Using ATtILA (Analytical Tools Interface for Landscape Assessments) to estimate landscape indicators and target restoration needs

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Biographical Sketch of Presenting Author

Jim Harrison has worked for EPA for 16 years. His ongoing projects include: developing biological and nutrient criteria, community-based environmental protection projects (Hiwassee River Basin initiative, and urban stream restoration), and geographic planning. He received the National Performance Review's "Hammer" award and EPA's Bronze Medal for co-leading the Southern Appalachian Assessment aquatic team. He holds the Master of Public Affairs Degree from the LBJ School at the University of Texas and a BS in Earth and Planetary Science from MIT. He is from the Blue Ridge Mountains ecoregion of Western North Carolina, and founded the Pigeon River Action Group.

Abstract

Water quality and ecosystem management should integrate multiple scale assessments encompassing basic, local-scale investigations to complex, multiple-stressor regional analyses. Landscape ecology provides theories to strengthen assessments. Geographic information systems (GIS) supply tools to implement them, such as landscape indicators - quantitative measurements of environmental condition or vulnerability for an area (e.g., ecoregion or watershed). Producing landscape indicators can be complex, lengthy, and require substantial GIS expertise.

EPA's Office of Research and Development, in cooperation with EPA Region 4 and TVA, has developed user friendly software that simplifies calculation of common landscape indicators, regardless of GIS knowledge level. ATtILA is an ArcView extension (requires ArcView 3.1 and Spatial Analyst 1.1) that accepts disparate data sources and is suitable across diverse landscapes, from deserts to rain forests to urban areas. The extension includes four families of indicators: landscape characteristics (e.g., percent forest cover), human stresses (e.g., population change and road/stream crossings), riparian characteristics (e.g., percent crop land within 30 meters of streams), and physical attributes (e.g., elevation range). Within each group users can: select indicators to calculate, choose input data, and modify selected assumptions. Display options include: maps of areas ranked by individual indicator values or multiple indicator weighted indices, and bar charts.

Multiple scale examples depict uses of landscape factors for: describing ecological regions of the Southeastern United States, exploring synergistic utility of South Carolina's ecological regions and hydrologic units, targeting restoration needs for Brasstown Creek's (GA/TN) sub-watersheds, and describing road and riparian influences on sedimentation in the Chattooga watershed (GA/NC/SC). Landscape indicators are readily available and should become integral for water quality assessments.

Introduction

Many of today's water quality problems stem from human uses of and impacts on landscapes (Naiman 1996). Solving these problems through restoration (Federal Interagency Stream Restoration Working Group 1998) and prevention (Center for Watershed Protection 1998) will depend on understanding the processes and links between landscape activities and subsequent stresses to and impacts on aquatic systems. As our understanding of aquatic ecosystems increases through integration of multiple measures of aquatic health including: chemistry, biological communities, habitat structure, channel geomorphology and hydrology (Karr 1993); we are also beginning to recognize the need to better describe and understand the myriad landscape practices and stresses that affect our waters. Advances in landscape ecology and Geographic Information Systems (GIS) techniques have made landscape factors viable tools for targeting water quality concerns (see Jones and others 1997). Landscape measures are proposed as one of the critical ecological indicators for nationwide application (National Research Council 1999a).

A wide array of environmental protection efforts have a continuing need to quickly and economically characterize important landscape factors affecting watersheds and ecological regions at many scales. These include community based environmental protection projects, watershed restoration projects, water quality standards development (including biocriteria, nutrient criteria and others), TMDL (Total Maximum Daily Load) screening and development efforts, nonpoint source identification and modeling efforts, and wide area statistical surveys of water resource integrity. Widespread, economical use of landscape measures requires more accessible and less expensive software, tools and data (see Berish and others 1999, and SAMAB 1996a & b.)

ATtILA (Analytical Tools Interface for Landscape Assessment)

Fortunately, landscape data, analysis tools and the information embodied in landscape factors are increasingly available to fill this knowledge gap. ATtILA (Analytical Tools Interface for Landscape Assessment) is an easy-to-use software extension for ArcView "desktop" GIS developed by EPA's Office of Research and Development (ORD) (Ebert and Wade 2000). It currently uses readily available land cover and other spatial data to summarize and map over 50 landscape factors thought to be important to water quality concerns (see Jones and others 1996). The Watershed Characterization System (WCS) is a complementary tool being developed by EPA Region 4 to facilitate site-specific and process modeling applications for TMDL development.

Landscape Characteristics available through ATtILA (listed below) use land use/land cover data such as MRLC (Multi-Resolution Landscape Characterization) (Vogelmann and others 1998a and 1998b), SAA (Southern Appalachian Assessment) (SAMAB 1996a & b), and other data such as aerial photography derived land use/land cover. Any available analysis boundaries (based on polygons/shape files) can be used including watersheds, hydrologic units, ecological regions, counties (all readily available as part of EPA's BASINS water quality tools, see Lahlou and others 1998), and others. Slope based factors also rely on slopes derived from digital elevation models (DEM's). The slope based factors are flexible; the user may specify desired slopes. Total area is also calculated for each factor.

Pagc - Percentage of crop land
Pagp - Percentage of pasture
Pagt - Percentage of all agricultural use
Pbar - Percentage of barren
Pfor - Percentage of forest
Purb - Percentage of urban
Pusr1 - Percentage of user defined class
Pwetl - Percentage of wetland
N_index - Percentage of all natural land use
U_index - Percentage of all human land use
AgcSL - Agricultural crop land on steep slopes

AgpSL - Agricultural pasture on steep slopes
AgtSL - Total agricultural land use on steep slopes
Usr1SL - User defined class on steep slopes

Human Stresses factors utilize land use/land cover, census population data, and road and stream line coverages. Assumptions for land use/land cover based Phosphorus & Nitrogen loading and impervious cover estimates can be tailored by the user to match local calibrations. Road based factors (*) include road class if available.

P_LOAD - Phosphorus loading
N_LOAD - Nitrogen loading
POPDENS - Population density
POPCHG - Change in total population
PCTIA_LC - Impervious cover, based on land use
RDDENS* - Road density by road class
RDLEN* - Total road length by class
STXRD* - Number of road/stream crossings by road class
PCTIA_RD - Percentage of impervious cover, based on road density
STPRD* - Length of roads in close proximity to streams (user defined distance) by class

Physical Characteristics utilize rainfall estimates such as PRISM (Daly and others 1997, and NRCS 2000) for precipitation factors, plus digital Elevation Models (DEM's) and stream line coverages for the other physical factors. Stream density and length (*) can be specific to stream order if available.

PRCPRNG - Precipitation range
PRCPMIN - Minimum precipitation
PRCPMAX - Maximum precipitation
PRCPMEAN - Average precipitation
PRCPSTD - Standard deviation of precipitation
ELEVRNG - Elevation range
ELEVMIN - Minimum elevation
ELEVMAX - Maximum elevation
ELEVMEAN - Average elevation
ELEVSTD - Standard deviation of elevation
SITE_ELEV - Elevation at point locations
SLPRNG - Slope range
SLPMIN - Minimum slope
SLPMAX - Maximum slope
SLPMEAN - Average slope
SLPSTD - Standard deviation of slope
STRMDENS* - Stream density
STRMLEN* - Total stream length

Riparian Characteristics utilize land cover and line coverages of streams. Buffers can be automatically generated for two user defined buffer widths and the resulting maps can be saved: for example - riparian natural for a 30 meter buffer.
Ragc - Percentage of stream length adjacent to cropland
Ragp - Percentage of stream length adjacent to pasture
Ragt - Percentage of stream length adjacent to all agricultural use
Rbar - Percentage of stream length adjacent to barren

Rfor - Percentage of stream length adjacent to forest
Rurb - Percentage of stream length adjacent to urban
Rusr1 - Percentage of stream length adjacent to user defined class
Rwetl - Percentage of stream length adjacent to wetland
Rnat - Percentage of stream length adjacent to all natural land use
Rhum - Percentage of stream length adjacent to all human land use

Innovative features are incorporated throughout the ATtILA extension and make it a flexible and easy to use tool. The custom reclassification dialog makes simple and intuitive use of a variety of land use/land cover data sets. For example, air photo derived land use data can be easily incorporated, and each custom reclassification can be saved for future use. The Create Indicator Atlas function quickly generates maps for any of the landscape indicators produced. The Create Indicator Index function allows evaluation of combinations of weighted landscape factors. Additionally, all user input dialogs are programed to select appropriate input themes (spatial data sets) based on searching the themes in one's ArcView Project for commonly used names such as watershed, basin, land cover, slope, census, stream, river, road, and many others. User defined classes can use any combination of land use/land cover classes.

Geographic Frameworks - Ecological Regions and Watersheds

Appropriate geographic analysis units for aquatic ecosystem studies are crucial to enhance understanding of important processes. Both ecological regions and watersheds are essential geographic frameworks necessary to describe, diagnose, and eventually, predict landscape influences on water resources. "...the issue is not whether to use watersheds (or basins or hydrologic units) or ecoregions for needs such as developing ecosystem management and non-point source pollution strategies or structuring water quality regulatory programs, but how to correctly use the frameworks together." (Omernik and Bailey 1997) ATtILA constitutes an important tool to facilitate GIS approaches for simultaneously using ecological regions and watersheds to describe and eventually understand aquatic ecosystem patterns and processes.

Ecosystem and ecological region definitions have been evolving to include: biotic and abiotic characteristics, human systems as a biotic influence, and multiple scales vs. only small areas (Omernik and Bailey 1997). While no universally accepted definition of ecological regions exists, many successful applications have resulted from classification approaches that delineate ecologically distinctive areas resulting "...from the mesh and interplay of the geologic, land-form, soil, vegetative, climatic, wildlife, water and human factors... present. The dominance of any one or a number of these factors varies with the given ecological land unit. This holistic approach to land classification can be applied incrementally on a scale-related basis from very site-specific ecosystems to very broad ecosystems." (Wiken 1986)

Ecological regions have several distinct advantages as a tool to define and promote integrity and stability as part of ecosystem management. Ecoregions illuminate ecosystem patterns at multiple scales, aiding visualization of differences between ecosystems. Most ecoregions include typical, minimally impacted areas that can be used to define reference (desired) conditions; a basis for comparison to impacted areas. Ecoregions' particular potentials for human uses (agriculture, forestry, etc.) result in characteristic patterns of human disturbance over time. Cumulative human disturbances yield a suite of risks to aquatic systems that is ecoregion specific. Ecoregions can be used as reporting frameworks that clarify patterns of environmental data (such as nutrient transport) reflecting both natural and human influences. Ecoregions allow development of management strategies appropriate to regional expectations, and thus, define areas where standardized management practices can be applied after being proven in individual sites or watersheds. Finally, since multiple areas within an ecoregion are "similar," they should respond similarly to stresses or management actions. Thus, ecoregions are appropriate areas for extrapolation of monitoring (statistical sampling for example) or research results (Bryce and others 1999a).

Consistent multi-scale ecoregional frameworks are being developed through international cooperation in North America (Commission for Environmental Cooperation 1997), through interagency cooperation in the United States (MOU 1995), and in many States at a finer scale. Ecological regions are showing many practical applications for water resource and water quality management (Davis and Simon eds. 1995). Ecosystem management within a geographic framework defined by ecological boundaries "...is a common sense way for public and private managers to carry out their mandates with greater efficiency." (National Research Council 1999b) The ecoregion frameworks incorporated in the following examples include the Omernik Level 3 (Omernik 1995) ecoregions as revised for Southeastern states, and Omernik Level 4 ecoregions drafted (still under review) for the State of South Carolina.

Watersheds, almost everyone agrees, are land areas where surface runoff drains to a specific point on a stream or other water-body (Omernik and Bailey 1997). They are also essential for study of natural and human effects on water quality and quantity. Watersheds come in all sizes ranging from small catchments ($\sim 10^6$ $m^2 = 1km^2$: first through third order streams) to large river basin systems ($\sim 10^{12}$ m^2: 9^{th} order) such as the Mississippi River (National Research Council 1999b). Watersheds are best used to assess contributions of human activities upgradient of specific points on streams or other water bodies.

Hydrologic units established by the USGS (8, 11 and 14 digit HUC's (Hydrologic Unit Codes)) are widely available and are often used as surrogates for watersheds. However, many HUC's are not watersheds (Omernik and Bailey 1997), and this must be recognized when using HUC's for water quality or landscape analyses. The USGS, NRCS and other agencies are cooperating to produce, within the next year, consistent 14 digit HUC's nationwide and watersheds generated from every stream confluence (node). GIS techniques can also be used to generate a watershed from any point on a landscape using digital elevation models (DEM's). Several of the following example products utilize 11 and 14 digit HUC's for the State of South Carolina (USGS 1999).

Scale

Understanding ecological scale effects is required to apply local information to processes that operate at larger scales: for example - plots to regions, watersheds to basins, catchments to ecological subregions and others. Several approaches to and definitions of scale can be important for ecological systems, where the interest is in describing ecosystem patterns, and the processes that drive those patterns. Cartographic, or map scale is simply the ratio of map distance to earth surface distance. Geographic scale, or extent, covers an area of concern. Operational scale covers the extent of operation of specific processes. Relative scale concerns the relationship between processes and the environment where those processes occur. Relative scale can be thought of as the relationship between grain size relevant to a particular process and the extent of the map area of concern (Jenerette and Wu 2000).

Geographic, operational and relative scale depend on the nature of the underlying data upon which they are based and cannot be changed without collecting additional data or resampling available data. Downscaling is generally not appropriate without careful use of auxiliary information. Upscaling (applying fine-scale information at a coarser scale) should be easier but is still a challenge to enhance ecological understanding. All of the examples that follow use (relatively) fine grained data aggregated to coarser scales.

Example Products: Large Areas - Satellite derived land use/land cover (LU/LC)

The following example products, based on the draft MRLC LU/LC for the eight states of EPA Region 4, illustrate the usefulness of ATtILA for describing the distributions and patterns of land use/land cover in the Southeastern United States. Figure 1 shows the distribution of N Index (sum of natural land use classes: forest plus wetland) for major ecological regions (Omernik Level III) of the Southeast. The Blue Ridge evidences the least human impact on the landscape, while the Mississippi Alluvial Plain (Delta) has the most human influence. Table 1 depicts examples of the range of selected landscape factors for three major Southeastern ecoregions. Both natural conditions (forests and wetland) and human stresses (urban development and land clearing for agriculture) show characteristic tendencies specific to each ecological region.

Table 1: Example selected landscape factors for several major Southeastern ecological regions

Ecological Region	**N Index %**	**Forest %**	**Wetland %**	**Urban %**	**Agriculture Total %**	**Pasture %**	**Crop %**
Blue Ridge	92.2	92.0	0.1	1.6	5.7	4.2	1.5
Southern Piedmont	73.7	72.0	1.6	5.2	19.2	9.8	9.4
MS Alluvial Plain (Delta)	27.0	3.2	23.8	0.9	71.8	7.3	64.6

Looking at a finer scale of ecological regions, Figure 2 shows the distribution of wetlands in South Carolina by ecological subregion (Omernik Level IV). The highest fraction of wetlands (~70%) occurs for the Mid Atlantic Floodplains and Low Terraces sub-region. The lowest fraction of wetlands (0.16%) occurs in the Blue Ridge. The Sea Islands/Coastal Marsh sub-region has approximately 35% wetlands, and the Southern Lower Piedmont about 0.75%. Thus, both of these examples indicate that aggregation of 30m resolution land use/land cover data to the level III and level IV ecological region scales can be done to meaningfully describe those regions.

The next three figures depict impervious cover estimates based on land use/land cover at three different scales. Figure 3 shows ranges of imperviousness for South Carolina sub-ecoregions (Omernik Level IV). Maximum imperviousness for any of the sub ecoregion areas is about 6.8%, small areas that cover part of urban Columbia. No areas are close to 10% impervious. Detrimental hydrologic effects are thought to be highly probable with impervious area greater than 10% (Schuler 1994, May and others 1997, and Booth and Jackson 1994). Figure 4 shows the range of imperviousness for 282 “11 digit” hydrologic units (11 digit HUC’s) in South Carolina. Thirteen (13), or 4.6%, of these 11 digit HUC’s have impervious estimates of >10%. At a yet finer scale, Figure 5 shows estimated impervious area for 1031 “14 digit” HUC’s in South carolina. Of these 14 digit HUC’s, 76 (7.4%) have impervious estimates >10%.

Examining imperviousness at these three scales (all based on the same 30m resolution satellite derived land use/land cover) clearly indicates that urbanization, leading to potentially hydrologically significant levels of impervious cover, is more likely to be a dominant process with adverse water resource integrity effects for smaller watersheds and for smaller, disjunct ecological areas. While the aggregation is meaningful at all three scales, significant aquatic stress is indicated more often for the smaller HUC’s. Expanded utilization of remote sensed information will be essential to understand urban development stresses on aquatic systems, prevent degradation due to urban expansion, and, hopefully, restore impaired urban aquatic systems (Cowen and Jensen 1998.)

ATtILA will be used at all of these scales to derive descriptive landscape factors products for the entire Southeastern United States as part of the Regional Ecological Assessment Program (REAP), an ecological assessment effort now being planned by EPA Region 4 (Atlanta, GA), EPA’s Office of Research and Development, and other partners.

Example: Sub-watersheds - Satellite derived LU/LC

Landscapes dominated by other human uses, such as agriculture, also have characteristic stresses and aquatic ecosystem impacts. The Brasstown Creek sub-watershed (part of the Hiwassee River Basin in Georgia and North Carolina) has been targeted for restoration action through a $2 million grant from the North Carolina Clean Water

Management Trust Fund (CWMTF 2000) to address sedimentation from stream bank erosion, riparian area degradation, and other stresses in the watershed.

Riparian and watershed landscape factors for Brasstown Creek catchments derived using ATtILA's riparian tools based on the Southern Appalachian Assessment's 30m resolution satellite data (SAMAB 1996b) show predominantly agriculture related stresses. These include specific catchments with high fractions of pasture on steep slopes (>5% slope), and those catchments with the lowest riparian N Index. Figure 6 illustrates the distribution of riparian pasture adjacent to streams for all of Brasstown Creek's catchments as an aid for prioritization of more detailed study of particular small watersheds for riparian and stream bank restoration projects. Riparian pasture using a 90m buffer (sufficient width to allow for locational uncertainty of the stream lines) shows a similar pattern of high stress for specific watersheds. Several catchments with a high percentage of riparian pasture also occur in Georgia. Since the NC Clean Water Trust Fund monies can only be used in that state, this analysis stresses that additional restoration resources will likely be needed to address the key Georgia catchments, promote a whole watershed approach, and ensure positive environmental results for Brasstown Creek.

ATtILA is also being used by the Tennessee Valley Authority (TVA) to develop a detailed landscape factors "atlas" for all of the drainages (30+ watersheds) within the Hiwassee and Ocoee basins to support restoration planning and project implementation by the Hiwassee Interagency Team - a multi-agency, federal, state and local watershed partnership.

Example: Watershed/Sub-watershed Scale - Air Photo LU/LC, Roads, Streams

Landscapes dominated by forestry activities may require finer grain, higher resolution landscape data to adequately describe key processes affecting aquatic ecosystems. The Chattooga River watershed (covering portions of Georgia, North Carolina and South Carolina) has been intensively studied (USEPA 1999) to support identification of impaired waters and development of sediment TMDL's (Total Maximum Daily Loads).

Air photo derived LU/LC (approximately 3m resolution), roads and streams produced by the Tennessee Valley Authority (TVA) as part of this study were used to test several other ATtILA features. Road/stream crossings were described using detailed roads line work (including all dirt and gravel roads) and stream coverages (perennial, intermittent and ephemeral channels). For the whole basin 856 road/stream crossings were identified. Upper Stekoa Creek, which includes the town of Clayton, GA, had the highest number of crossings (208) among all of the Chattooga sub-watersheds. Figure 7 shows the distribution of road density for Chattooga sub-watersheds; again, upper Stekoa Creek having the highest road density of 3.6 miles/mi^2. Roads are believed to be one key sedimentation process related to forestry and other land use activities in the Chattooga watershed. Pruitt found that storm event sediment yield (combined suspended sediment and bed load) was significantly related to total drainage density (as defined by combined stream and road density) for 5 drainages sampled (Pruitt 1999).

Figure 8 depicts the distribution of riparian N Index adjacent to streams for the same Chattooga sub-watersheds, indicating that riparian area degradation is also likely to be an important process contributing to sedimentation through stream-bank erosion. Again, Stekoa Creek showed the lowest riparian N Index of 49.4 % among the sub-watersheds. The riparian N Index using 90m buffers was nearly identical to the "adjacent to streams" value for all sub-watersheds. High resolution riparian information may also be important to understand landscape influences on stream temperature and effects on salmonid species (Nagasaka and Nakamura 1999). The ATtILA riparian and road/stream tools have substantial potential for describing and understanding sedimentation and other problems and processes throughout the Southeast.

Conclusions

Ready availability of landscape data, and the tools required for meaningful and inexpensive analysis of that data, argue for more rapid and extensive use of landscape factors for many types of water quality studies and projects. Landscape factors incorporating stream reach and watershed stressors have been used to construct a risk index system as part of data evaluation for the Environmental Monitoring and Assessment Program (EMAP) in EPA Region 3. Both water chemistry and biological in-stream measures were consistent with the risk index assessment (Bryce and others 1999b). Another promising potential use of landscape factors is to build empirical models relating in-stream measures of biology, habitat and chemistry to important landscape factors driving key processes affecting in-stream quality (Harrison 1998). Using appropriate combinations and scales of ecological regions and watersheds to develop calibrated landscape-in-stream models should allow extrapolation of in-stream condition estimates to many waters lacking in-stream data. Relevant uses for such extrapolations include: screening for problem areas, targeting of additional monitoring to confirm problems, prioritization of TMDL and restoration efforts, and evaluation of water resource condition for large areas, including areas lacking in-stream data.

Key remaining challenges for further development of landscape/in-stream models include: development of specific relationships for particular ecological regions, and insuring that the models work well for landscapes dominated by urban, agriculture or forest land uses, rather than only a narrow portion of the landscape. This will require careful identification of predominant landscape stresses affecting water resource integrity by ecological region.

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