A GIS-based inventory of sediment pollution for watershed restoration planning

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Abstract

Under the Clean Water Act, U.S. states are required to establish water quality standards, list impaired waterbodies and create Total Maximum Daily Loads (TMDL) for impaired waters. Sediment contributes greatly to the water impairment in Tennessee, with agriculture often cited as the primary source. The watershed (catchment) in our study, Pond Creek, is listed as impaired for sediment and will require a TMDL and watershed restoration plan in the near future. The Tennessee Valley Authority (TVA) has developed an Integrated Pollutant Source Identification tool, consisting of aerial photographs, GIS database, and set of analysis spreadsheets to help plan watershed restoration efforts. We used this tool to assess sediment delivery from pastures, soil loss from eroding streambanks and riparian buffer condition in Pond Creek Watershed. We found that the user-friendly IPSI tool provides excellent maps and tables that can be used to educate farmers and other interested citizens, and to identify key restoration efforts.

Introduction

Under the U.S. Clean Water Act (CWA), states are required to establish water quality standards, list impaired waterbodies and create Total Maximum Daily Loads (TMDL) for impaired waters (Hession *et al*., 2000). A TMDL is a calculation of the maximum amount of a pollutant load plus a margin of safety that a waterbody can receive and still meet water quality standards described by Section 303 of the CWA (USEPA, 2002). In practical terms, TMDLs often become the blueprint for watershed restoration plans. Each state agency responsible for environmental quality and regulations uses a wide range of tools to develop defensible TMDLs for pollutants or conditions such as pathogens, sediment, nutrients, dissolved oxygen, metals and water temperature (USEPA, 2005).

Currently, there is an increased focus on nonpoint source (NPS) pollution since many of the point sources are now regulated and have shown marked improvements over the past decades. NPS pollutants such as sediment and nutrients contribute greatly to the water impairment in Tennessee, with agriculture often cited as the primary

source (USEPA, 2004). Aquatic life is often threatened either directly (e.g. clogged gills in fish) or indirectly (e.g. loss of habitat) due to excess sediment in waters. Increased sediments loads can decrease light penetration, which can influence water temperature and dissolved oxygen levels. Also, as sediment enters the waters, it brings with it nutrients such as nitrogen and phosphorus that are attached to soil colloids. Excess nutrients are a concern due to possible eutrophication of surface waters (Aschmann *et al.*, 1999). Removing sediments from water also adds greatly to the cost of supplying potable water to many communities.

Pasture animals such as beef cattle can destabilise the stream banks and cause undercuts to the bank, allowing for the introduction of pollutants such as nutrients and sediments. Additional inputs of nutrients occur when animal feed lots, pastures, loafing areas, traffic lanes and pens are located close to waters. Animal waste from these lots or pens can pollute local waterways either by runoff due to precipitation or hosing down during routine cleaning. Nutrients are also added to the stream by direct input of waste from animals in the water (Lory, 1999). In addition, poorly maintained and overgrazed pastures show high rates of soil loss (Mwendera

et al., 1997) and contribute to the sediment load of nearby streams and lakes. The reduction of NPS pollutants from all these sources will improve water quality in nearby streams and is a goal of TMDL development.

Land-use attributes can also greatly affect water quality by influencing additions of NPS pollutants to waterways. For example, N and P mobilisation depends on the relationship between source and transport factors, resulting in spatially and temporally dynamic critical source areas (Heathwaite *et al*., 2000). Impairment of water quality can be reduced by good land use management practices (Basnyat *et al.*, 2000). For agricultural NPS pollution, both federal and state funds are made available to aid the development and implementation of techniques to limit the inputs of nutrients, pesticides and sediments into the water (USEPA, 1998). Many best management practices are available for animal husbandry, including rotational grazing, alternative watering systems, stream fencing to protect stream banks and buffers, and pasture improvement.

The initial phase of most TMDLs is the identification of the major sources of point sources and estimates of NPS pollutants in a watershed (catchment). This is often accomplished by windshield surveys, land-use inventories and point source identification. The suite of TMDL development tools available through the Environmental Protection Agency (EPA) generally requires hydrological, topographical and land-use information to model both point and nonpoint pollutant delivery from different parts of the watershed (USEPA, 2005a). The land-use maps are usually five or more years old (the current landuse data available via the EPA/BASINS website http://www.epa.gov/OST/BASINS are from 1992) and are at a coarse resolution of 30 m. They are generally derived from old satellite data from LandSAT.

The Tennessee Valley Authority (TVA) has developed an Integrated Pollutant Source Identification (IPSI) system, consisting of aerial photographs of the entire watershed, a GIS database and a set of analysis tools to help plan and implement watershed restoration efforts. This approach was used to assess the Little River watershed in Tennessee, to "assist with efforts to influence practices that adversely impact water resources, to restore impaired streams and to keep additional streams from becoming degraded" (TVA, 2003). One advantage of using IPSI is that it does not require a high level of hydrological modeling experience. It is a visual and easily manipulated database that may serve as a more practical tool for watershed plans rather than the more complicated and temperamental TMDL modeling tools. IPSI requires the availability of high resolution (1 m or better) aerial photographs which are rapidly becoming more available in the U.S. and many other regions of the world.

Pond Creek is located in the Upper Tennessee River Basin, within the Watts Bar/Fort Loudon watershed (U.S. Geological Survey Hydrologic Unit Code 06010201) as shown in Figure 1. The total watershed area is approximately 9543 ha, of which dairy and pasture-based beef operations are the dominant land use. The topography of this watershed, typical of the ridge and valley region of the eastern U.S., shows gently rolling hills, with many meandering tributaries, and agriculture located in the floodplain. Elevations range from 239 m to 336 m. The soils in this region are predominantly Inceptisols and Ultisols.
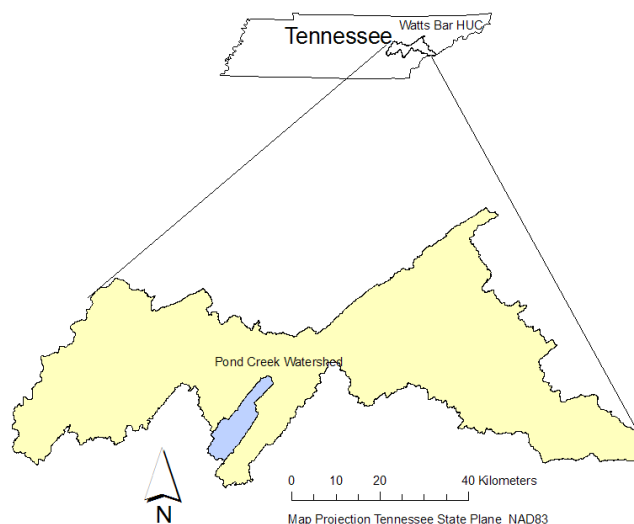

Figure 1.   Location of Pond Creek within Watts Bar hydrological unit in Tennessee

Studies conducted by the University of Tennessee in 2001 and 2002 (Day, 2002; Sasser, 2003) showed consistently high levels of sediments, nutrients and pathogens throughout Pond Creek. As a result, it was added to the state's list of impaired streams in 2003, thus requiring the development of TMDLs for these pollutants. We decided to focus on sources of sediment in Pond Creek, since other pollutants often travel in sediment. Total suspended solids measured at eight sampling sites along the creek have been as high as 577 mg L^{-1} (Day, 2002).

The objectives of this study were to:

1. Create a current, 0.3 m resolution landuse map of Pond Creek watershed based on aerial photographs.
2. Use TVA's IPSI tool to estimate the sediment delivery from pastures in the watershed.
3. Use TVA's IPSI tool to estimate soil loss from eroding stream banks.
4. Use the landuse map to classify and evaluate riparian condition along impaired sections of the stream.
5. Evaluate the usefulness of the IPSI tool for watershed planning.

Methods and materials

The nonpoint source inventory was based on colour infrared aerial photographs taken in March, 2002. Plant chlorophyll is highly reflective in the near infrared, allowing inferences about vigour and type of vegetation. The photograph scale was 1:24 000.

Based on hydrology, Pond Creek's watershed was divided into 19 subwatersheds (Figure 2), ranging in size from 24 to 985 ha. The entire watershed was divided into unique polygons, each one assigned a land-use code based on land-use characteristics interpreted from aerial photography (TVA, 2003). In this study, we were interested in the polygons classified as 'pasture' in four different conditions. 'Good pasture' (probably hay) is well maintained and covers most of the soil. 'Fair pasture' exhibits uneven
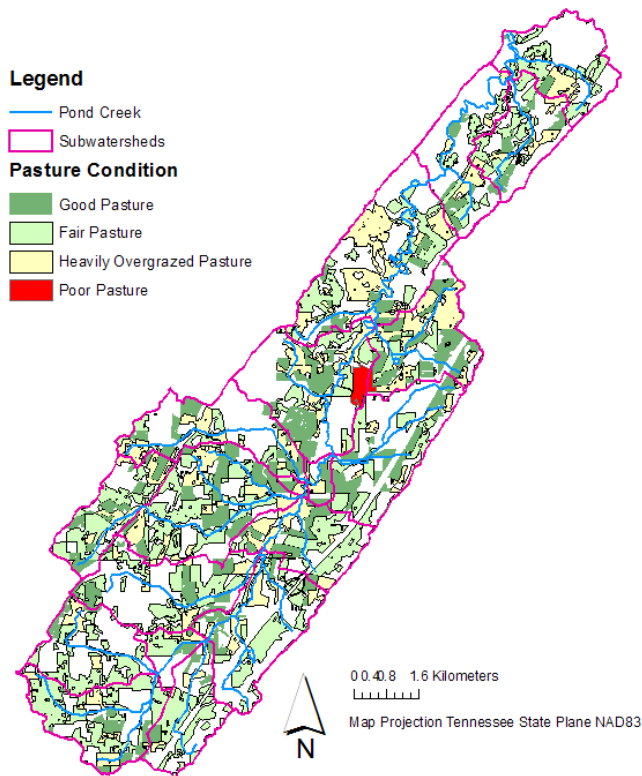
Figure 2.   Subwatersheds and pastural condition, based on photointerpretation

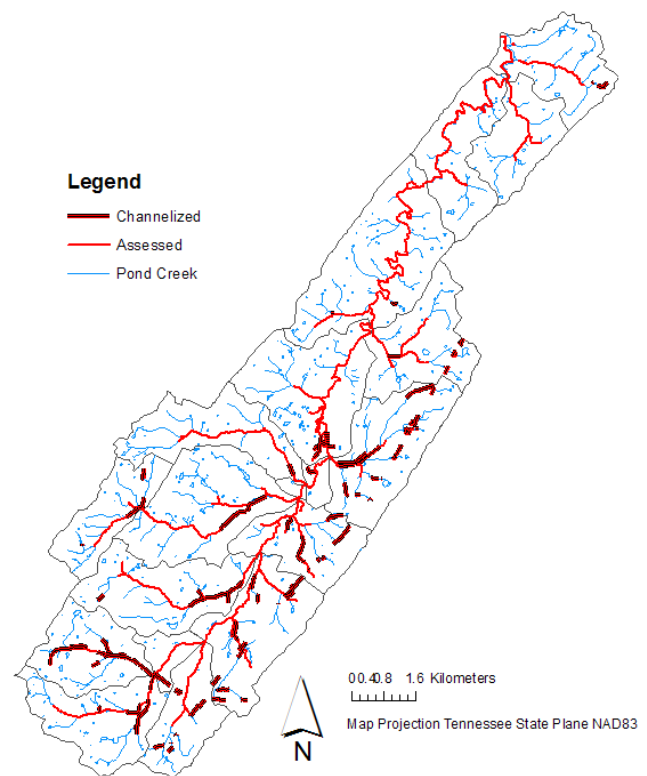

Figure 3.   Stream segments assessed for erosion, chanelisation and riparian buffers

growth and condition and minimal maintenance. 'Heavily overgrazed pasture' shows large areas of open soil and poorly maintained vegetation. 'Poor pasture' is characterised by sparse cover, shallow soils and steep slopes, and often has gullies.

Sediment delivery from pasture was based on the Universal Soil Loss Equation (USLE), using parameters recommended by the Natural Resources Conservation Service (NRCS) for this region of Tennessee. Granted, not all of the sediment leaving an eroding surface will end up in the waterway; some will settle out or be diverted along the way. However, knowledge of the relative amounts from different areas of the watershed can be helpful to direct restoration efforts and educate farmers and other stakeholders. Watershed-specific soil erodibility and slope-length factors were area-weighted.

Stream segments that are 'eroding' have visible, collapsed banks. It can be assumed that just about all of the sediment lost from the stream banks will contribute directly to the sediment load of the stream. Values for stream bank erosion rates were estimated from calculations based on the average bank height and average recession rates of eroding banks (TVA, 2003). Values of these parameters were also obtained from the local NRCS using critical erosion rates. Since streambank erosion is very much related to riparian buffers along the stream, we decided to also assess riparian condition throughout the watershed. The left and right bank buffer widths were divided into five classes: 1 = 0 to 5 m; 2 = 5 to 9 m; 3 = 9 to 15 m; 4 = 15 to 30 m; 5 = greater than 30 m. The density or percent of stream bank vegetation cover was divided into three classes: 1 = 0 to 33%; 2 = 34 to 66%; 3 = 67 to 100%. Due to limitations in aerial photointerpretations, only 73.4 km of Pond Creek and its tributaries were evaluated for right and left bank vegetation conditions (see Figure 3).

Results and Discussion

Overall, the percent of land in pasture in the Pond Creek watershed is 55%, ranging from 35% in subwatershed 1 to 94% in subwatershed 9 (Figure 1). Of all pasture in the entire watershed, 25.9% is classified as 'Good', 45.5% is 'Fair', 27.1% is 'Heavily overgrazed' and less than 1% is 'Poor' (data not shown). Three subwatersheds have more than 40% of pasture classified at heavily overgrazed or poor; only two subwatersheds have any pasture rated as poor (data not shown).

All pastures in the entire watershed contribute an estimated sediment load of 2015 Mg yr^{-1} (Table 1), which is much less than the estimated sediment load from eroding streambanks that were evaluated (3829 Mg yr^{-1}). However, the cost for pasture improvement is much less than streambank restoration, so immediate efforts to improve pastures are warranted. The bulk of sediment loss (83%) from pasture, or 1685 Mg yr^{-1}, is from heavily overgrazed pastures. Heavily overgrazed pastures account for 95% of the total sediment delivery from pasture in three subwatersheds, where the target of watershed restoration efforts should be improvement of these pastures to at least fair condition (Table 1). If these pastures cannot be renovated, they should be allowed to revert to natural conditions and animal access restricted. The 41 ha in poor pasture need immediate attention and should be a top

Table 1. Esimated sediment loading (Mg yr⁻¹) from pastures and soil loss from streambanks in Pond Creek watershed and its subwatersheds.

SubW-ID	Total area of subwatershed (ha)	Total length stream (km)	Good pasture pasture	Fair pasture	Heavily overgrazed	Poor pasture	Total pasture	Estimated soil loss-eroding streambanks
1	495	17.5	0.3	13.9	66.9	0.0	81.1	154
2	535	20.5	1.5	12.7	85.6	0.0	99.8	190
3	418	10.5	1.3	13.9	86.9	0.0	102.1	194
4	985	30.1	1.4	21.5	368.1	0.0	391.0	743
5	775	26.0	2.3	8.3	116.9	77.5	205.0	390
6	541	16.7	2.9	6.3	200.8	23.4	233.4	444
7	72	2.1	0.3	0.4	12.8	0.0	13.6	26
8	670	22.8	2.2	10.6	39.6	0.1	52.5	100
9	24	0.6	0.1	0.3	8.8	0.0	9.2	17
10	557	15.8	1.6	5.8	122.9	0.0	130.2	248
11	447	13.9	1.0	10.5	91.7	0.0	103.2	196
12	801	25.1	2.4	18.7	144.8	0.0	165.9	315
13	395	13.4	1.1	9.5	52.8	0.0	63.3	120
14	648	17.6	1.5	14.1	50.3	0.0	65.9	125
15	648	19.9	0.8	12.2	84.3	0.0	97.3	185
16	129	3.3	0.3	4.2	19.3	0.0	23.8	45
17	382	9.7	0.6	11.6	31.2	0.0	43.4	82
18	553	16.8	0.9	17.4	56.8	0.0	75.0	143
19	469	14.3	0.5	14.4	44.1	0.0	59.1	112
Total	9543	297.0	11	206.0	1685.0	101.0	2015.0	3829

priority for any restoration plan.

Of the 297 km of digitised perennial streams in the Pond Creek watershed, 73.4 km were accessed for streambank erosion, with 47.8 km classified as 'eroding' (data not shown). The range of estimated soil loss from eroding streambanks is 0 Mg yr⁻¹ to 500 Mg yr⁻¹ (Table 1). Best management practices directed at reducing streambank erosion would be beneficial in these sections of the watershed, such as fencing cattle out of the stream, revegetation and riprap in sections unsuitable for revegetation.

More than 30 km of the stream were classified as channelised, meaning they had been straightened in some form to reduce or redirect flooding (data not shown). Restoration of the natural stream channel in these sections of Pond Creek might also lessen bank erosion downstream from the channelised segments.

The recommended width for stream riparian buffer zones is 30 m in our region. More than half of the stream sections evaluated for vegetation condition were found to have both left and right bank vegetation widths of less than 5 m (Table 2). The vegetative cover, however, was estimated as 67% or greater in more than half of the evaluated stream sections. Several subwatersheds showed serious problems with vegetative cover, and restoration efforts should be directed at increasing riparian zones to a minimum of 30 m.

Summary and conclusions

Aerial photointerpretation and GIS tools such as IPSI are useful to estimate delivery of NPS pollutants such as sediment in a watershed. The resultant inventory, available

Table 2. Summary of streambank and riparian buffer conditions in Pond Creek Watershed (km).

Total digitized streams from aerial photograph	297.0
Total length of streambanks (both left and right) evaluated for vegetative cover	73.4
Categorized as "eroding"	47.8
Left bank vegetation width	
0 to 5 m	38.3
5 to 9 m	7.2
9 to 16 m	11.3
16 to 30 m	6.4
> 30 m	10.1
Right bank vegetation width	
0 to 5 m	39.8
5 to 9 m	6.3
9 to 16 m	10.8
16 to 30 m	7.2
> 30 m	9.3
Left bank vegetation cover	
1 = 0% to 33%	6.8
2 = 34% to 66%	21.3
3 = 67% to 100%	45.4
Right bank vegetation cover	
1 = 0% to 33%	8.1
2 = 34% to 66%	20.8
3 = 67% to 100%	44.6

on a subwatershed scale, can be used to prioritise watershed restoration efforts, educate stakeholders and improve implementation of best management practices. It is possible to also use aerial photography to identify and assess other sources of NPS such as leaky septic fields, sites where livestock have access to water, feedlots, row crops, and construction sites.

Acknowledgements

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