Strategies for Stream Classification Using GIS

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ABSTRACT

Classification of streams into perennial, intermittent or ephemeral is necessary in certain fields. Environmental studies can benefit from a map showing stream classification. In addition, it is necessary to know the stream classification for issues like urban planning and permits. In this study, we developed strategies for stream classification using Geographic Information Systems (GIS). With public domain data, it was possible to develop different strategies for stream classification. Our focus was the Upper Neuse River basin in North Carolina. In our study, soils information from the SSURGO database, Land Use/Land Cover data, elevation data from NED and high-resolution LIDAR information, and hydrographic information from NHD and EDNA derivatives were used to develop the stream classification strategies. The results were promising and showed an acceptable degree of consistency from field studies available in the Upper Neuse River basin.

INTRODUCTION

Classifying streams is an important subject that has not received enough attention in the scientific literature. In particular, the most common methods to solve the problem for specific needs are field based. There are several ways to define perennial, intermittent and ephemeral when referring to streams (Gritzner and Millet, 2003b). This study uses definitions from the USGS (Gritzner, 2003). The definitions are related to time and state that a perennial stream is one which flows continuously; an intermittent (or seasonal) stream is one which flows only at certain times of the year when it receives water from springs or from some surface source such as melting snow in mountainous areas; and an ephemeral stream is one that flows only in direct response to precipitation, and whose channel is at all times above the water table. It is important to notice that the previous definitions have implications such that a connection of the flow conditions with the water table, which in turn is influenced by climate changes and seasonal variations. Geographic information systems (GIS) technologies have made excellent progress in the last several years, making it possible to integrate several data layers for such purposes as mapping and modeling efforts. One data layer that has not been available in a reliable way, especially in a more detailed scale (county and city level, for example) is that of stream classification. There is therefore a need to investigate new approaches and strategies to classify streams that do not depend strongly on field methods. Field methods produce reasonable data if applied properly (Gritzner and Millet, 2003a) but can be expensive and are prone to errors due to incorrect measurements or inability to reach certain areas. This study focuses on strategies based on GIS and remotely sensed data, using different types of digital information such as soil texture and elevation, with a case study in the Upper Neuse River basin in North Carolina.

THE NEED FOR CLASSIFYING STREAMS

Streams classification is necessary in certain fields. For example, environmental studies and mapping activities, in particular water quality surveys, can benefit from stream classification maps. States like North Carolina have specific laws for perennial and intermittent streams with respect to buffer zones (Darling et al., 2002). Urban planning and zoning also benefits from detailed classifications of streams into perennial and intermittent. For research and cartographic purposes there are clear benefits in having a detailed classification of perennial and intermittent streams: hydrologic modeling studies, land use and land cover analyses, inundated areas determination, hydropower potential, recreational areas delimitation and so on. So far the classified streams maps available are mostly from the United States Geological Survey (USGS). (Gritzner, 2003) The mapping program standards from the USGS allowed for a fairly subjective classification system. Both the USGS and the Natural Resources Conservation Service (NRCS) have developed maps displaying classified streams (Darling et al., 2002). The use of methodologies or models using remotely sensed data and GIS has not been fully exploited yet. There is digital data already available that contains information about soil texture and elevation that can be used for such classification efforts.

Field Methods for Stream Classification

Currently, only the State of North Carolina and Fairfax County in Virginia have implemented field techniques for stream classification. As was mentioned in the previous section, the State of North Carolina (Darling et al., 2002) has specific regulations for perennial, intermittent and ephemeral streams. In particular the method developed by the North Carolina Division of Water Quality (NCDWQ) offers a fairly complete and thorough form (included in the Appendix) for field technicians to fill out. The form includes observations for primary and secondary indicators, including recent alluvial deposits present, a bankfull bench present and geomorphological indicators such as an active or relic flood plain, a continuous bed and bank, natural levees, head cuts in the channel and grade control points. An important factor in the form is the sinuosity of the stream. Hydric soils on the streambed are included in the form, raising the question of the presence of water for extended periods of time. Also, the form pays special attention to biological indicators, including fibrous roots or rooted plants present in the streambed, or the existence of periphyton, bivalves, fish, amphibians, aquatic turtles, crayfish, macrobenthos, iron oxidizing bacteria/fungus, filamentous algae, or wetland plants in the streambed. Such indicators are definitely obtainable only with field work. The results in the form come in the form of a score for each of the indicators, after which the points are added for primary and secondary indicators, and then a grand total of points is computed. From the form itself, it says that if the total number of points is greater than or equal to 19 points, then the stream is at least intermittent. The use of this method has a strong subjective component and requires an experienced and trained eye to be effective. Detecting the biological indicators is not a trivial task and depends on the seasons. On the other hand, it is a thorough method that accounts for several factors for the determination of the type of stream.

The method developed for Fairfax county in the State of Virginia (Gritzner and Millett, 2003a) closely follows the one from the NCDWQ. However, an important observation to be made is that the method is called “Perennial Stream Field Identification Protocol”, thus it is a method geared toward identifying perennial streams. It is important to note that the method includes a more detailed protocol for its use, suggesting the use of GIS data layers to support the data acquisition. In addition, the protocol requires the field personnel to assess how difficult was to find the indicator, for example “Benthic Macroinvertebrates” and “Bivalves”, it calls for a description like “Strong” if the indicator is easily found in all samples; “Moderate” if only takes a few samples to locate the indicator; “Weak” if sampling takes 10 minutes or more to locate the indicator; and “Absent” if the indicator is not present all together. The final score in the Fairfax, VA method then has to be analyzed in terms of specific seasonal effects. From the protocol (See the Appendix, the references and Gritzner and Millet, 2003a), a minimum total score of 25 would normally classify a stream as perennial. A lower score can still have the stream identified as perennial but other supporting information such as observation of flow under specific seasonal conditions and key biological indicators. One interesting guideline for other supporting information calls for information provided by long-term residents in the area or local professionals who can testify for the perenniality of the stream, or historical records such as aerial photographs or land surveys or even newspaper articles with pertinent information. Thus the Fairfax method gives more space to personal judgment in the stream classification.

ANALYTICAL METHODS FOR STREAM CLASSIFICATION

The United States Geological Survey in Massachusetts did a rigorous study developing a logistic regression equation to estimate the probability of a stream flowing perennial (Gritzner and Millett, 2003a). The method was developed relating perennial or intermittent stream identifications to selected basin characteristics. The study was quite restrictive to what streams it applied to: only naturally flowing streams were included, which means it excluded regulated flow by dams, intakes, groundwater wells, diversion, wastewater discharges, etc. The data used to develop the model were measured flow and observations in the field. Measurements for long drought periods were excluded in the analysis. A total of 305 stream sites were included, out of which 134 were intermittent and 171 were perennial. The probability function developed originally related the probability of a stream flowing perennially from the cube root of the drainage area, the drainage density, the square root of the areal percentage of stratified drift deposits, mean basin slope and the location within the state of Massachusetts. The method turns out to be unreliable for drainage areas of less than 0.14 squared miles and areas such as the entire Cape Cod and island basins. The original study had later a follow up update where a new set of variables were determined to be necessary for the equation: cube root of the drainage area, the drainage density, the square root of the areal percentage of stratified drift deposits, the mean basin elevation and the areal percentage of forestland. With these changes, the new version of the equation correctly predicts the transition point from an intermittent to perennial stream (break point) about 75% of the time within a certain probability range. The study had more interesting results that are applicable to other projects. For instance, a point on a stream that has a drainage area greater than 2 squared miles will almost always be perennial. And for points with less than a 2 square mile drainage area, the stream is classified in a range of about 53% to 63% of the time. In cases where there are relatively few intermittent streams, when reaching the originating point of the stream, the intermittent classification becomes weaker. The state of Georgia developed a logistic regression equation to determine nominal stream density range. Unfortunately there is not a good reference of this study in the public literature.

The Bureau of Land Management in Oregon conducted a broad study that included the determination of the theoretical distribution of intermittent channels (Gritzner and Millett, 2003a). The portion of the study that dealt with the intermittent channels was a modeling process where the authors used mostly soils data. The input includes soil permeability based on texture and infiltration, soil depth, and theoretical catchment area of first order streams. To get an initial stratification of the soil, the study used the Natural Resources Conservation Service (NRCS) soil survey of Coos County from 1989. The permeability was used, assuming permeable an infiltration rate greater than 6 inches per hour. Plus, permeable soils are sandy soils derived from sedimentary rock. From the same soil survey, the soil depth was determined keeping in mind to exclude points where the depth was greater than 36 inches. Several assumptions and simplifications were made in this study:

- The flow recession was based on a summer dry period of 100 days.
- Small headwater catchments were assumed to be unconfined.

- The hydraulic gradient defines the rate at which all the water from the ridgelines of small watersheds flows downhill.
- Hillslopes into first order channels average a 60% slope.
- Unit hydraulic gradient of 0.452 feet per day was estimated from the average hillslope above.
- A constant transmissibility coefficient of 36 cubic feet per day was computed from soil depth and permeability.
- Darcy's Law predicted a flow rate of 16.27 cubic feet per day, without adjustments for changes of water viscosity from temperature.
- Small headwater watersheds were assumed circular.
- Flow recession and flow rate: 1627 feet per season. The contributing area is 95 acres. Small catchments or watersheds up to this size may go dry under the assumptions. However, a 25% safety factor was applied and so the maximum size then drops to 76 acres.

The results of this study are compiled in a map showing perennial and intermittent streams for the East Fork Coquille watershed in Oregon (Gritzner and Millett, 2003a).

GIS Strategies and Approaches for Stream Classification

The scientific literature contains scarce if any publications on GIS and remotely sensed digital data based methodologies for stream classification. One of the most important and necessary aspects in stream classification is that of reliable and accurate information regarding stream delineation in digital format. Currently there is the National Hydrography Dataset (NHD), which is the merging of the United States Environmental Protection Agency (USEPA) Reach File version 3 (RF3) and the USGS DLG-F datasets for hydrography, available from http://nhd.usgs.gov. And, for the purpose of this study, there is the Elevation Derivatives for National Applications (EDNA) from the USGS, with more information available at http://edna.usgs.gov. The main difference between NHD and EDNA is that NHD is digitized from 1:100,000 and 1:24,000 maps and EDNA is a pure derivative from digital elevation data (National Elevation Dataset, or NED, more information available at http://ned.usgs.gov). The details of the methodology behind the processing the digital elevation data are beyond the scope of this project and are found elsewhere in the literature (Jenson and Domingue, 1988). However, for this study, streams were produced using threshold values equivalent to those of EDNA at 5000, 1000 and 250. The methods in this study focus on the use of already proven field methods and how can they be transferred to a GIS based system. In particular, the focus of this study was the NCDWQ field method already mentioned in this document. As was mentioned before, the NCDWQ field method focuses on primary and secondary indicators, using soils and geomorphology and biological indicators. However, the use of biological indicators does not make sense on a larger scale GIS based system. It is extremely difficult, if not impossible, to accurately quantify several of the parameters in the NCDWQ field method. However, other parameters are important and are feasible to obtain or estimate from remotely sensed data. These are discussed below:

- Hydrologic soils and soil texture differences: there are public domain digital information databases accessible from the web. In particular, the STATSGO (NRCS State Soil Geographic) database, and the SSURGO (NRCS Soil Survey Geographic) database. Both of them, in particular SSURGO, are works in progress and provide very high quality data for several areas of the conterminous United States. The SSURGO database is due for completion some time in 2008. Any digital soil database, provided that has complete information, can be transformed or mapped to represent a soil classification with hydrologic soil groups to denote the degree of saturation.
- Sinuosity: this study computed it as ratio of channel length to valley length. From this definition, the sinuosity ratio of 1 is a straight stream, sinuous is 1 to 1.5 and meandering is a ratio greater than 1.5 (Kunze, 2004). From personal communications with Janet Gritzner, professor at South Dakota State University, there is a strong relationship between sinuosity and slope, where a stream maintains its slope by means of sinuosity. Thus, the more the sinuosity, the more gentle the slope. Also, for streams in soft sediments, a sudden change where a stream increases its meandering significantly, then the point is probably a change from ephemeral to intermittent.
- Land use: depending on the quality and detail of land use and land cover data, it is possible to determine by comparison the current classification for a part of a

stream and the type of current land use for a stream segment. However, land use is information that changes with time and so care must be taken with how it is handled and what conclusions are made from it.

- Groundwater and base flow: contributions from base flow and groundwater can help a stream maintain its status of perennial during dry seasons. However, finding high quality information for this purpose is challenging. Also, groundwater recharge is sensitive to climate changes and seasonal effects.
- Pfafstetter stream ordering system: the Pfafstetter stream ordering system (Verdin and Verdin, 1999) allows for streams to be ordered at several levels (number of digits), making it easy to determine, for a given Pfafstetter code, its relative position with respect to the main stream. The number of digits determines if the stream is the main channel or which branch is it. This provides criteria for a possible relationship between the number of digits and the likelihood that a stream is ephemeral or intermittent.

It is important to keep in mind that the comparison at the end is done with the stream lines and the digital data layers explained above. The results are clearly dependent on the threshold used to produce the streams from the digital elevation model (DEM). The strategies and criteria presented above are still a work in progress and there are other criteria and possibilities to investigate.

CASE STUDY: UPPER NEUSE RIVER BASIN

The methods discussed in the previous section were tested and mostly developed in a case study area. The Upper Neuse River was chosen because of its importance and also because of the availability of very high quality, high resolution elevation data (digital elevation model, DEM) from LIDAR (LIght Detection And Ranging) sensors in 9.331 x 9.331 meter grid cells. The data was provided to us by the USGS office in Raleigh, NC (Terziotti and Kannan, 2004, personal communication). From the data, a shaded relief was produced (see Figure 1 below) and a full analysis of the data was performed. The data was projected into a suitable spatial reference (Albers) for analyses and then a specific cut was done for the hydrologic unit code (HUC) # 03020201. The resulting region is shown in Figure 1 below. For the Neuse River basin, we also got a land use and land cover (LULC) dataset from the USGS office in Raleigh (Terziotti and Kannan, 2004, personal communication) made by EPA. The dataset was produced in 1996, it is a 15 meter resolution, and is an interpretation from SPOT and ETM+ using both supervised and unsupervised classification. The data is shown on Figure 2 below. We also obtained high quality soil texture information from our collaborators at the USGS office in Raleigh. The data needed some editing, however, due to having different parts at different stages of data quality control (part of it was unofficial SSURGO data in the process of certification). Some manual editing was necessary to complete part of the details of the soil texture. With the DEM data, a complete analysis was done to delineate the streams at the equivalent of EDNA analyses at thresholds of 5000, 1000 and 250. One detail is necessary to keep in mind and it is the resolution of the elevation data used for the EDNA processing and the elevation data from the LIDAR sensors: the LIDAR data used was 87 sq meter data and the standard 5000 threshold EDNA stream drains 4,500,000 sq meters. So the actual threshold for an equivalent to EDNA 5000 is: 4,500,000/87 = 51,684. Similarly, for 1000, we get: 10,337 and for 250: 2,584. With these values, the stream lines were computed. However, for the case of EDNA 250 equivalent, there were some software limitations that have required a more detailed and much slower process. However, the EDNA 5000 and EDNA 1000 equivalents did not have any problems and compared favorably with current high resolution NHD for North Carolina. Figures 3 and 4 show the resulting EDNA 5000 and 1000 threshold equivalents streamlines for a portion of the Upper Neuse River basin. Figure 5 shows the EDNA 5000 and 1000 with the high resolution NHD lines for the same area. The results show quite a good correlation between computed streamlines from the LIDAR data and existing high resolution NHD data. The application of the strategies and criteria for stream classification mentioned before is still a work in progress; the results are so far promising but it is labor intensive and of careful details. At this point, there was no access to field data for verification purposes, so it is not possible to tell how well the strategies measure up against real data conditions.

DISCUSSION AND CONCLUSIONS

The classification of streams into perennial/intermittent/ephemeral is a challenging problem that so far has been approached mostly with field methodologies and mathematical models using stream gauge data. For the case of the Upper Neuse River in North Carolina, the stream gauge data for the application of a similar logistic equation (Gritzner and Millett, 2003a) to the one from Massachusetts is not appropriate because many of the gauges have interrupted records. The quality of the LIDAR elevation data is excellent and shows great promise in this and further studies. The soil texture digital data, as well as the land use and land cover data available for the Neuse River basin are also of great quality and will yield good results in the future. The current efforts are a work in progress and there are more ideas and strategies to further investigate. There is a need for field data for verification purposes and future direction in the project efforts. Hopefully soon such data becomes available to enhance the current results and work in progress.

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APPENDIXES

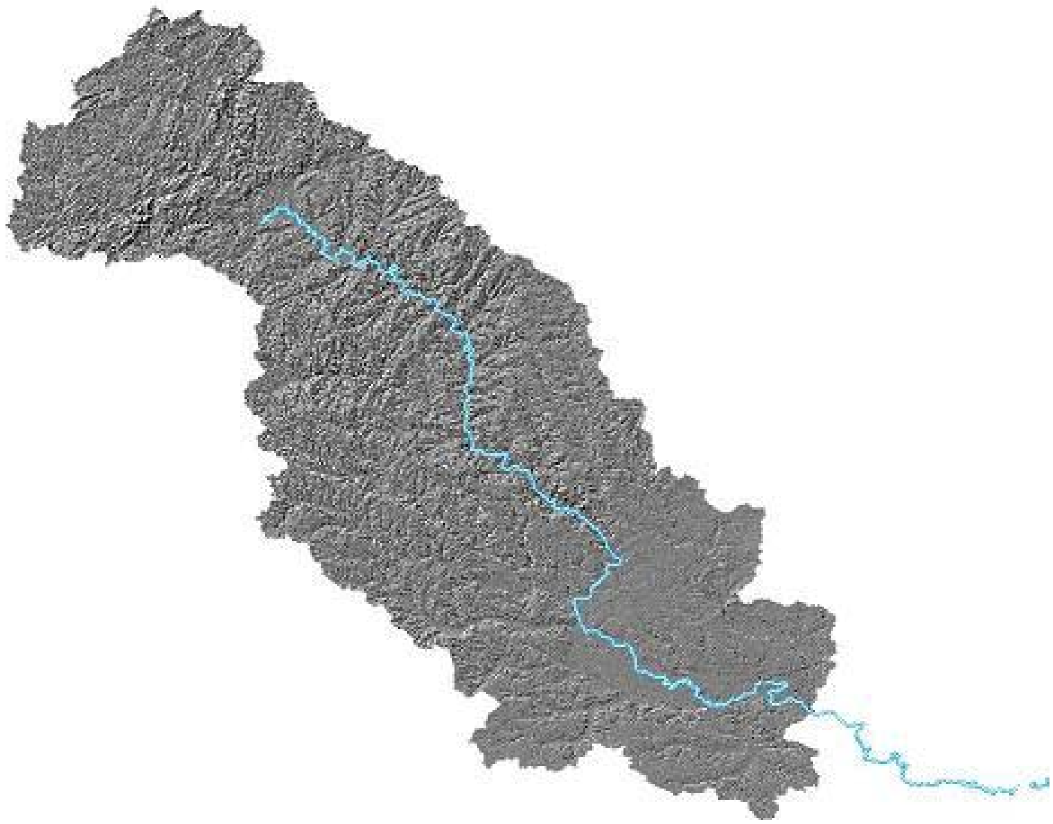

Figure 1: Upper Neuse River basin, with the shaded relief from LIDAR data and the blue line for the main channel of the Neuse River. HUC # is 03020201

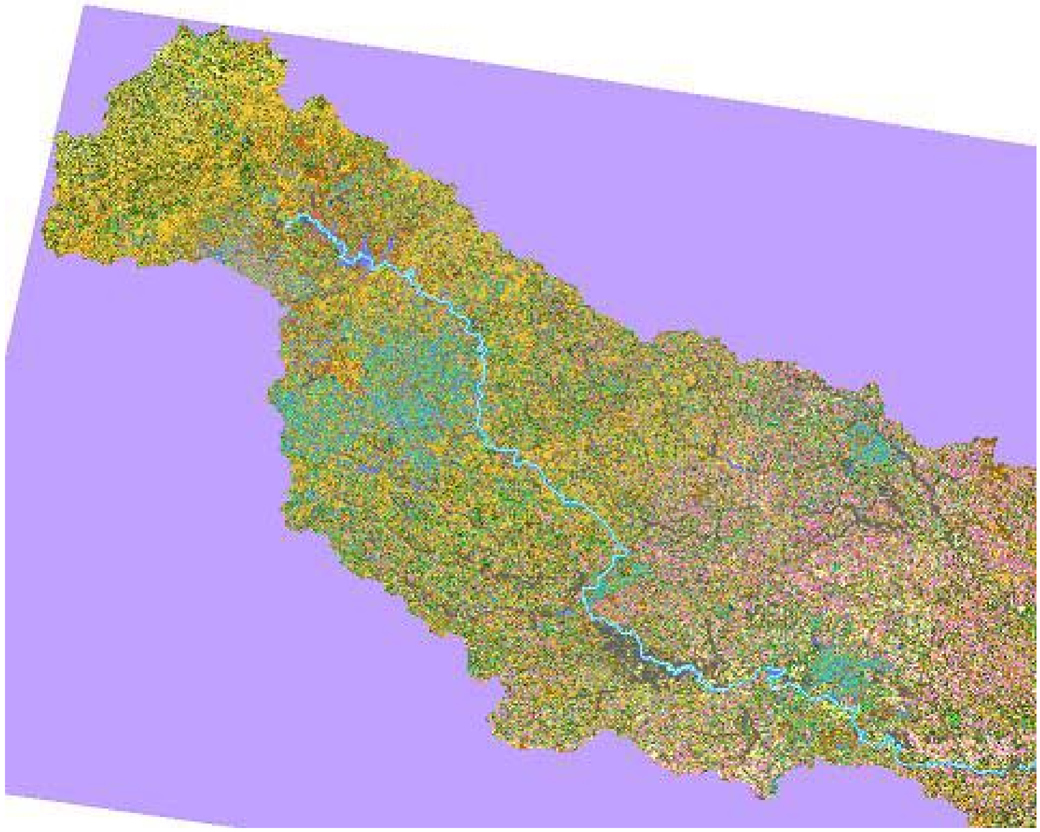

Figure 2: Upper Neuse River basin, showing the USEPA land use and land cover data 1996 at 15 m resolution, from SPOT and ETM+ sensors.

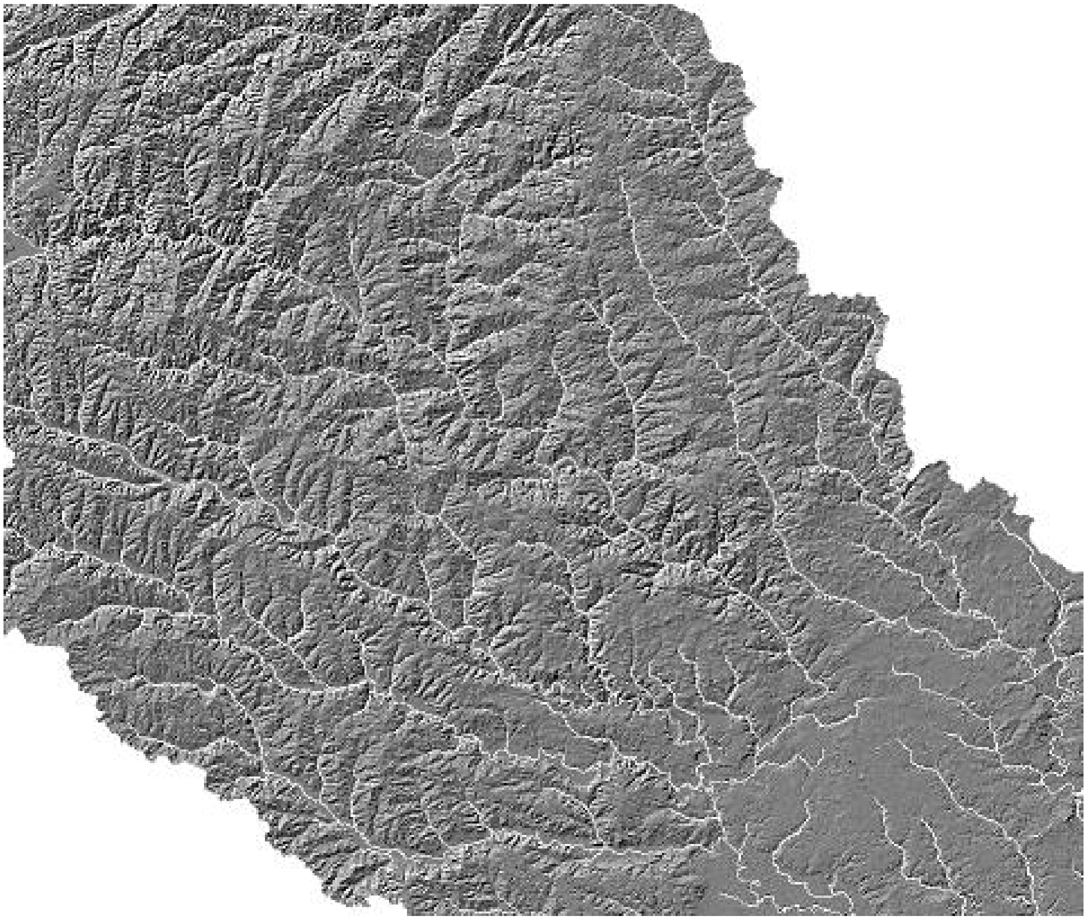

Figure 3: Upper Neuse River basin, showing the EDNA 5000 threshold equivalent streamlines.

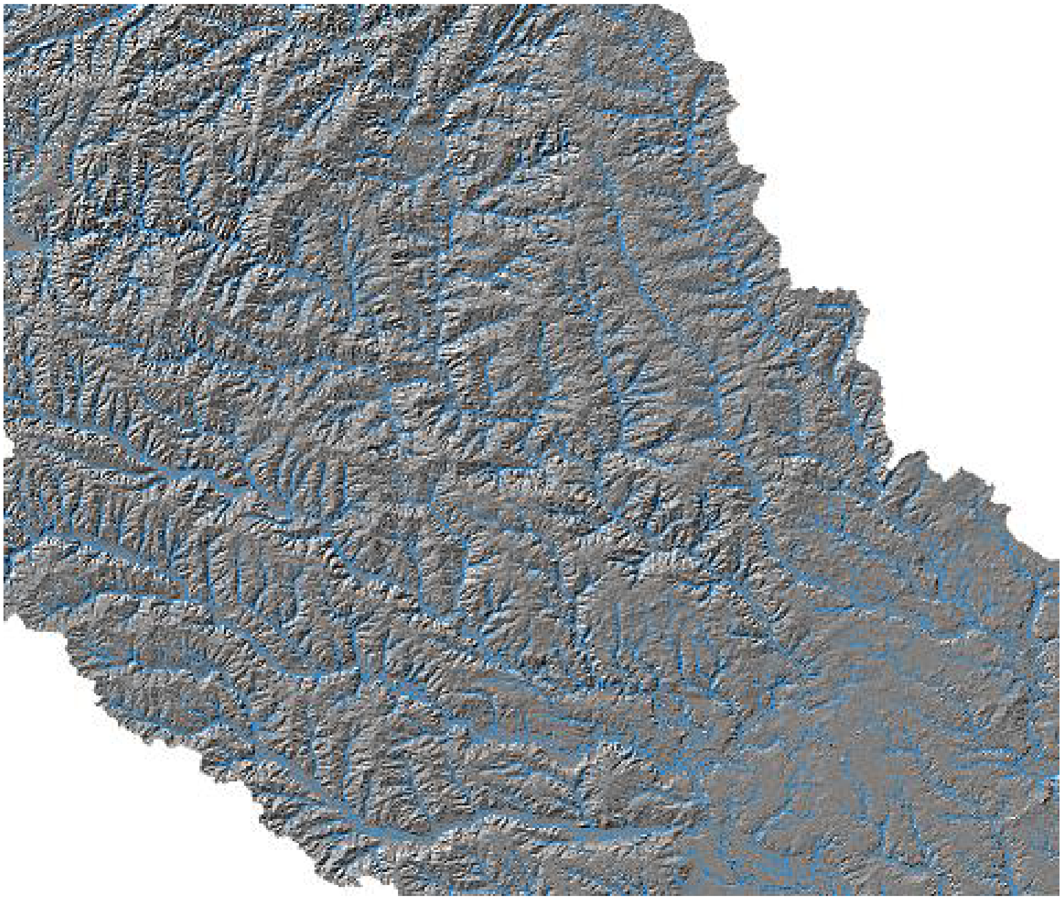

Figure 4: Upper Neuse River basin, showing the EDNA 1000 threshold equivalent streamlines.

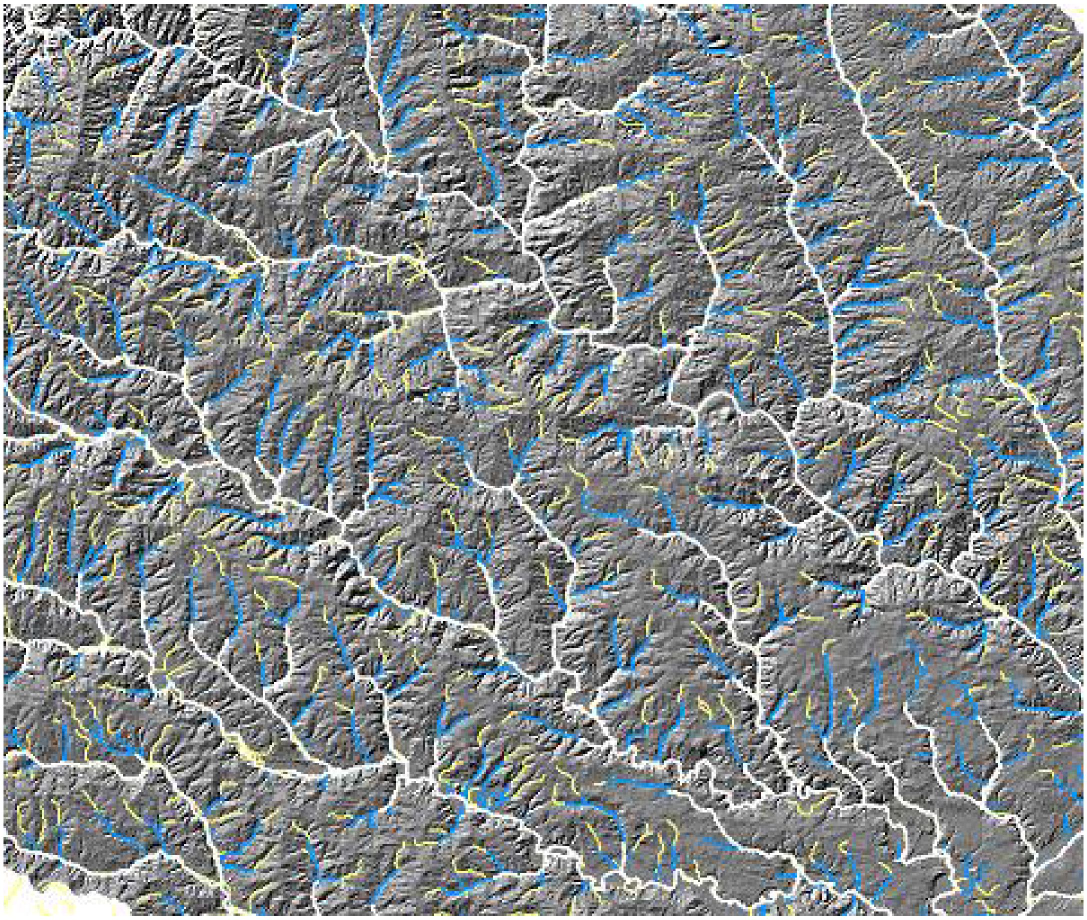

Figure 5: Upper Neuse River basin, showing the EDNA 1000 (blue) and 5000 (white) thresholds equivalent streamlines, together with the high resolution NHD (yellow).

NCDWQ Stream Classification Form: **Copyright by NCDWQ (North Carolina Department of Water Quality, Raleigh, NC):**

NCDWQ Stream Classification Form

Project Name:	River Basin:	County:	Evaluator:
DWQ Project Number:	Nearest Named Stream:	Latitude:	Signature:
Date:	USGS QUAD:	Longitude:	Location/Directions:

PLEASE NOTE:** ***If evaluator and landowner agree that the feature is a man-made ditch, then use of this form is not necessary. Also, if in the best professional judgement of the evaluator, the feature is a man-made ditch and not a modified natural stream—this rating system should not be used*

Primary Field Indicators: *(Circle One Number Per Line)*

I. Geomorphology	**Absent**	**Weak**	**Moderate**	**Strong**
1) Is There A Riffle-Pool Sequence?	0	1	2	3
2) Is The USDA Texture In Streambed Different From Surrounding Terrain?	0	1	2	3
3) Are Natural Levees Present?	0	1	2	3
4) Is The Channel Sinuous?	0	1	2	3
5) Is There An Active (Or Relic) Floodplain Present?	0	1	2	3
6) Is The Channel Braided?	0	1	2	3
7) Are Recent Alluvial Deposits Present?	0	1	2	3
8) Is There A Bankfull Bench Present?	0	1	2	3
9) Is A Continuous Bed & Bank Present?	0	1	2	3

*(*__NOTE__: If Bed & Bank Caused By Ditching And __WITHOUT__ Sinuosity Then Score=0*)*

10) Is A 2nd Order Or Greater Channel (As Indicated On Topo Map ***And/Or*** In Field) Present? ***Yes***=3 ***No***=0

PRIMARY GEOMORPHOLOGY INDICATOR POINTS:______

II. Hydrology	**Absent**	**Weak**	**Moderate**	**Strong**
1) Is There A Groundwater Flow/Discharge Present?	0	1	2	3

PRIMARY HYDROLOGY INDICATOR POINTS:______

III. Biology	**Absent**	**Weak**	**Moderate**	**Strong**
1) Are Fibrous Roots Present In Streambed?	3	2	1	0
2) Are Rooted Plants Present In Streambed?	3	2	1	0
3) Is Periphyton Present?	0	1	2	3
4) Are Bivalves Present?	0	1	2	3

PRIMARY BIOLOGY INDICATOR POINTS:_______

Secondary Field Indicators: *(Circle One Number Per Line)*

I. Geomorphology	**Absent**	**Weak**	**Moderate**	**Strong**
1) Is There A Head Cut Present In Channel?	0	.5	1	1.5
2) Is There A Grade Control Point In Channel?	0	.5	1	1.5

3) Does Topography Indicate A

Natural Drainage Way?	0	.5	1	1.5

SECONDARY GEOMORPHOLOGY INDICATOR POINTS:______

II. Hydrology	**Absent**	**Weak**	**Moderate**	**Strong**
1) Is This Year's (Or Last's) Leaflitter ___Present In Streambed?	1.5	1	.5	0
2) Is Sediment On Plants (Or Debris) Present?	0	.5	1	1.5
3) Are Wrack Lines Present?	0	.5	1	1.5
4) Is Water In Channel ***And*** >48 Hrs. Since Last ***Known*** Rain? *(*NOTE: If Ditch Indicated In #9 Above Skip This Step And #5 Below**) ____________	0	.5	1	1.5
5) Is There Water In Channel During Dry Conditions ***Or*** In Growing Season)?	0	.5	1	1.5
6) Are Hydric Soils Present In Sides Of Channel (Or In Headcut)?	***Yes****=1.5*	***No***=0		__

SECONDARY HYDROLOGY INDICATOR POINTS:______

III. Biology	**Absent**	**Weak**	**Moderate**	**Strong**
1) Are Fish Present?	0	.5	1	1.5
2) Are Amphibians Present?	0	.5	1	1.5
3) Are AquaticTurtles Present?	0	.5	1	1.5
4) Are Crayfish Present?	0	.5	1	1.5
5) Are Macrobenthos Present?	0	.5	1	1.5
6) Are Iron Oxidizing Bacteria/Fungus Present?	0	.5	1	1.5
7) Is Filamentous Algae Present?	0	.5	1	1.5

8) Are Wetland Plants In Streambed?	**SAV**	**Mostly OBL**	**Mostly FACW**	**Mostly FAC**	**Mostly FACU**	**Mostly UPL**
(**NOTE:** If Total Absence Of All Plants In Streambed As Noted Above Skip This Step **UNLESS** SAV Present*).* ______	*2*	1	.75	.5	0	0

SECONDARY BIOLOGY INDICATOR POINTS:______

TOTAL POINTS (Primary + Secondary)=____(If Greater Than Or Equal To 19 Points The Stream Is At Least Intermittent)

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