage during more moderate to high flows. In this paper, we describe the procedures we are using to develop models of stream-water depth and water connectedness.

METHODS

<u>Measurements of Stream Cross Sections:</u> Cross sections were surveyed with a TOPCON® GTS-223 total station (Figure 1). Traditionally, when cross sections are surveyed, multiple points (usually at least 20) are measured along a transect defined by a tape stretched across the channel to ensure a straight transect perpendicular to flow (Harrelson et al. 1994). However, because there usually were only 3 people on each survey crew and the width of the river made it difficult to continually move the tape for subsequent cross sections, we used a tape only for 2 cross sections in each reach. The endpoints of those cross sections were permanently marked with rebar so they later could be used for measuring discharge and water-surface elevations. For all other cross sections, the hydrologist located the approximate position of each and marked an exposed rock within the cross section with a waterproof Paintstik®. The rod man in each crew located the first paint mark in each reach and identified points on the left and right channel banks that were in line with the mark. He then proceeded across the transect, stopping for total station measurements where hydraulically important changes in the streambed slope occurred. All subsequent cross sections were measured the same way.

Figure 1 A total station was used to measure cross sections (left), and stream reach within the study area (right).

To capture the complexity of the riverbed adequately, cross-section transects were located relatively close to one another longitudinally. The average longitudinal distance between adjacent transects was approximately 7.2 ft. Thus, while the cross sections were not entirely parallel to each other, the proximity of adjacent transects coupled with the efficiency of breakpoint surveying assured that the hydraulically important features were captured by the many hundreds (or more) points measured in each reach. In the nearly 200-ft reach used for illustration purposes in this paper, 782 points were surveyed.

To tie the measured points to the ground spatially, at least 3 points on the adjacent floodplain were marked permanently with rebar in each reach. Global positioning system (GPS) measurements were made with a Trimble® GPS Pathfinder® Pro XR receiver directly over the rebars to determine position and elevation. These points also were surveyed with the total station each time cross-section measurements were made so that the elevation of each cross-section point could be corrected to actual elevation.

Measurements of Discharge and Water-Surface Elevation: Measurements of both discharge and water-surface elevation were planned for summer 2005 but streamflows were fairly low throughout the entire summer. Consequently, a wide range of flows were not available so the rating curve has yet to be developed. Thus, for illustration purposes, in this paper we developed a rating curve for the 40+ years of discharge and water surface elevation data from streamflow measurements from a USGS station (01595200, Stony River near Mount Storm, WV) approximately 4 miles downstream from the study reach.

Water-surface elevations will be measured using a total station each time discharge is measured. There will be sufficient discharge measurements to cover a wide range of flows that can be gauged safely. A measurement will be made at a point of relative laminar flow in each of the 2 cross sections used for discharge. The ground level at a rebar installed for GPS measurements also will be surveyed to correct the water-surface elevation from a value relative to the height of the instrument to the actual elevation. Discharge will be measured with a AA-type current meter and 4-ft wading rod across the discharge transects.

GIS and Hydrologic Modeling: A rating curve that describes the relationship between water-surface elevation and discharge was developed with TableCurve®2D software (http://www.systat.com/products/TableCurve2D/) using data from the downstream USGS station (Figure 2). When field measurements of discharge and water-surface elevation are completed, a similar rating curve will be developed for each reach that will replace the single rating curve developed with USGS data. If USGS data are used for the actual rating curve, we recommend that the user request and use the USGS-developed rating curve for the site of interest (if available).

A flow duration curve was developed for the historical average daily USGS data that describes the percentage of time a given flow is equaled or exceeded (Figure 3). Even when actual field measurements are available, this step will be retained. However, because the flow duration curve is for a downstream location, an additional step (described later) will be needed for the final reach analyses.

Next, water depths associated with flow duration values (i.e., the percentage of time that a given flow is equaled or exceeded) of interest were determined using the equation for the flow duration curve. For example, for a flow exceedence value of 95 percent (a very low flow), the equation defining the flow duration curve gives the discharge associated with that value as 7.17 ft^3 s^{-1} (Figure 3, Table 1). Applying that discharge value to the rating curve yields a water depth of 1.95 ft (Figure 2, Table 1). These depth-of-water values above the thalweg, or deepest part of the streambed, were used to calculate water-surface elevations (Table 1).

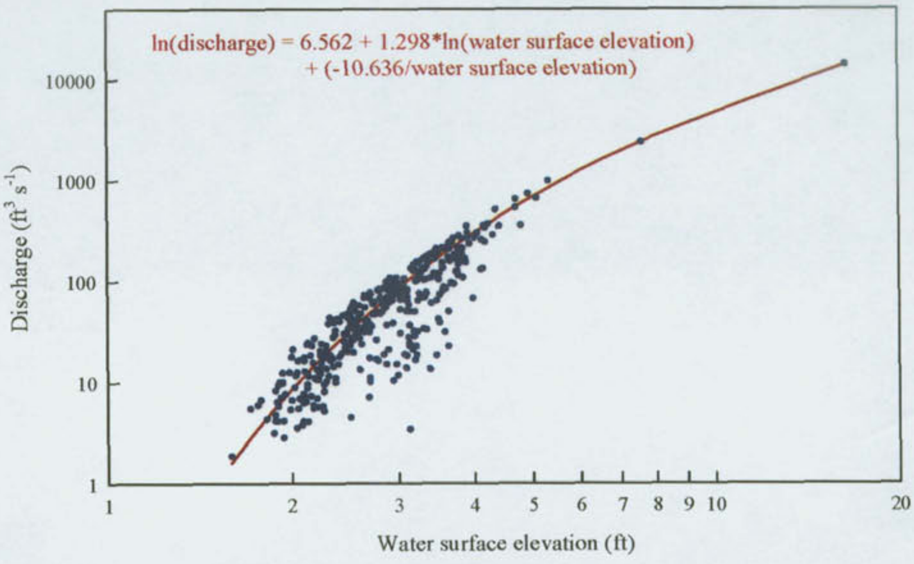

Figure 2 The rating curve developed from USGS data describes the relationship between discharge and water-surface elevation for Stony River.

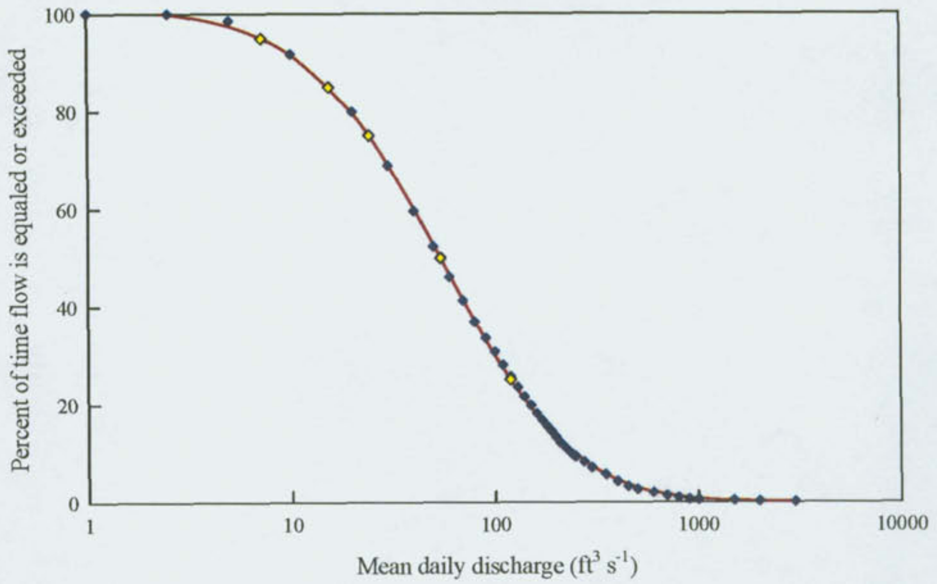

Figure 3 The flow duration curve developed from USGS stream-gauge data for Stony River.

Once all of the mathematical relationships have been developed, this information can be applied to the streambed. First, a triangulated irregular network (TIN) of the reach bottom was developed using ArcGIS™ from the x, y, z coordinates of the total station data (Figure 4). Then a digital elevation model (DEM) of the streambed was interpolated from the TIN into grid format (0.25-m cell size) (Figure 5). Later, water-surface elevations for a range of discharges will be overlaid on this DEM.

Table 1 Discharge, water depth, and actual water-surface elevations for selected flow duration values for Stony River.

% of time flow is equaled or exceeded	Mean daily discharge	Water depth above streambed	Actual water surface elevation
	($ft^3\ s^{-1}$)	(ft)	(ft)
95	7.17	1.95	2848.93
85	15.44	2.19	2849.17
75	24.21	2.37	2849.35
50	54.33	2.74	2849.72
25	119.90	3.23	2950.21

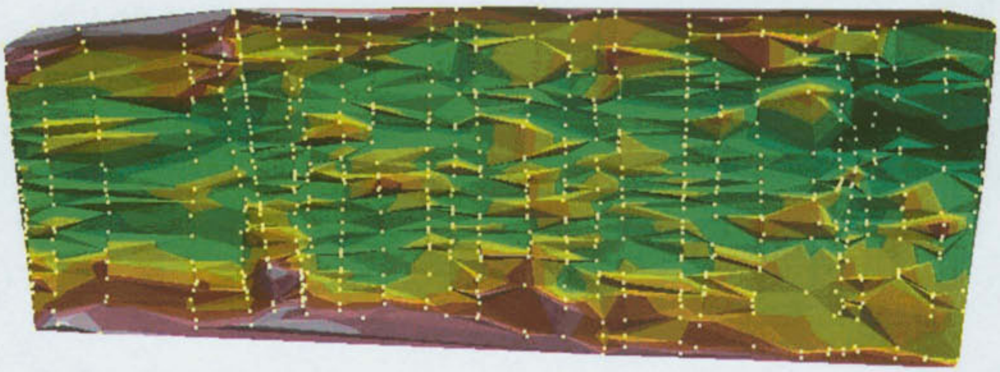

Figure 4 The triangulated irregular network (TIN) developed from the x, y, z coordinates for the surveyed cross-section data for a reach in Stony River. The dots are the surveyed points.

Figure 5 Digital elevation model (DEM) of the streambed that was interpolated from the TIN into grid format.

The HEC-GeoRAS (http://www.hec.usace.army.mil/) extension for ArcView™ was used to extract channel geometry data needed for flow analyses from the streambed grid. Water-surface elevations were calculated for adjacent cross sections throughout the reach using HEC-RAS (http://www.hec.usace.army.mil/) for all of the flow duration values of interest. For this example, we used a wide range of flow duration exceedence values: 95, 85, 75, 50, and 25 percent. The resulting water-surface elevation data were exported from HEC-RAS into ArcView™ using the HEC-GeoRAS extension.

The Spatial Analyst™ extension for ArcView™ was used to calculate a depth-of-water grid for each flow duration value. This was done by building a water surface elevation TIN using HEC-GeoRAS and then converting from TIN to grid format. The 0.25-m cell size was the same as that used for the streambed grid. The streambed grid then was subtracted from the water surface grid. A query was run to define all difference values > 0, i.e., to identify where water was present. Where the difference value was ≤ 0, that cell in the water surface grid was set to null such that the elevation values of the original streambed surface are shown in the resulting maps. Where the difference values were > 0, water depths are depicted. A common legend was developed for depth of water across all flow duration values. Finally, water depths for each flow duration value were overlaid on the streambed grid (Figure 6).

Additional Steps for Reach-Specific Measurements: When the field measured discharge and water-surface elevation data are available, the rating curve for each reach must be linked to the flow duration curve from the USGS gauging station. To do this, a mathematical relationship between the discharge measured for each reach and the corresponding same-time discharge at the USGS gauging station will be developed. Using the previously developed flow duration equation, discharge at the USGS station can be determined for any flow duration value of interest. The corresponding reach discharge can be determined from the newly developed reach vs. USGS discharge relationship. The water-surface elevation corresponding to that discharge then can be determined for the reach using the rating curve developed for that reach. Once these relationships have been developed, modeling and mapping can proceed as described previously. When the GIS modeling is completed, water depths at various locations throughout the reaches will be ground-truthed.

APPLICATIONS

The maps of water connectedness and water depth that will be developed will be used by biologists who are trying to determine why fish do not live in these specific reaches. They will focus on determining whether the physical channel characteristics create: (1) conditions in that generally prohibit fish migration into them, (2) conditions that prohibit migration from the reaches to more habitable conditions during high flows which, consequently, result in their demise during extreme events, or (3) prolonged periods of low flows that result in unconnected habitats. For the latter, measurements of temperature, dissolved oxygen, and periphyton levels (as a deoxygenator) are being collected over time under different flow conditions within a variety of habitats. These will be analyzed in conjunction with the channel and flow characteristics to determine whether periods of limited water depth and connectedness are sufficient to create biologically stressful conditions for fish species found elsewhere in this river.

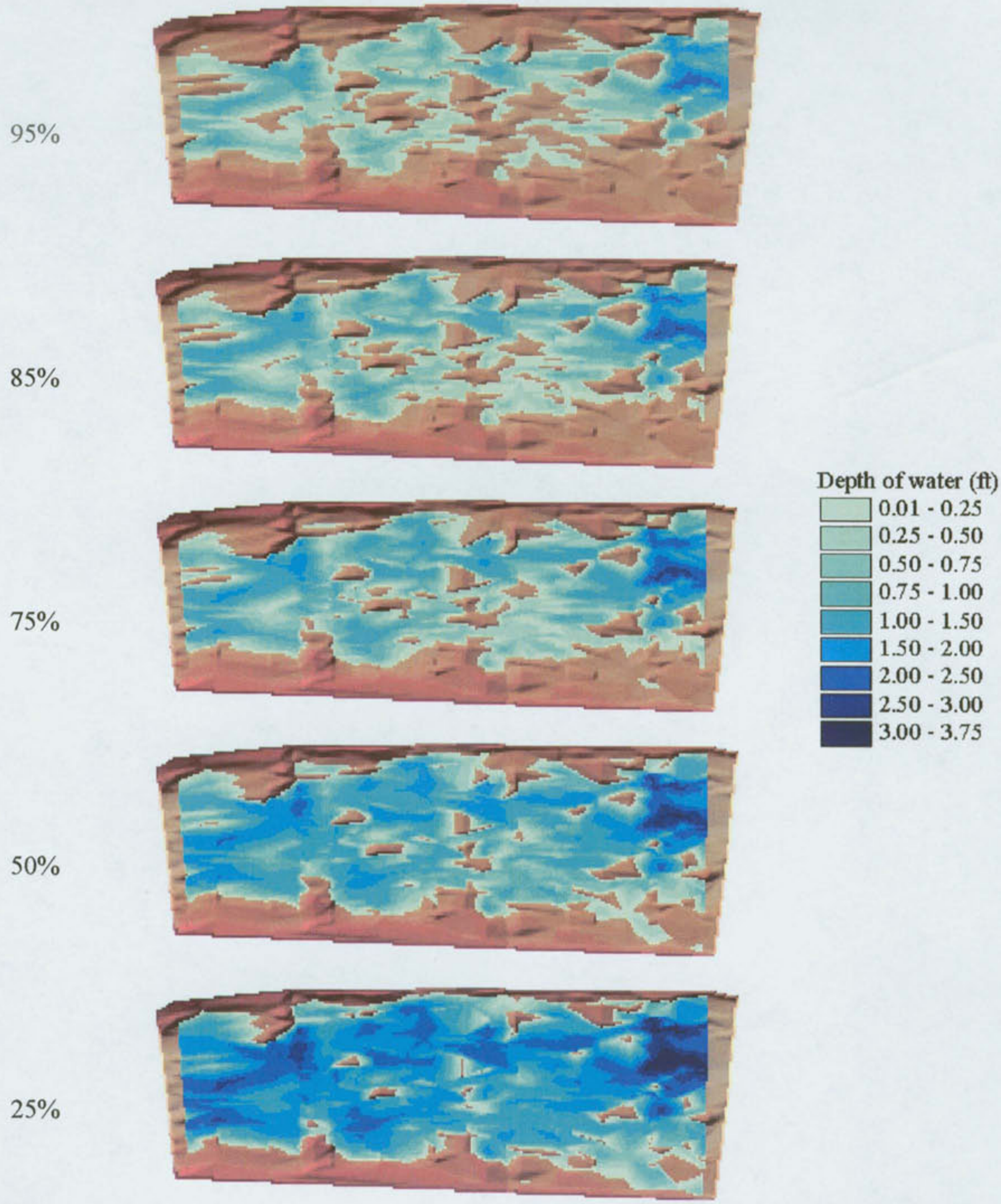

Figure 6 Water connectedness and depths for the different flow duration values given at left.

While we are performing these analyses to identify potential limiting conditions for Stony River, this type of modeling and mapping exercise could be applied to other issues. For example, refugia availability, stresses, and passage limitations could be assessed for threatened, endangered, and sensitive aquatic species; hydraulic characteristics, such as froude numbers, and bed characteristics could be correlated to habitat presence and availability (both volume and area) under different flow regimes; and water exchange could be studied in relation to pool topology.

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Go To Table of Contents