INTRODUCTION AND EXECUTIVE SUMMARY

Stream networks of southern Ontario are carved into a complex architecture of glacial landforms and sediments, draining to base-levels of the lower Great Lakes (Huron, Erie, Ontario). These fluvial systems have evolved over relatively short geologic timescales of about ten thousand years, with longitudinal profiles, and boundary materials still strongly conditioned by the glacial landscape. Based on longitudinal profiles derived from the 10 metre provincial digital elevation model (DEM) version 2.0.0 (OMNR, 2008), potential stream power in the study area drain to eleven (11) major river catchments across southern Ontario (Figure 1). Due to multi-scale variance in raw DEM stream gradients from both real and artifact sources, vertical slice and multi-pass moving window approaches are used to generalize channel slope to the reach scale (typically ~1 to 2 km, as a representative spatial scale for fluvial processes operating over long time periods). Results of a slope-area analysis demonstrate that fluvial channels may be oversteepened or under-steepened in association with glacial landform classifications. Specific stream power (w) results generally fall within the theoretical domain for single-channel meandering rivers, with an “average” condition of w ~ 30 W/m.

Despite higher stream powers in some reaches, single-channel meandering fluvial plains still dominate the landscape of southern Ontario due to the moderating effects of 1) bed material sediment calibre from inherited coarse-grained valley fills limiting fluvial bedload transport, and/or 2) bank strength controlled by sediment cohesion and vegetation. Understanding the spatial properties of stream power can provide insights into regional patterns of sediment transport and alluvial floodplain development with application to applied aspects of aquatic ecology, archeology, erosion assessment, stream restoration, and urban storm water management.

1) STUDY AREA AND STREAM POWER

Peninsular southern Ontario is surrounded by the Great Lakes of Huron, Erie, and Ontario, which are perched within a low-relief topography of Paleozoic sedimentary bedrock and Pleistocene glacial sediments. River systems in the study area drain to base-levels of these three lower Great Lakes and have relatively small drainage areas (<50 km²) and steep slopes (10–20%).

The purpose of this study was to map the spatial properties of stream power in southern Ontario, for eleven (11) major watersheds (Figures 1 and 2), within the context of glacier formation and transport (Chapman and Putnam, 1984, 2007). As these fluvial systems are carved into the complex architecture of glacial overburden and have evolved over relatively short timescales of about ten thousand years, it is expected that the longitudinal profiles and boundary materials may still be strongly conditioned by the glacial landscape.

Specific stream power w = power per unit bed area (units of Watts per m²), is a measure of the potential energy available in fluvial systems to perform geomorphic work, namely sediment transport (Bagdoll, 1986; Parker et al. 2011). In practical terms, mapping the spatial distribution of specific stream power only requires models of gross channel properties, such as channel slope (s) and width (w), as well as estimates of discharge (Q) conveyed through the drainage network:

\[ w = s Q / w \]  

Where w is the specific weight of water (978.23 kg m⁻³ s⁻¹ at 20°C).

2) DISCHARGE AND WIDTH REGIME MODELS

Continuous mapping of discharge and channel width along each river profile was derived from 5-digit Regime models predicted by drainage area (A) — calculated from the provincial 10 m digital elevation model (DEM). Discharge (Q) models are based on flood frequency analysis of the annual maximum mean daily discharge for 210 stream flow gauging in southern Ontario (WSC, 2011). Channel width (w) models are based on rapid surveys of bankfull width from ~500 sites. Locations of stream flow gauges and rapid width surveys are presented in Figure 1. Statistical regression of log-transformed data were used to produce power-law regime models of the form:

\[ Q = w A^{a} \]  

where statistical results for southern Ontario yield a = 0.18 and b = 0.91 for flood discharge frequencies of a 1 year return period (Q10); and a = 1.2 and b = 0.5 for bankfull channel width (w). Statistical regression models and data, including 95% confidence and prediction intervals, are plotted in Figure 3. The detailed sub-region results for the model coefficients and exponents are presented in Tables 1 and 2.

3) DEM Channel Slope Extraction

Channel slope (s) was evaluated based on longitudinal profiles derived from Ontario’s provincial 10 m Digital Elevation Model (DEM) version 2.0.0 (OMNR, 2008). Longitudinal profiles of selected major river drainages in southern Ontario were extracted as 3D points from the DEM using GIS, and channel gradient was subsequently generalized as outlined in Figures 4 and 5. The scaling of the vertical slice was based on the reported absolute vertical accuracy of the DEM (2.5 m), and the moving window averaging was intended to represent reach scale patterns in channel slope (1-2 km). The generalized channel slopes were used to calculate and map specific stream power as presented in Figure 1.

REFERENCES AND ACKNOWLEDGEMENTS

From mapping of specific stream power (Figure 1), a sample of 117 reaches were selected and classified based on glacial landforms by Chapman and Putnam (1984, 2007). Results of a slope-area analysis demonstrate that fluvial channels may be over-steepened (e.g. moraines) or under-steepened (e.g. till plains) in association with glacial landform classifications (Figure 4A). Specific stream power (w) results generally fall within the theoretical domain for single-channel meandering rivers (10–60 W/m; Narson and Crake, 1992), with an “average” condition of w ~ 30 W/m. Constant stream power curves for southern Ontario (based on Eq. 1, 2, and 3) plot on a slope-area graph with a slope exponent of 0.4 (Leopold and Wolman, 1957). Despite higher stream powers in some reaches which are often associated with multiple-channel platforms, single-channel meandering fluvial plains still dominate the landscape of southern Ontario due to the moderating effects of bed material sediment calibre and bank strength.

Systematic decreases in bed material size downstream are frequently interrupted by glacial landforms and sediments, in some cases inherited coarse-grained valley fills limiting fluvial bedload transport. Expected downstream variations in grain size for a theoretical “graded” profile have been previously described by Hack (1957), as summarized in Eq. 4 and presented in Figure 6B. Limitations on bedload transport, particularly in cobble-dominated channels, will suppress bar development and thus multiple-channel platforms.

\[ s = 0.006 (MA)^{0.31} \]  

Where M is the median particle size in mm (Hack, 1957). Also, high relative bank strength, controlled by sediment cohesion and vegetation, will limit formation of multiple channels by restricting bank erosion and channel widening. As demonstrated in Figure 6C, many single-channel reaches fall above the multiple-channel anabranching threshold (s*; Eq. 5) for low relative bank strength (s* ≤ 1.0); however, they tend to be consistent with the single-channel meandering domain for higher bank strengths (s* ≥ 2.0) (Eaton et al. 2010).

\[ s* = 0.040 \mu + 1.41 \Omega^* \]  

Where \( \mu \) is the critical threshold slope for multiple-channel anabranching, and \( \Omega^* \) is dimensionless relative bank strength, and \( \Omega^* \) is dimensionless discharge (Q*) versus channel slope. (Eaton et al. 2010).

The spatial properties of stream power can contribute to understanding regional patterns of sediment transport and alluvial floodplain development, with application to many other disciplines.