Environmental Modelling & Software 63 (2015) 240–250

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

An automated, objective and open source tool for stream threshold selection and upstream riparian corridor delineation

Avit Kumar Bhowmik [a], [*], Markus Metz [b], Ralf B. Schäfer [a]

[a] *Quantitative Landscape Ecology, Institute for Environmental Sciences, University of Koblenz-Landau, Fortstraße 7, 76829 Landau in der Pfalz, Germany*
[b] *GIS and Remote Sensing Platform, Biodiversity and Molecular Ecology Department, Research and Innovation Centre – Fondazione Edmund Mach, Via E. Mach 1, 38010 S. Michele all'Adige (TN), Italy*

ARTICLE INFO

Article history:
Received 17 June 2014
Received in revised form
3 October 2014
Accepted 17 October 2014
Available online 7 November 2014

Keywords:
Automation
Algorithm
Stream network
Digital elevation model
Upstream riparian corridor
Stream sampling point

ABSTRACT

The extraction of stream networks from digital elevation models (DEMs) and delineation of upstream riparian corridors (URCs) for stream sampling points (SSPs) are frequently used techniques in freshwater and environmental research. Selection of an accumulation threshold (AT) for stream extraction and delineation of URCs are often done manually. Two algorithms are introduced in this paper that allow for automated AT selection and URC delineation. ATs are selected to yield the highest overlap of DEM-derived and traditionally mapped streams as well as to assure extraction of all mapped streams from DEMs. URCs are delineated after snapping SSPs to DEM-derived streams. The new tool showed similar or better performance than comparable algorithms and is freely available, interfacing the open source software packages R and GRASS GIS. It will improve the extraction of stream networks and the assessment of magnitude and scale of effects from riparian stressors (e.g. landuse) on freshwater ecosystems.

Software and data availability

Name of the algorithm	Automated Accumulation Threshold computation and RIparian Corridor delineation (ATRIC)
Developer	Avit Kumar Bhowmik, Markus Metz and Ralf B. Schäfer
Contact address	Quantitative Landscape Ecology, Institute for Environmental Sciences, University of Koblenz-Landau, Fortstraße 7, 76829 Landau in der Pfalz, Germany
Telephone	+49 6341 280 31331
Fax	+49 6341 280 31326
E-mail	bhowmik@uni-landau.de
Year first available	2013
Hardware required	Please consult http://www.r-project.org/ and http://grass.osgeo.org/
Software required	R and GRASS GIS
Availability and cost	Freely available as a supplementary material
Program language	R
Program size	32 KB
Name of data set	ATRIC_Data
Form of repository	Files
Size of archive	55 MB
Access from	http://doi.pangaea.de/10.1594/PANGAEA.825001

1. Introduction

The increasing availability of high quality digital elevation models (DEMs) has advanced the automatic extraction of stream networks (DeVantier and Feldman, 1993). Extraction of streams from DEMs often achieves higher accuracy, precision and efficiency than mapping by traditional field survey and historical map digitization (Moore et al., 1991; Olivera, 2001). Moreover, DEM-derived stream networks (DSNs) are topologically clean and homogenous. Therefore, they have largely been applied in modeling abundance and distribution of aquatic communities

---

[*] Corresponding author. Tel.: +49 6341 280 31331; fax: +49 6341 280 31326.
E-mail addresses: bhowmik@uni-landau.de (A.K. Bhowmik), markus.metz@fmach.it (M. Metz), schaefer-ralf@uni-landau.de (R.B. Schäfer).

http://dx.doi.org/10.1016/j.envsoft.2014.10.017

(Moore et al., 2000; Narumalani et al., 1997) and geo-computation on physiochemical processes, i.e. carbon flux and greenhouse gas emission in streams (Teodoru et al., 2009). DSNs are also more suitable for the calculation of hillslope travel distances (Ogden et al., 2001) and for the measurement of hydrological proximities (Tesfa et al., 2011) than traditionally mapped stream networks (MSNs).

Extracted DSNs also allow for simple determination of different hydrological features from corresponding DEMs such as flow direction, catchment size, stream density, stream order and stream flow periodicity (Gichamo et al., 2012; Hughes et al., 2011). These features are useful tools in many fields of freshwater research, e.g. cartography, geomorphology, ecology and water resources management. For example, catchment size, drainage density and stream orders provide important information for fluvial geomorphological studies and thus help in deriving hydrograph and sediment production that depict suitability of a region for agriculture and urbanization (Berhane and Walraevens, 2013; Maidment et al., 1996). Water resources management practices can benefit from accurate and homogenous mapping of temporary streams and can eventually contribute to restoring habitats of aquatic communities (Wang et al., 2002). Moreover, stream orders and catchments are useful for flood and non-point source pollution modelling (Di Luzio et al., 2004), assessing economic values of riverine land parcels (Bastian et al., 2002) and planning for construction works (Forman, 2003).

Numerous geographic information system (GIS) tools enable DSN extraction, among them “r.watershed” (Metz et al., 2011) and “r.stream” (Jasiewicz and Metz, 2011) in GRASS GIS (GRASS Development Team, 2014), and “ArcHydro” (Maidment, 2002) and “TauDEM” (Tarboton, 2005) in ArcGIS (ESRI, Redlands, 2001) and QGIS (QGIS Development Team, 2014) are widely applied. These tools extract DSNs by four consecutive steps: i) pit removal, ii) flow direction raster computation, iii) flow accumulation raster computation and iv) extracting streams as cells exceeding an accumulation threshold (AT) (see Tarboton et al. (1991) for terminologies). The first three steps are largely automated (Arge et al., 2003; Danner et al., 2007; Garbrecht and Martz, 1997; Tarboton, 2005), whereas the AT for distinguishing between stream and non-stream cells is often set arbitrarily and then DSNs are manually (visually) compared to MSNs (Tarboton et al., 1991). This manual procedure via trial and error may either result in too many (non-existing) streams (lower AT than optimal) or miss streams or stream stretches (higher AT than optimal) (Montgomery and Foufoula-Georgiou, 1993). In addition, this procedure is laborious.

Values of AT vary according to the scale of studies, i.e. larger scale studies require higher order streams and thus higher AT values and vice versa (Tarboton, 2005). However, the AT selected for a large scale study using a low resolution DEM might also be suitable for a small scale study using a high resolution DEM. A few stream network extraction algorithms using automated AT consider the scale of studies (resolution of DEMs) but do not compare DSNs with MSNs. These algorithms compute ATs by (1) slope-area power links (Montgomery and Foufoula-Georgiou, 1993) and (2) stream drop analysis, i.e. statistical significance of the difference between extracted first and higher order streams (Tarboton, 2005). However, ATs computed by these algorithms require further validation with respect to geomorphology, soil and climate of the study area as they strongly affect actual stream initiation, as well as by available MSNs (Lin et al., 2006).

Many studies require extraction of DSNs that approximate given MSNs, e.g. fitting statistical and geo-statistical models to the observations on MSNs that require hydrological parameters from DEMs (as done by “STARS” (Peterson and Ver Hoef, 2014), “SSN” (Ver Hoef et al., 2014) and “rtop” (Skøien et al., 2014)), catchment extraction from DEMs for outlets defined on MSNs (Hofierka et al., 2009; Tarboton, 2005) and DEM-based geo-computation on the processes that are observed in MSNs (Lagacherie et al., 2010). Hence, a few studies automated the AT selection process through comparison with MSNs, also considering the scale of MSNs. These automation are based on (1) statistical relations with landscape parameters at stream sources of MSNs (Heine et al., 2004) and (2) minimizing lateral displacements (*d*) between stream sources of MSNs and DSNs (Lin et al., 2006). However, algorithms relying on landscape parameters are highly demanding in terms of input data and computation. The minimized lateral displacement between mapped and DEM stream sources may result from non-existing streams related to a low AT. Consequently, the number of DEM-derived streams should be considered during optimization. Furthermore, lateral displacements are often observed between MSNs and DSNs due to differences in data sources, equipment and human processing, which leads to imprecision in the selection of mapped stream sources and outlets from DEM (Peterson and Ver Hoef, 2014; Soille et al., 2003). This may consequently hinder the extraction of an approximate DSN. The suggested solution of “burning in” MSNs (Maidment et al., 1996; Peterson and Ver Hoef, 2014) alters DEMs and may affect subsequent analyses (Callow et al., 2007).

The advent of high quality DEMs also allows for the delineation of riparian corridors for streams and stream sections of DSNs by geomorphological analyses (Abood et al., 2012; Fernández et al., 2012; Holmes and Goebel, 2011). The land cover in riparian corridors interacts with many processes within streams and has a strong influence on water quality and energy fluxes (Verry et al., 2004). Therefore multiple stressors that act on riparian scales also affect stream communities and processes (Marzin et al., 2013). However, communities and processes in streams are typically monitored at stream sampling points (SSPs) in governmental monitoring programs (Biss et al., 2006). The SSPs are ideally representative for the whole stream network and usually physicochemical variables such as pH and temperature as well as biological quality elements such as fish or invertebrates are monitored (Stevens Jr. and Olsen, 2004). Hence, SSPs can be used to quantify potential effects from riparian scale stressors on the biological endpoints (e.g. community composition of invertebrates). This in turns requires computation of upstream riparian corridors (URCs) of given sizes (length and width), for which these stream sampling points serve as outlets (Dahm et al., 2013; Lorenz and Feld, 2013; Marzin et al., 2013). To our knowledge, no algorithm has been developed for automated delineation of such URCs for given SSPs and sizes. To date such corridors are often “drawn by hands” (Colson et al., 2008).

Moreover, the available algorithms for automated AT selection and riparian corridor delineation for streams and stream sections were mostly developed on proprietary software and hence are not accessible. The development of comparable open source software algorithms has been suggested to improve reproducibility, reliability and communication in geoscientific research (Rocchini and Neteler, 2012; Steiniger and Hay, 2009).

Two novel algorithms are presented in this paper: (1) automated AT selection that objectively approximate DSNs to given MSNs and (2) automated URC delineation for given SSPs and sizes from governmental biomonitoring data. The combination of the two algorithms is called “automated Accumulation Threshold computation and RIparian Corridor delineation (ATRIC)”. ATRIC has been developed by combining two freely available open source software packages. ATRIC is compared with other available algorithms regarding the goodness of DSNs, and its computational efficiency and potential fields of application are discussed.