Executive Summary

Identifying Temporary Headwater Streams and Channel Heads in the North Carolina Piedmont

by

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Headwater streams begin upstream at the channel head and extend downstream to the confluence of second or third order streams. They may exhibit ephemeral, intermittent, or perennial flow regimes and often comprise a disproportionate share of the drainage network. Recent studies estimate that intermittent and ephemeral streams comprise 59% (3,200,000 km) of total stream length in the United States. Dense, dendritic and fractal networks exponentially expand the extent of stream reaches. These vast networks are squeezed into the landscape and thus unsurprisingly have a substantial impact on downstream water quality, biodiversity, water supply, nutrient cycling, and water treatment costs. However, despite the importance and predominance of headwater streams in the landscape, their extent remains poorly mapped and understood.

The National Hydrography Dataset (NHD) is the digitized version of USGS 1:24,000 scale topographic maps, which are typically used to locate streams for a variety of planning and regulatory purposes. Numerous studies have found the NHD to be inadequate for determining the extent of stream networks, with underestimations of 56 percent in North Carolina and up to 300 percent in urban areas reported. Moreover, the Piedmont eco-region is expected to urbanize by 165 percent over the next 50 years. Since these small streams thoroughly perfuse the landscape and serve as the most proximate intersection of the lotic and terrestrial environments, they are especially sensitive to development pressure. Thus any attempt to protect the integrity of the Piedmont's environmental services and water resources will be extraordinarily difficult, and prohibitively costly, if this urban growth cannot be managed to avoid the maximum amount of harm. This study presents a reliable method for locating these streams, including intermittent and ephemeral streams that were recently held to be jurisdictional waters by the EPA.

Fieldwork was undertaken from June to October of 2014 in the Edeburn and Korstian Divisions of the Duke Forest. Drainage lines were walked from the downstream position of perennial flow to the upstream channel head position with a high-resolution satellite Global Positioning System (GPS). Four types of channel segments used to categorize stream reaches: (1) presence of water, (2) channelized, (3) presence of pools & riffles, and (4) well-defined concentrated flow. Dietrich and Dunne's (1993) definition of the channel head, the upstream limit of concentrated flow, was used to classify the four simple types of channel heads recorded in this study: (1) headcuts, (2) spring saps, (3) headwater ponds, & (4) first-order stream heads. Ultimately a total of 117 channel heads and 67 km of streams were mapped in this study. The NHD only displayed 24 km of streams over the same area. This means that the NHD only captured ~35 percent of the actual stream network, a significant underestimation.

GIS analysis was completed to see if a better estimation of the stream network could be achieved. Three flow routing algorithms (D8, D∞, MD∞) and grid resolutions (3-meter, 6-meter, 10-meter) were used for sensitivity analysis (9 combinations total) to test flow accumulation thresholds. Two flow accumulation thresholds were selected: (1) Upslope-accumulated area (UAA) $A = \left(\sum_{i=1}^{\#\, of\, cells} cell_i\right) x\ (Cell\ Area)$, and (2) Slope-area ($A_S$) $A_S = A * S^1$ where S is local slope (m/m). UAA and A_S values were extracted from mapped channel head locations to compute probability density functions (PDFs) and cumulative distribution functions (CDFs). Median UAA values were found to range from 0.075 – 1.122 hectares and median A_S values ranged from 43.98 – 1731.39 (where A is in m^2).

Grid resolution was found to be the dominant control on flow accumulation threshold values with the 3-meter and 10-meter DEM providing the smallest values. Flow algorithm choice only appeared to be pertinent for the coarsest DEM, 10-meter, where the MD∞ algorithm produced half the predicted flow accumulation value of D8. 50^{th} (median) and 75^{th} quantile CDF channel head values were then used to create stream networks for the 3-meter DEM with the MD∞ algorithm, which had the smallest flow accumulation values. These predicted streams were compared to mapped streams and channel heads.

The 75^{th} quantile channel head values provided the best approximation of the stream network, with minimal overprediction. There was a negligible difference between the two flow accumulation threshold methods, although A_S did tend to outperform UAA using the 75^{th} quantile channel head values. Median channel head values produced a stream network with significant overprediction and feathering, particularly for the A_S threshold.

A hypsometric curve was also created for the study site, which determined that it is generally dominated by fluvial erosion, but also influenced diffusive processes. A scaling relationship between local slope (m/m) and UAA (ha) was then created with a slope-area curve. The curve gives every grid cell in the DEM (~7 million) a set of x, y coordinates that can be plotted in two-dimensional coordinate space. The slope of this curve, or “rollover” point, transitions from $\frac{dS}{dA} > 0$ at low contributing areas (positive) to $\frac{dS}{dA} < 0$ at large contributing areas (negative). This transition is associated with a change from diffusive, transport-limited hillslopes to fluvial erosion processes. The curve was fit with a piecewise regression with breakpoints at the median and 75^{th} quantile channel head values. The transition from positive to negative slope in the regression occurred at the median channel head value. The finding that half the channel heads occur before this transition point suggests that groundwater and subsurface water contributions may be significant, as channel initiation begins before critical hillslope length is reached.

The 75^{th} quantile channel head CDF value was found to accurately delineate the extent of the stream network, while minimizing overprediction. This method for stream network prediction greatly enhances the accuracy hydrography of data when compared to the NHD, especially for temporary headwater streams. While field mapping channel heads is time and labor intensive, it can be used to better inform and test predictive methods that can quickly and more accurately determine the extent of the stream network.

Approved

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