TOWARDS AN AUTOMATED TOOL FOR CHANNEL-NETWORK CHARACTERIZATION, MODELING, AND ASSESSMENT

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Abstract: Detailed characterization of channel networks for hydrologic and geomorphic models has traditionally been a difficult and expensive proposition, and lack of information has thus been a common limitation of modeling efforts. With the advent of datasets derived from high-resolution mapping techniques such as LIDAR (light detection and ranging), however, it is possible to resolve a great deal of information useful for hydrologic and geomorphic modeling. A channel-characterization tool is being developed to automate the extraction and reduction of data from high-resolution digital elevation models (DEMs) to derive meaningful information about channel morphology at a reach scale. The tool, with some initial guidance from users, will automate the process of extracting cross-sections, at user-defined intervals, perpendicular to channels throughout a watershed channel network. In the current version some user interaction is still needed to identify channel banks, but the tool is able to extract channel and flood-plain characteristics for ephemeral stream networks. Channel characteristics derived using the new tool were compared with field measurements and mapping to evaluate performance on the USDA-ARS Walnut Gulch Experimental Watershed in southeastern Arizona. The channel characterization tool was designed to compliment the Automated Geospatial Watershed Assessment (AGWA) tool by facilitating parameterization of the Kinematic Runoff and Erosion model (KINEROS2). It is anticipated that future versions of the tool will incorporate vegetation characterization along riparian corridors. This information will further assist with hydrologic model parameterization, and can also be combined with geomorphic conditions/indicators and output from the hydrologic models to evaluate channel condition and vulnerability on a reach basis.

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INTRODUCTION

GIS-based hydrologic modeling tools have greatly simplified the process of watershed modeling. Using interfaces built within a GIS, or external interfaces with access to GIS functionality, it is now possible to rapidly and inexpensively delineate a watershed and its channel network, subdivide it into model elements, derive necessary model input parameters, run the model, and visualize model output (e.g. Miller et al., 2002; Goodrich et al., 2006). All this can be done using national climate, soil, land-cover, and DEM data products that are available free of charge via the Internet. One significant shortcoming of this approach, however, is that the limited resolution of nationally available DEMs cannot presently support the extraction of any meaningful information about the characteristics of the channels themselves.

Watershed models commonly rely on the simplifying assumption that channel flows can be adequately described by dividing the channel network into a series of connected, trapezoidal reaches, each with a single, average parameter set. Even with this simplification, however, it is still necessary to define an average parameter set for each reach, and obtaining representative values in the field is a difficult, subjective task even when sufficient resources are available to do so throughout an entire channel network. To circumvent this problem, many modeling tools, including AGWA, utilize empirical relations between contributing area and channel characteristics to derive channel parameters in the absence of observed data. These relations, commonly known as hydraulic-geometry relations, vary significantly with climatic and geologic setting and must therefore be established in the region of interest before they can be applied with any confidence. They further represent only an average condition, and as such do not allow for the substantial variability observed in natural channels, even on a reach scale.

High-resolution DEMs created from airborne Light Detection And Ranging (LIDAR) remote-sensing data provide a means of deriving reliable, observation-based information about channel properties. Although these are presently available only in select locations, they are steadily becoming more widely available and it is the authors' opinion that nationwide coverage is inevitable. This paper describes our initial efforts to develop tools and methodologies that will allow us to improve the parameterization of hydrologic and geomorphic models by extracting the information contained within LIDAR DEMs.

LITERATURE REVIEW

Model Sensitivity to Channel Dimensions: Channel beds represent the primary interface between surface and sub-surface hydrologic systems. As such, the accurate representation of channel dimensions within process-based hydrologic models is just as important as substrate material when calculating the exchange between these systems. Accurate simulations of runoff volume are thus predicated on the accurate estimation of channel dimensions. For example, Miller et al. (2004) evaluated the sensitivity of the Kinematic Runoff and Erosion Model (KINEROS2; Smith et al., 1995) to changes in channel width. They found that a 30% change in channel width resulted in a 10-13% change in runoff volume (Table 1).

Erosion, transport, and deposition of sediment within a stream channel are a function of stream power, or the energy associated with a flow at any given point in the channel network. Channel characteristics (width, depth, slope, and the presence or absence of a floodplain) are strongly influenced by the collection of flows, or flow regime, that a watershed experiences over time. For an individual event, however, the channel characteristics are the primary factor governing stream power, and thus determine whether or not a given reach will be aggrading or degrading. Error in the estimation of channel characteristics thus translates directly into error in model predictions of sediment yield (Table 1). Geomorphic studies that seek to determine the short- and long-term fluxes in sediment and evaluate channel stability on a watershed scale will similarly depend on accurate information about the initial conditions (Semmens, 2004).

Peak flows are also strongly influenced by channel geometry (Table 1). Channel width in particular governs the exposure of a flow to frictional resistance from the channel bed, and thus the rate and timing of water movement through a channel network. Regional hydraulic-geometry relations provide average channel dimensions as a function of contributing area, and remove the natural variability of channels at any given location. Using regional hydraulic-geometry relations to parameterize channel dimensions in a watershed model can therefore misrepresent local conditions and interfere with peak-flow calculations.

Table 1. Effects of systematically changing channel width on hydrologic simulations with KINEROS2 (from Miller, 2003). Reported values represent the percent change in model output.

	Multiplier of channel width						
	0.7	**0.8**	**0.9**	**1**	**1.1**	**1.2**	**1.3**
Runoff	12.76	8.41	4.07	0.00	-3.85	-7.31	-10.52
Sediment yield	3.88	2.60	1.30	0.00	-1.30	-2.38	-3.37
Peak Runoff	11.90	8.13	4.12	0.00	-4.12	-8.01	-11.97
Transmission Losses	-10.82	-7.13	-3.46	0.00	3.19	6.06	8.70

LIDAR As a Source of Channel Morphologic Information: Airborne LIDAR remote sensing has become a standard method for the acquisition of high-resolution topographic data. Post-processing of the raw data can remove early returns associated with vegetation and buildings to create 'bare earth' DEMs. Contractor specifications and published evaluations over smooth, homogeneous terrain (e.g. Krabill et al., 1995; Krabill et al., 2000) indicate that ground positions and elevations from LIDAR data have root mean square error (RMSE) of 1-2 m for x, y positions and 15-20 cm for elevations. This level of accuracy, and the relatively low cost per square mile ($500 to $1500) have made LIDAR an attractive option for many federal and state agencies in need of high-resolution topographic data (Bowen and Waltermire, 2002).

The measurement of channel morphology has proved to be a popular application for LIDAR technology. Direct comparisons of field-survey data and LIDAR DEMs have demonstrated that LIDAR is a viable source of channel morphologic information. Bowen and Waltermire (2002) found that when applied to areas with greater topographic relief, such as river corridors, the RMSE for LIDAR elevations declined to 43 cm. This decline in performance is attributed largely to the greater effect of horizontal error when surface slopes are higher (e.g. along channel banks). This effect becomes problematic when attempting to use repeat LIDAR DEMs to determine morphologic change over time (e.g. Canfield et al., 2005). It does not, however, pose a significant problem for defining channel shape because horizontal errors will not systematically interfere with channel width calculations in the many cross-sections along any given reach.

Limitations of LIDAR data for channel morphologic investigations include its inability to see beneath the surface of water in perennial rivers and streams and that post processing to derive the 'bare earth' DEM can be less effective in areas of dense riparian vegetation. For the purposes of watershed-scale modeling, however, these limitations are less significant than for more detailed hydraulic modeling. Even with water obscuring the channel bed it remains possible to determine the most sensitive channel dimensions: slope and width. The impact of riparian vegetation can be minimized by collecting LIDAR data after the leaves have fallen.

METHODS

A semi-automated channel-characterization tool has been developed for use in ArcGIS 9.0 as a support tool for AGWA 2.0 (Goodrich et al., 2006). Originally written as a collection of AMLs, the tool has been rewritten in Visual Basic and is now packaged as a dynamic link library (.dll) file that can be loaded as a custom tool in ArcMap. Once loaded, the Cross-Section Analyzer toolbar is displayed on the screen (Figure 1). The general procedure for using the tool is outlined in Figure 2 and described in more detail below. The tool extracts elevation data at user-defined intervals along transects that are drawn on screen. The data are written to a database table that is added to the map view and can then be displayed in a separate graph window, or VB-enabled "live" chart (Figure 3). The graph window allows the user to click on the data points that the user judges to represent the channel banks, and computes the cross-section width, depth, and area.

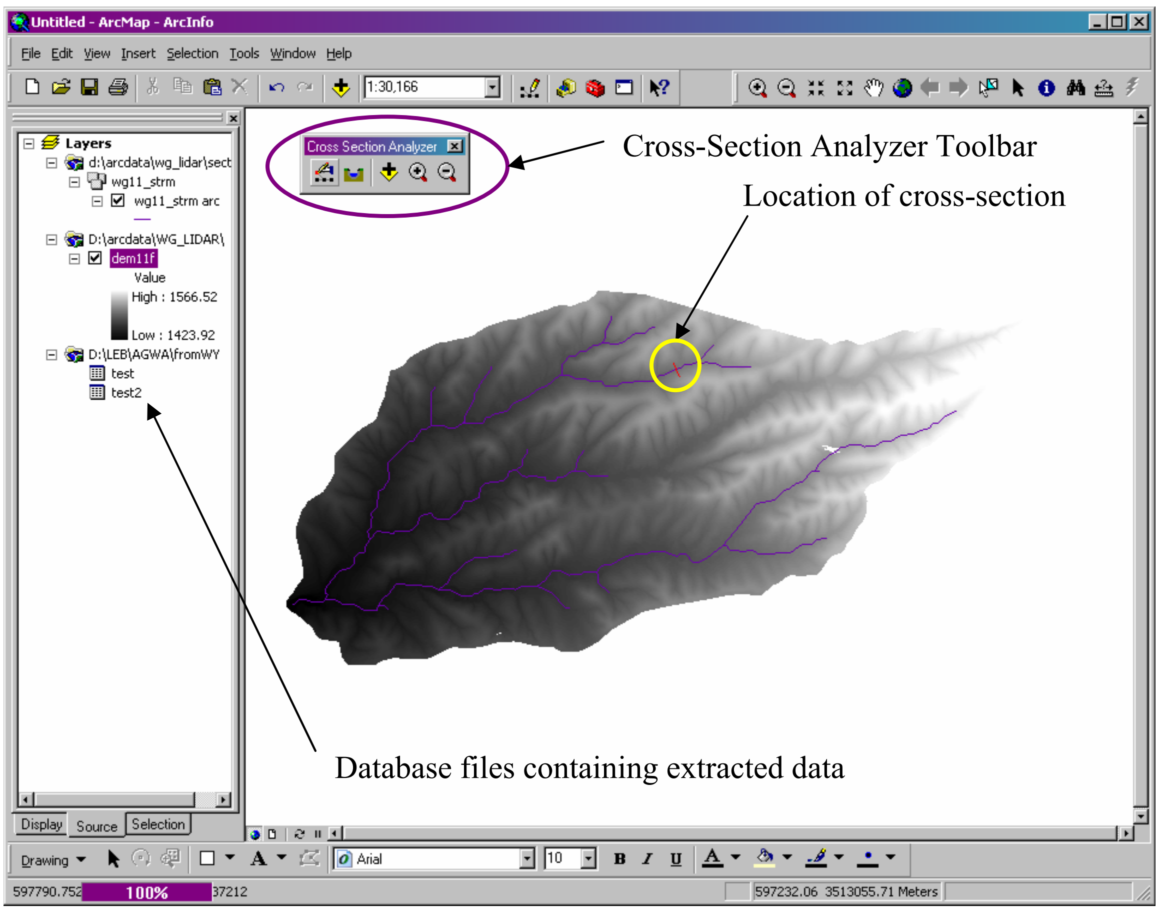

Figure 1. Screen capture showing the Cross-Section Analyzer toolbar, an example cross-section, and how the extracted data is made available to the graphing tool.

Channel width is taken to be the distance between the tops of the two opposite channel banks. Channel depth is then computed by weighting the difference in elevation between each point along the profile and the datum represented by the bank-full elevation. Cross-sectional area is then computed as the product of width and average depth, which is the equivalent to the sum of the rectangular areas below the bank-top elevation at each point along the section.

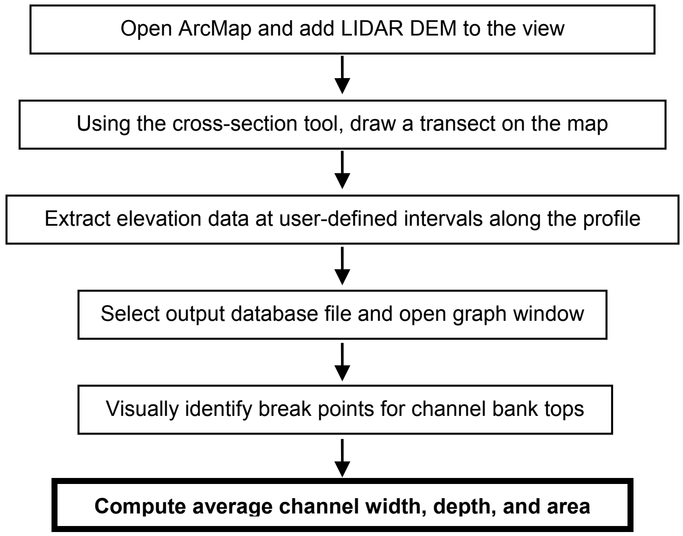

Figure 2. Diagram illustrating the methodology for extracting channel dimensions using the channel-characterization tool.

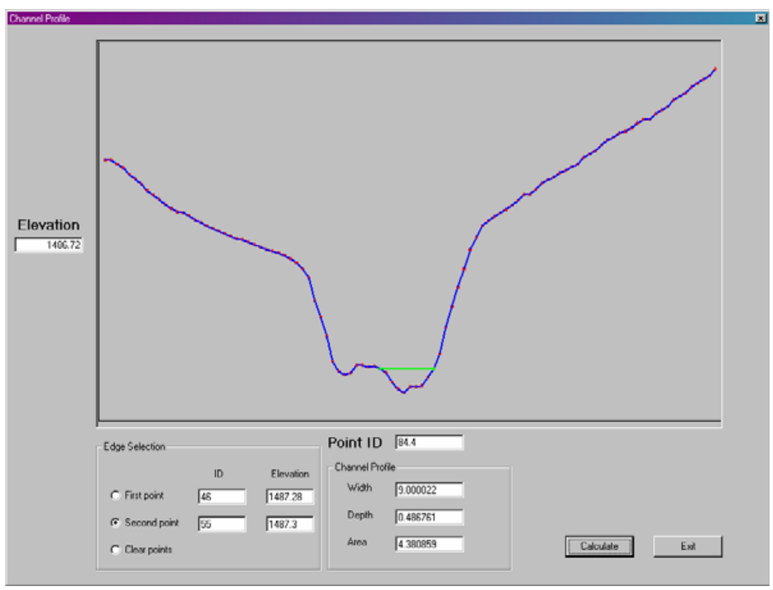

Figure 3. Screen capture of the graph window illustrating how channel banks are identified to permit channel width, depth, and area calculations. Units are inherited from the LIDAR data.

Initial testing of this methodology on the semi-arid USDA-ARS Walnut Gulch Experimental Watershed, Arizona, has produced positive results. Direct comparisons of cross-sections surveyed in the field with a Sokkia total station and those extracted from a 1-meter LIDAR DEM were conducted for ephemeral channels throughout Walnut Gulch. Using an earlier version of the channel characterization tool presented here, Miller et al. (2004) found good agreement between LIDAR and field measurements of channel width, depth, and area. Figure 4 illustrates the relationships and error between the channel dimensions derived from the LIDAR DEM and the field data. An inspection of Figure 4 shows that the LIDAR data are well distributed across the 1:1 line, indicating that there is little, if any, systematic bias in the data. There is slightly greater uncertainty in the estimates of depth, which is consistent with the difficulty in measuring small variations in bed topography.

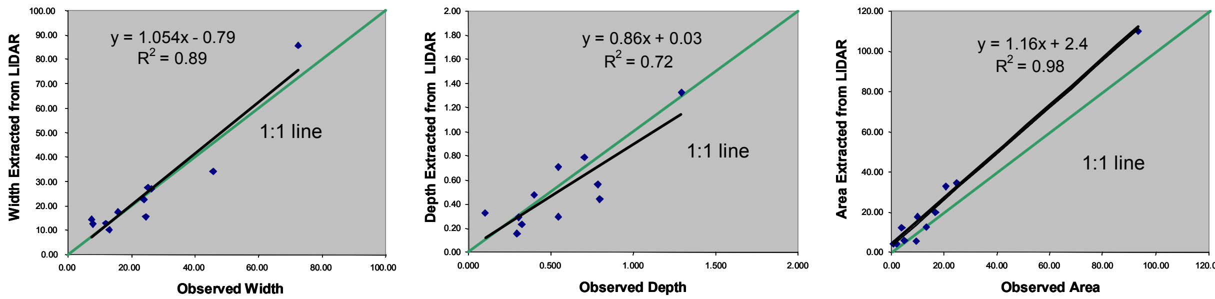

Figure 4. Estimated values for channel width (m), depth (m), and cross-section area (m^2) extracted from LIDAR DEM plotted against values obtained from ground-based total station surveys. Linear regression models are shown on the figures with coefficients of determination.

It should be noted that whether in the field or using a GIS, extracting channel cross-section data is a somewhat subjective exercise, especially in ephemeral streams such as those found in Walnut Gulch. The classic thalweg-bank-floodplain complex found on perennial streams is often absent in a sandy wash. Actively degrading channels may form no definitive bed or bank features to guide the observer in determining the appropriate bankfull depth. Field observations in such environments are relatively challenging, and the researcher must often utilize secondary information such as flood debris, soil properties, or vegetative characteristics. None of these tools is available to the researcher attempting to design a cross-section based on profiles extracted from a DEM. The user must rely on the presence of obvious landscape features; where none exist the prospect of determining an appropriate width or depth is futile. However, in the majority of cases, the channel form was clearly apparent in the graphical representation of the channel profiles. Thus, this approach shows promise for the future development of fully automated GIS-based techniques.

ONGOING RESEARCH AND FUTURE DIRECTIONS

Development of the Channel Characterization Tool is ongoing. Current efforts are focused along three fronts: adding functionality to automatically place and extract cross-sections throughout a watershed channel network or provided reach map; further automating the process of extracting channel dimensions; and calculating reach-average characteristics, metrics, and longitudinal trends. The first two of these are linked through the need to first delineate a watershed and its channel network.

An alpha version of a watershed delineator has been developed that has the capability of creating a watershed pour point at any point along a stream. The tool then delineates the watershed and channel network upstream of the pour point. Watershed characteristics commonly used in predictive geomorphology (e.g. average slope, size, maximum flow length, etc) can then be calculated via standard spatial analyses. We are currently building a VB-based tool to derive suitable multiple-regression equations based on the suite of spatial variables and the estimated channel width, depth, area that come from the analysis tool. The user will thus be able to generate a set of "training" morphologies within the watershed and then have hydraulic-geometry equations automatically generated from their watershed characteristic tool set. These equations can then be used in one of two ways: to parameterize a hydrologic model using equations derived locally, or to guide the automated extraction of channel characteristics at additional sites throughout the watershed.

It is our goal to fully automate the process of extracting channel morphologic information throughout a channel network. We hope to do that in such a way that it is flexible enough to be used by many different modeling and assessment tools, and is capable of being extended as new information and techniques become available. To accommodate these needs we plan to allow the user to specify the length of reaches defined during the delineation process. The process of upscaling or aggregating information from individual cross-sections into reach-averaged values is a critical step in watershed modeling and geomorphic and biological assessments. The flexibility to define reach length based on modeling or assessment objectives will thus enable broad applicability of the tool. Making the tool compatible with an open-source framework for environmental modeling, such as the one being developed through the Interagency Steering Committee on Multimedia Environmental Modeling (http://www.iscmem.org/) will be pursued to maximize its ability to connect with other models and modeling tools.

Another feature we are planning to incorporate is vegetation characterization. In addition to topographic information, LIDAR imagery can be used to obtain information about the height and structure of vegetation along riparian corridors. This information can be processed and reduced in much the same fashion as the topographic data to derive reach-average stream physical habitat characteristics, and to improve hydraulic roughness estimates based on in-channel vegetation. It can also be combined with remotely sensed land-cover information of multiple resolutions to develop indicators useful for a wide variety of monitoring and assessment activities.

CONCLUSIONS

Watershed hydrologic models are sensitive to the characteristics of channels despite their simplistic representation of those characteristics. Field surveys are not a viable means of obtaining channel information at the watershed scale, but airborne LIDAR remote sensing provides a promising source of rapidly and relatively inexpensively obtaining it. The utility and increasing availability of LIDAR data suggest that we can expect it to become more widely available in the future.

A semi-automated channel-characterization tool was developed to extract channel dimensions from LIDAR data for use in hydrologic modeling. The tool was designed to be compatible with the ArcGIS-based AGWA 2.0 (Goodrich et al., 2006), but can be used independently to support a wide variety of modeling and assessment activities. Testing of the tool has demonstrated that it produces results that are comparable with those derived from field surveys. Further automation of the channel-characterization procedure will permit standardized, repeatable measurements of geomorphic and eventually ecological characteristics along stream corridors. The derivation of reach-averaged characteristics from these measurements will ultimately support a wide range of modeling, monitoring, and assessment activities.

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