Topographic and Soil Maps Do Not Accurately Depict Headwater Stream Networks

By Thomas Colson, James Gregory, John Dorney, and Periann Russell

Topographic and soil maps are often used to determine the location of headwater stream corridors for federal and state planning and regulatory purposes. Yet these maps are often inaccurate, raising serious questions about their use in regulatory applications.

Headwater streams are the first- and second-order intermittent or perennial streams throughout a watershed that serve as a critical hydrologic link between the surrounding landscape and the larger, connecting stream outflows (Stanford, 1996). Small first-order streams can represent up to 85% of the drainage network (Peterson et al., 2001) and often drain a major portion of the watershed area (McGlynn and Seibert, 2002).

Federal and state water quality programs designed to protect the ecological functions of headwater stream corridors often utilize U.S. Geological Survey (USGS) topographic maps, with a 1:24,000 scale, to determine the location of headwater streams for planning and regulatory purposes. The significant nexus assessments now required by the U.S. Army Corps of Engineers for "waters of the United States" determinations often focus on small streams and the hydrologic/ecologic connections of those streams to wetlands and to the nearest downstream traditional navigable waters (Corps, 2007). Many consultants are using the National Hydrography Dataset (NHD) (USGS, 2000), the digital equivalent of USGS topographic map blue lines (blue lines represent water), to substantiate significant nexus determinations.

North Carolina's 1997 Neuse River Basin riparian buffer rule (15A NCAC 02B .0233) and subsequent buffer rules apply to intermittent and perennial streams as shown on USGS 1:24,000 scale topographic maps and Natural Resources Conservation Service (NRCS) county soil survey maps. Yet applying these rules reveals several errors in the USGS topographic maps' and the NRCS soil maps' depiction of small first-, second-, and, sometimes, third-order streams. John Dorney and staff of the Wetlands and Stormwater Branch of the North Carolina Division of Water Quality (NCDWQ) manage the state's riparian buffer rule program. Given the stream mapping errors and the fact that the inaccurate maps were being used for planning and regulatory purposes, John Dorney, with assistance from James Gregory, set out to develop a field methodology for identifying the origins of first-order streams (NCDWQ, 2005) and to initiate research on the nature and extent of stream mapping errors. The NCDWQ methods for identifying the origins of intermittent and perennial streams were implemented in early 1999 and have been extensively tested across North Carolina and in several other states. The methods are used in North Carolina for the riparian buffer rules and other regulatory applications as well as for field mapping of headwater streams to determine map errors. For an extensive literature review on stream mapping standards and map errors in depiction of stream networks, see Colson (2006).

Thomas Colson, CFM, GISP, Ph.D. is a Project Manager at Froehling & Robertson in Raleigh, North Carolina. James Gregory, CPSS, PWS, Ph.D. is a Professor in the Department of Forestry & Environmental Resources at North Carolina State University in Raleigh, North Carolina. John Dorney, M.S is Supervisor and Periann Russell, M. S. is Geomorphologist with the Program & Policy Development Unit, Wetlands and Stormwater Branch, North Carolina Division of Water Quality in Raleigh, North Carolina.

This article focuses on work in North Carolina to assess headwater stream errors on NRCS and USGS maps. The extensive stream mapping errors on USGS topographic maps and NRCS soils maps raise serious questions about use of these maps in regulatory applications for which they were not intended.

Preliminary Stream Surveys

In 1998 and 2000, teams of NCDWQ staff members conducted global positioning system (GPS) ground surveys of headwater stream networks in small catchments (about 0.5 mi^2 in size) in all three major physiographic regions of the state and compared total stream length on the ground to that shown on maps (Gregory, et al., 2002). Those data showed that NRCS soil maps usually overestimate the presence of small streams and that USGS 1:24,000 scale topographic maps greatly underestimate the presence of small streams (Table 1). The only exception was in the Coastal Plain where many ditches are depicted as blue lines on USGS maps.

These preliminary studies found several types of errors with the USGS maps:

Table 1. Percent error in total stream length within the study watersheds as depicted on NCRS and USGS maps compared to onsite determinations.

Region	NRCS Map	USGS Map
Coastal Plain	+29	+31
Piedmont	+3	-25
Northern Mountains	+25	-48
Central Mountains	+25	-30
Southwestern Mountains	+35	-54

1. Most first-order, many second-order, and some third-order streams were not depicted on the maps.
2. Drainage density varied among quadrangles, often between adjacent quadrangles.
3. At quadrangle borders, blue lines on one quadrangle often did not continue on the adjacent quadrangle.
4. Some quadrangles depicted both intermittent and perennial streams while some depicted only perennial streams.
5. Accuracy of classification (i.e. intermittent vs. perennial) of small streams depicted on the maps was very low.
6. Errors in representation of topography often affect accurate representation of the stream network.

Stream Mapping Research

In 2004, North Carolina State University, in cooperation with NCDWQ and the North Carolina Department of Transportation (NCDOT), initiated further research to address the issue of error-prone stream maps. Specifically, they began to conduct more extensive tests of the accuracy of stream maps and to test the feasibility of digital mapping of streams with LiDAR- (a laser remote sensing technology) and GIS-based methods (Colson, 2006). Objectives of that research were to:

1. Collect extensive GPS data on the stream networks of small study watersheds across the physiographic variability of North Carolina to study errors in current maps and to test digital methods of mapping stream networks.
2. Test and optimize methods for creation of fine resolution digital elevation models (DEMs) from LiDAR bare earth elevation data and for processing the DEMs to optimize stream mapping accuracy.
3. Compare and optimize GIS methods that delineate the stream network on the DEM.
4. Develop logistic regression models to predict the locations and lengths of streams in the DEM in order to delineate an accurate stream network.

Thomas Colson (2006) conducted feasibility studies with field data from nine study watersheds. Periann Russell has continued collection of additional field data (23 study watersheds to date) and development of logistic regression models.

Described below is the analysis of errors in stream maps conducted by Thomas Colson (2006). Stream maps analyzed in this research included NRCS county soil survey maps and the high resolution (1:24,000 scale) NHD.

Methods

Nine rural watersheds, each averaging about one square mile in size, among the three major physiographic regions in North Carolina—the Coastal Plain, Piedmont, and Mountains—were selected so that the study included a diverse set of U.S. Environmental Protection Agency "Level IV Ecoregions" (Griffith et al., 2002) and North Carolina Soil Systems (Daniels et al., 1999). Stream lines on both USGS and NRCS maps were compared to field-surveyed streams in terms of horizontal accuracy and network characterization using geographic information systems (GIS) analysis.

Beginning at the mouth, all intermittent and perennial streams in the study watersheds were surveyed with mapping-grade GPS by recording the coordinates of points along the thalweg (the lowest point) of each stream channel at relatively evenly spaced intervals and at each confluence. A total of 2000 stream channel points were recorded using the mobile GIS developed by Colson et al. (2006). The locations of 171 intermittent and perennial stream origins were determined in accordance with the NCDWQ protocol for stream origin identification and stream type classification (NCDWQ, 2005). Maps of the actual stream networks were created in GIS by connecting the GPS points with straight lines. Average horizontal accuracy (estimated) of coordinates for the entire set of GPS points was ±1.8 ft.

NHD blue lines, based on scanned USGS 1:24,000 topographic maps, were downloaded from http://nhd.usgs.gov/data.html. To create digital versions of the streams shown on the soil maps, printed soil maps from county soil survey publications were digitally scanned. The scanned images were then georeferenced using ERDAS Imagine, a geospatial imaging tool, and more recent USGS aerial photography obtained from http://seamless.usgs.gov. Stream networks were then digitized from the georeferenced maps using ArcGIS, a GIS software program.

Total stream lengths of the networks and the number of stream segments in each stream order in the study watersheds were compared between the field-surveyed stream networks and those depicted on the NRCS and USGS maps.

Using a multiple ring buffer approach in the GIS, locations of mapped stream lines were compared to that of the GPS-surveyed stream channel points to determine the horizontal accuracy of the NRCS and USGS maps. For details of the methods, see Colson (2006). Two buffer ring criteria were used for testing the horizontal accuracy of the mapped streams.

1. A 10 foot buffer test was used to determine the percentage of GPS stream centerline points located within 10 feet of either side of the mapped stream. The percentage of GPS points located beyond the buffer represented the probability of horizontal error that is visually detectable at the scale and line size of the USGS 1:24,000 scale maps.
2. A minimum accuracy threshold test determined whether 90% of the GPS points were within 50 feet of either side of a mapped stream.

Results and Discussion

Figures 1 and 2 illustrate the differences between the stream networks on the maps and the GPS-surveyed stream network for a study site located in Person County, North Carolina. In the Person County watershed, the soil map overestimated the total stream length by 38%, with 40,416 feet of streams compared to 29,278 feet on the ground, and the NHD underestimated total stream length by 56%, with a total of only 12,998 feet. For all nine study watersheds, the average total stream lengths were 23,295 feet on the ground, 15,306 feet (-34 %) on the NHD, and 35,968 feet (+ 54 %) on the NRCS soil survey maps. Error in total stream length on the NHD ranged from -69 % for a mountain watershed to +10 % for a coastal plain watershed. The NHD stream networks in all study watersheds did not include most of the first-order streams found during the field survey, lacked a number of second-order streams, and in some cases, lacked some third-order streams. Stream networks shown on soil maps included many lines representing first-order and occasionally second-order intermittent streams that were classified in the field as ephemeral.

As can be seen in Figures 1 and 2, the USGS and NRCS maps did not accurately depict the stream's centerline location or sinuosity (curviness) when compared to actual streams on the ground. For the nine study watersheds, the mean percentages of GPS stream centerline points within 10 feet of a mapped streamline were 15.72 % for the NHD and 16.12 % for the soil maps.

The results demonstrate that the NRCS and USGS maps have a high frequency of error in terms of horizontal accuracy of stream segments and completeness of stream networks.

Figure 1. Comparison of streams shown on NRCS 1:24,000 scale soil survey map to GPS ground truth in a watershed in Person County, NC.

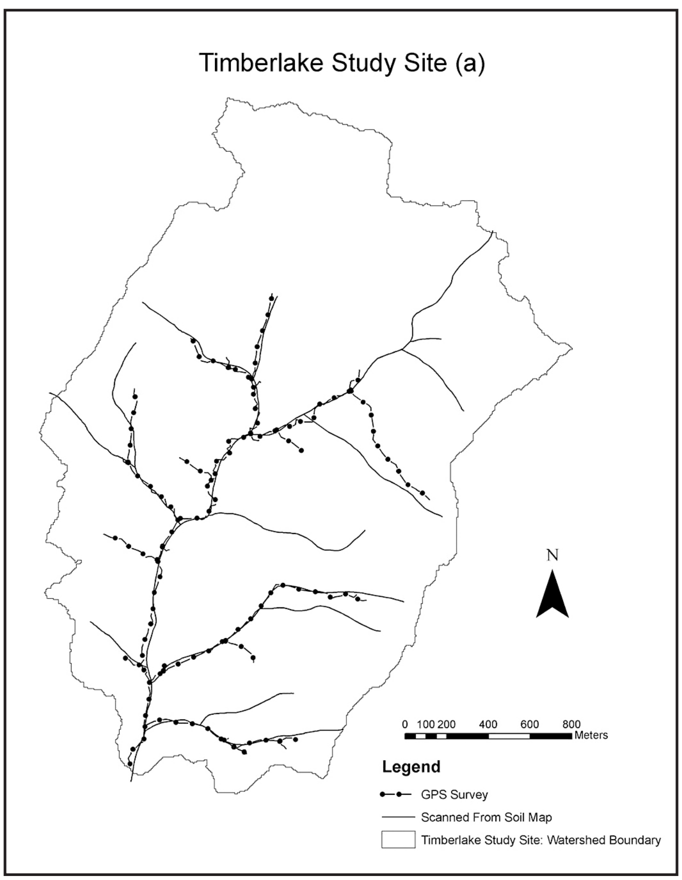
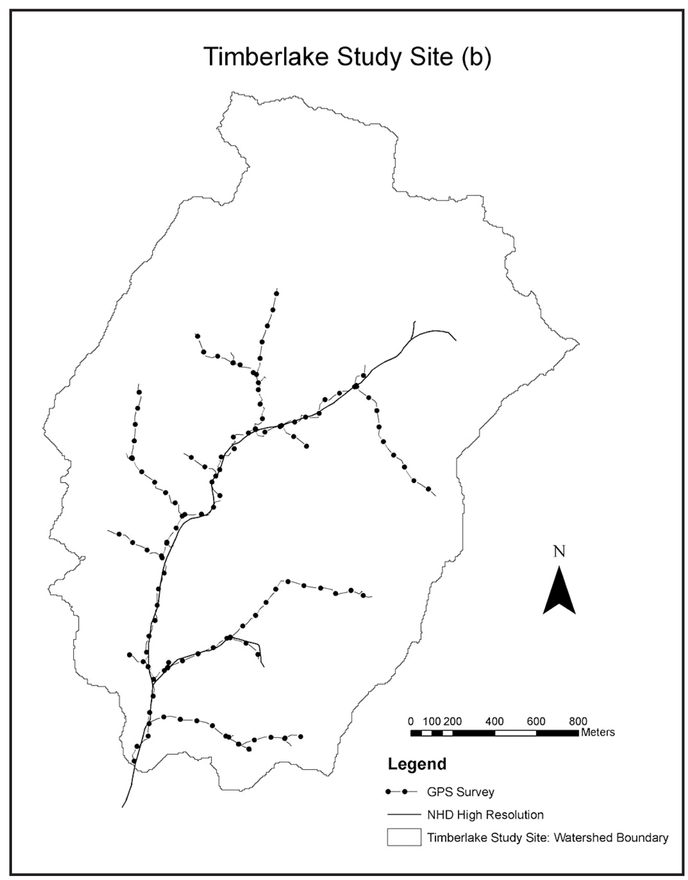


Figure 2. Comparison of streams shown on USGS 1:24,000 scale topographic map to GPS ground truth in a watershed in Person County, NC.



Where actual stream locations varied the most from the mapped stream lines, the patterns of horizontal errors indicated possible combinations of random or systematic error in drawing the map stream lines from aerial photos and errors introduced by rectification and data projection. Cartographic generalization that straightens sinuous channels may also contribute to the relatively low percent of GPS points that are close to the tested NHD stream lines (Figures 1 & 2). Soil maps had slightly better overall horizontal accuracy than the NHD likely due to the extensive ground surveys that are conducted in the process of producing soil maps.

The large negative bias in completeness of stream networks depicted on the NHD is partially due to the inability of cartographers to see and interpret the character of small streams on aerial photos, particularly in forested areas. Cartographic guidelines that limit the density of streams for aesthetic reasons and specify minimum distances of stream origins from ridge tops and minimum lengths of stream segments also contributed to map error. The variation in stream network characteristics among USGS quadrangles is due to differing methods and photo interpretative judgments used by different cartographers in drawing stream maps from aerial photos and possible changes in stream mapping guidelines over time.

Conclusion

Our results demonstrate that the nationwide USGS 1:24,000 scale stream maps provide only limited information about headwater streams, the most ecologically and hydrologically important elements of stream networks in watersheds. The cartographic generalization and advanced age of the NHD make it the least complete stream data set both in terms of stream network and stream geometry representation. Stream data represented on soil maps are more complete, but are not available in digital format and can be obsolete.

While stream lines on USGS topographic maps and NRCS soil maps were originally included for different purposes and drawn with different standards, these maps are useful for landscape assessment and planning purposes. However, the extensive errors in the depiction of headwater streams on USGS and NRCS maps calls into question their use in regulatory applications for which they were not intended. In our experience, field work is currently the only accurate method for determining the origins, locations, and classifications of headwater streams and the hydrologic and biologic continuity of headwater stream networks for regulatory purposes. ■

References

Colson, T.P., J.D. Gregory, S.A.C. Nelson, and E.G. Shipman. 2006. A mobile geographic information system to support stream identification. Proceedings, Geographic Information Systems and Water Resources IV, AWRA Spring Specialty Conference, May 8-10, 2006, Houston, TX. American Water Resources Association, Middleburg, VA.

Colson, T.P. 2006. Stream network delineation from high-resolution digital elevation models. Ph.D. Dissertation, Department of Forestry & Environmental Resources, North Carolina State University, Raleigh, NC. *Available at* http://www.lib.ncsu.edu/theses/available/etd-10302006-122024/.

Daniels, R.B., S.W. Buol, H.J. Kleiss, and C.A. Ditzler. 1999. Soil Systems in North Carolina. Department of Soil Science, Technical Bulletin 314, North Carolina State University, Raleigh, NC.

Gregory, J.D., S.D. Smith, E. Fleek, and D. Penrose. 2002. What is a Stream? Proceedings, Watershed 2002, Feb. 23-27, 2002, Ft. Lauderdale, FL, Water Environment Federation, Alexandria, VA.

Griffith, G.E., J.M. Omernik, J.A. Comstock, M.P. Schafale, W.H. McNab, D. R. Lenat, T.F. MacPherson, J.B. Glover, and V.B. Shelburne. 2002. Ecoregions of North Carolina and South Carolina, (color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia. (map scale 1: 1,500,000).

McGlynn, B.L. and J. Seibert. 2002. Distributed assessment of contributing area and riparian buffering along stream networks. *Water Resources Research* 39 (4):1082.

North Carolina Division of Water Quality (NCDWQ). 2005. Identification methods for the origins of intermittent and perennial streams. Version 3.1 [Online]. *Available at* http://h2o.enr.state.nc.us/ncwetlands/intermittent_perennial.html.

Peterson, B.J., W.M. Wollheim, P.J. Mulholland, J.R. Webster, J.L. Meyer, J.L. Tank, E. Marti, W.B. Bowden, H.M. Valett, A.E. Hershey, W.H. McDowell, W.K. Dodds, S.K. Hamilton, S. Gregory, and D.D.Morrall. 2001. Control of nitrogen export from watersheds by headwater streams. *Science* 292 (5514): 86-90.

Stanford, J., 1996. Landscapes and catchment basins. In *Methods in Stream Ecology*, F.R. Hauer and G.A. Lamberti (eds.), Academic Press, San Diego, CA. pp. 3-22.

U.S. Army Corps of Engineers (USACE). 2007. U.S. Army Corps of Engineers jurisdictional determination form instructional guidebook. *Available at* http://www.usace.army.mil/cw/cecwo/reg/cwa_guide/cwa_guide.htm.

U.S. Geological Survey (USGS), 2000. The National Hydrography Dataset Concepts and Contents [Online]. *Available at* http://nhd.usgs.gov/chapter1/index.html.

May is American Wetlands Month

May is the month we recognize and celebrate the wonderful ways wetlands enrich the environment and people. Events are scheduled across the country to educate, involve, and engage Americans who want to better understand the value of one of Earth's most important ecosystems.

To learn more about activities associated with American Wetlands Month, please visit the U.S. Environmental Protection Agency's website at http://www.epa.gov/owow/wetlands/awm.