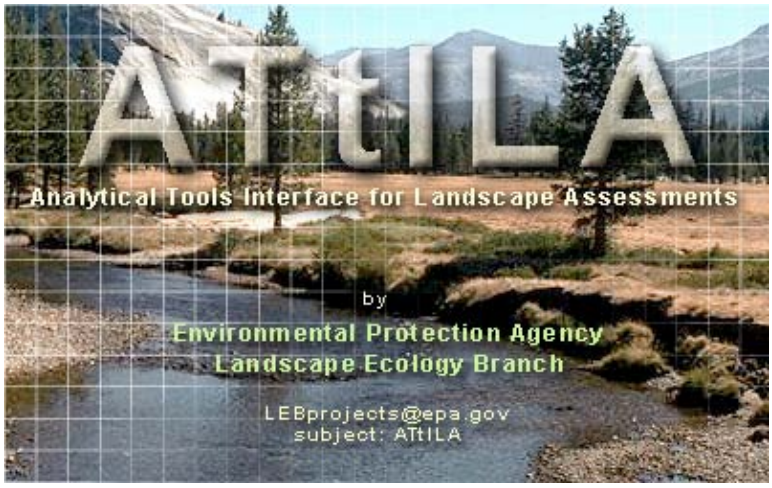



# *Analytical Tools Interface for Landscape Assessments*

(ATtILA)

User Manual

EPA/600/R−04/083

Version 2004

Lead programmer: Donald W. Ebert
Programmer: Timothy G. Wade

U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Environmental Sciences Division
Landscape Ecology Branch
Box 93478
Las Vegas, NV 89193

***Notice:*** The information in this document has been funded wholly by the United States Environmental Protection Agency. It has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

# Contents



# I. What is ATtILA?

ATtILA is an ArcView extension that allows users to easily calculate many common landscape metrics. GIS expertise is not required, but some experience with ArcView is recommended. Four metric groups are currently included in ATtILA: landscape characteristics, riparian characteristics, human stressors and physical characteristics. There are also four display options to view metric results. ATtILA is written in Avenue, ArcView's programming language, and is designed to accommodate spatial data from a variety of sources.

This guide provides basic information on installing and using ATtILA. It also provides information on sources of data compatible with ATtILA. However, it is not meant to provide background in landscape ecology. It is the user's responsibility to make appropriate use of ATtILA output when conducting analyses or assessments. Users should also have some experience with spatial analysis and spatial data to ensure proper use of ATtILA. New users should read through this manual at least once to familiarize themselves with potential pitfalls associated with spatial data, ArcView limitations, or ATtILA processes. Important points are usually identified by italics in this document. A collection of appendices are included that contain a metric glossary, default land cover coding schemes, sample metadata, and more detailed information on some methods used in ATtILA. Please report bugs and forward comments to: LEBProjects@epa.gov and include "ATtILA" in the subject line.

# II. System Requirements

## A. Hardware

Because of the size of landscape data sets and the complexity of the calculations to generate some metrics, we recommend a minimum of a Pentium III 1 GHz (or equivalent) with 256 MB of memory (RAM). These are minimum recommended specifications, and computers with faster processors and more memory are preferred.

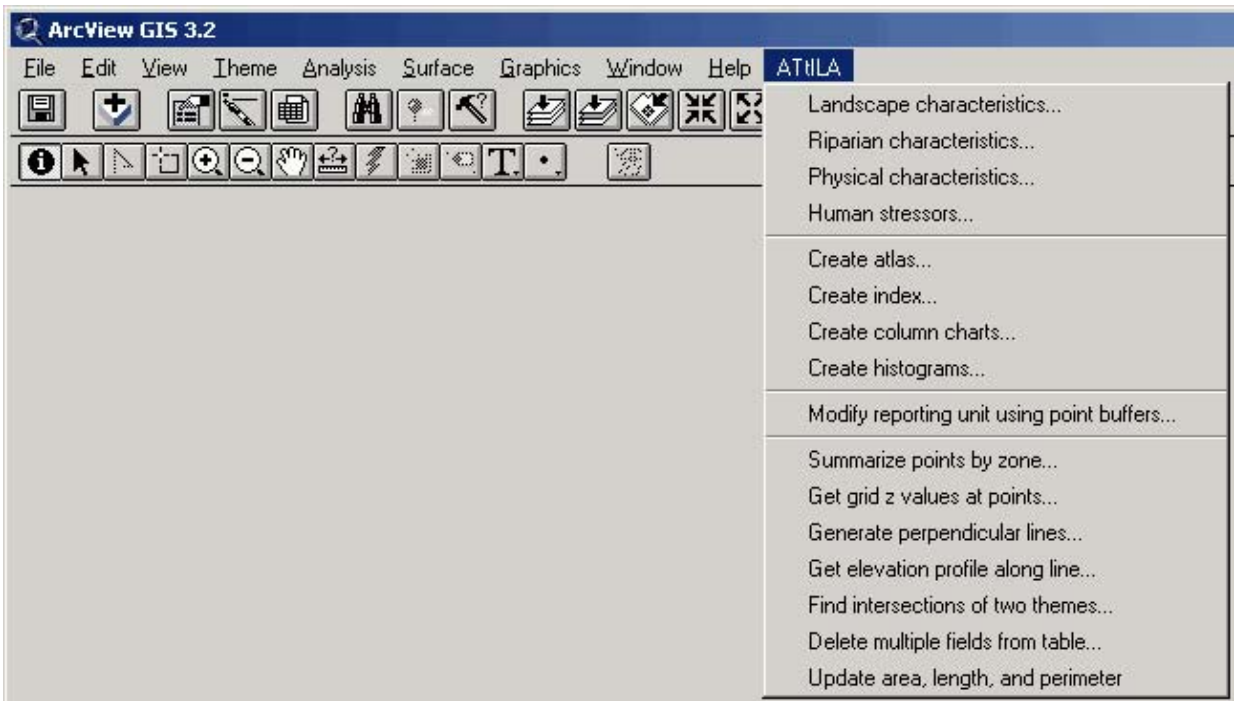
*Note:* ATtILA is intended for a 17 inch monitor (or larger) with resolution of at least 1024 x 768. A quirk inherent to ArcView may truncate text in dialog boxes on smaller monitors or lower resolution settings.

## B. Software

ATtILA requires ArcView 3.1 or later and the Spatial Analyst extension. Both UNIX and Windows (95 and newer) environments are supported.

# III. Installing ATtILA

To load the ATtILA extension, copy the attila*.avx (where * represents the version number) file to ArcView's extension directory. The Windows default location is C:\ESRI\AV_GIS30\ARCVIEW\EXT32, the location varies on UNIX systems, but will be called "ext" in the ArcView installation directory (you may require root privileges to do this). In ArcView, make the project window active, go to the File menu, click on Extensions, and turn on ATtILA. This will add an ATtILA menu to the far right of both the view and the table Graphical User Interfaces (GUI). The view GUI is shown below. Some menu items may be gray or "ghosted" if the data types they require are not present in the table of contents.



# IV. Data Requirements

ATtILA is extremely flexible. It will accept a wide range of data as input for its various metrics. Spatial data sets are available from many sources, with a broad range of scales and spatial and thematic accuracy. Users are responsible for choosing data appropriate for their application or assessment.

Different metrics require different input data. To run the entire suite of metrics, you will need each of the data sets described below. Along with the descriptions, we provide examples of data sets that can be used for inputs along with some Internet links for downloading them. Most of the examples given cover the conterminous United States and are available for download free of charge. They are suitable for regional to national scale assessments. For local studies, it is recommended that you use higher resolution data if available. Use of ATtILA is not restricted to using these particular data sets, but can be run with any input data set that matches the required data set type. Vector themes may be ArcInfo coverages or ArcView shapefiles. Raster themes must be in ArcInfo GRID format. Specific sites for each type of data are given below, but there are also online clearinghouses that distribute many types of spatial data. A good place to start is the ESRI Downloadable Data website.

*Note:* The extension assumes all your data is in the same projection and datum with the same map units.

***Reporting units***

A reporting unit is a polygon that defines any area of interest (watershed, ecological region, county, etc.). The reporting unit theme may contain one or more polygons. The reporting unit theme may also contain one or more multi−part polygons (multiple polygons which may or may not be disjunct but contain the same ID field value), however, ATtILA will spatially merge these different polygons into a new single shape (see merge operations in ArcView's Help Index). All subsequent metric calculations will be performed on the new shape as a whole instead of as individual polygons (i.e., one metric value is calculated using all of the polygons with the same ID field value).

*Notes:* All reporting unit theme attributes are copied into the ATtILA output theme unless the input reporting unit theme contains multi−part polygons. If multi−part polygons are encountered, only the reporting unit's id field is maintained in the ATtILA output theme.
In any one ArcView session, Spatial Analyst has a limit of 32,767 calls that can be made to the Grid Engine. This limitation is not for any one script run or for any one ATtILA run, but for any one ArcView session. If you've had an ArcView project open for a while and have performed a number of Spatial Analyst operations, it is likely you have significantly less than 32,767 requests left for the Grid Engine when you try another operation. If that operation surpasses the available number of request left then that operation will fail. This can often be very confusing because that same operation might have run successfully in the past under what may seem to have been similar circumstances. If the operation ran successfully in the past, you can probably get it to work again by simply shutting down ArcView and restarting.
This limitation in the number of calls to the grid engine can have profound impacts on the number of reporting units that can be successfully used for ATtILA runs. For metrics that make use of Spatial Analyst's Grid Engine, the maximum number of polygons in the reporting unit theme is dependent on the number of calls still available in the ArcView session, whether or not the metric is calculated one reporting unit at a time, and the number of requests the metric's script makes to the grid engine. This impact manifests itself more often when the metric is calculated one reporting unit at a time. In a case such as this, even if the script makes just one call to the grid engine, the maximum number of polygons allowed in the reporting unit theme is 32,767 provided no other calls have been made to the Grid Engine prior to the running of this metric. For metrics where this limitation is likely to be encountered, mention shall be made in the metric's description later in the manual.

***Land cover***

Land cover must be an integer grid. Land cover codes must be known to correctly generate metrics. National Land Cover Data(NLCD; Vogelmann et al., 2001) is suitable for this theme and is available for the conterminous U.S. through the Multi−Resolution Landscape Characterization (MRLC; Loveland and Shaw, 1996) program. Another source is the USGS GAP program, however, as with all of ATtILA's data inputs, any data set that meets the stated minimum requirements may be used.

*Note:* If your land cover data contains zeroes that represent NoData, it is possible to calculate incorrect values for some metrics. In this case, convert the zeroes to NoData, or include 0 in the Water/No Data class (values in this category are ignored in metric calculations). NLCD data *does* contain zeroes that represent NoData.

***Elevation and slope***

Elevation and slope must also be grids, but can be either integer or floating point. You will need to know if slope is represented in percent or degrees to correctly set threshold values for some metrics in ATtILA. It is possible to generate either percent or degree slope from a Digital Elevation Model (DEM) in ArcView with the Spatial Analyst extension. The Derive Slope menu item from Spatial Analyst's Surface menu will calculate slope in degrees as the default. Percent slope can be obtained by using Spatial Analyst's Map Calculator (see "slope (request)" in the ArcView's help index). DEMs are available from the USGS website in several scales by quadsheet. The National Elevation Database (NED) is available at 30 meter resolution for the conterminous U.S. It is recommended you choose a DEM resolution similar to your land cover resolution.

*Note:* It is very important that the horizontal and vertical units are the same in the elevation data when generating slope. DEM data are often in decimal degrees and must be projected before calculating slope.

***Streams***

Streams must be a line theme. Stream order may be used if it is present in your data, but it is not necessary. Stream order values should be integer or character (e.g. 1, 2, 3 or first, second, third). One source of stream data is the National Hydrography Dataset (NHD), a joint USGS/US EPA effort.

***Roads***

Roads must also be a line theme. A road class attribute may be used if it is present in your data, but it is not necessary. Road class values should be integer or character (e.g., 1, 2, 3 or interstate, state highway or surface street). Road data are available from the USGS (DLG), as well as many commercial companies.

***Population***

Population must be a polygon theme. Any level of data is acceptable (county, tract, block, etc.), although you should use an appropriate level for the scale of your reporting units. Population data for the United States are available from the Census Bureau.

***Precipitation***

Precipitation must be an integer or floating point grid. Precipitation data are available from the National Climate Data Center or from regional climate centers (links to these are on the NCDC page) for a small fee. Free data may be available from your state climate center. Daymet climate data are available from the University of Montana.

***Water Quality***

Water quality sites must be a point theme. Data is available from the EPA's STORET system or from the USGS NAWQA program.

# V. The Metrics

The majority of ATtILA's functions work with views. These are discussed in sections V through VII. Section VIII covers ATtILA's table functions.

There are four metric categories listed in the ATtILA menu, each of which includes several related metrics. Making a selection displays one or more dialogs in which you enter information such as the metrics to calculate and the data sets to use.

- Before calculating metrics, the map units must be set in the view properties.

- All temporary and final output is written to the work directory set in Project Properties. The default setting is the $HOME system variable, which is usually either c:\temp (older version of Windows) or c:\Documents and Settings\[username]\Local Settings\Temp (Windows 2000 and XP). ArcView does not handle spaces in pathnames well in some cases. Be aware of this problem when saving data or projects.

- When generating the majority of metrics, the analysis environment defaults to cell size of the land cover grid and the extent of the reporting unit theme. You may override these values by manually setting the analysis properties in the Analysis menu. For several metrics, however, to speed analysis or to more accurately calculate metrics, the analysis extent is reduced to each individual reporting unit in the reporting unit theme, and adjusted slightly to align with the boundaries of the land cover grid. This is done automatically within the scripts for these metrics and will override any settings in the general analysis properties.

- On all dialogs, brief help is available by moving the cursor over the metric code or input box (more information is displayed in the status bar at the bottom of the ArcView window).

- Pressing Shift while clicking on an ATtILA menu item will provide a brief overview of that item's function and/or a listing of the available metrics that can be calculated with that selection.

- You may calculate any metric by checking the box next to it. If a metric is gray or "ghosted", it is not available. This is likely due to the metric requiring a land cover code that is not present in your data or a theme that is not available in your view.

- Descriptions of the metric codes used in ATtILA are available in Appendix 1.

- Metrics are only calculated for selected reporting units. If nothing is selected, the metric will be calculated for all units. When a subset of reporting units is selected, only selected polygons will be included in the output shapefile.

***Output Information***

ATtILA creates a new shapefile, associated attribute table and a metadata file each time metrics are generated. By default, the new shapefile is stored in the project working directory, which is the $AVHOME directory unless changed by the user. $AVHOME is usually C:\temp (older versions of Windows) or c:\Documents and Settings\[username]\Local Settings\Temp (Windows 2000 and XP) in Windows or your home directory for UNIX. The default name for the new shapefile is Attila1.shp. If previous output exists, output will be named Attila{n}, where n is one more than the highest previous output file number. Each metric you generate will create one or more fields in the new attribute table. You must have write permission in the directory where the shapefile will be stored. The new shapefile is automatically added as a theme in the active View's table of contents.

If necessary, the output shapefile will be spatially merged, that is there will be exactly one record in the attribute table for each unique ID in the reporting unit theme. If the reporting unit theme has multi−part polygons, only the ID field from the original reporting unit theme will be passed to the output attribute table. If the reporting unit theme does not have multi−part polygons, all fields are carried over to the output attribute table. In either case new fields containing selected metric values are appended to the output attribute table. In all cases, area and perimeter fields are created (or updated if they already exist). Area is the vector−based measurement of the total polygon area (i.e., it contains the total land and water area in the reporting unit), including all parts of multi−part units. Perimeter is the total perimeter of the reporting unit, including all parts of multi−part units.

It is common to calculate metrics that are located in different modules. This can result in multiple new shapefiles, each with a partial set of metrics needed for analyses. There are two ways to get all metrics into one table or shapefile. The ID field can be used to join two or more tables, so all metrics are in one table. Perhaps an easier way is to calculate the first set of metrics, and then use the output shapefile from that step as the reporting unit theme for the next set of metrics. Use that output for the next input, and so on. This way, the last output shapefile will contain metric values from all runs.

When ATtILA calculates any metric based on land cover or slope, it also calculates and reports the percent overlap between the raster data and each reporting unit. This is done by comparing the Area field described above to the total number of cells in the raster data contained in the reporting unit multiplied by the area of one grid cell. Values below 100% indicate that the reporting unit extends beyond the land cover or slope grid and the metric value may not be representative of the entire reporting unit. Values in the high 90's are usually a result of measuring area using different methods (raster vs. vector) and do not necessarily indicate insufficient overlap between the land cover or slope grid and a particular reporting unit.

Many metrics produce other map products necessary for the calculation of the selected metrics from the initial data inputs. By default, these map products are discarded at the end of the ATtILA metric runs. Several however can be retained and placed in a view of the user's choice by selecting "Metric values and maps" in the Output Type: dropdown box. Many of these secondary map products can then be used as input data sources in future ATtILA runs.

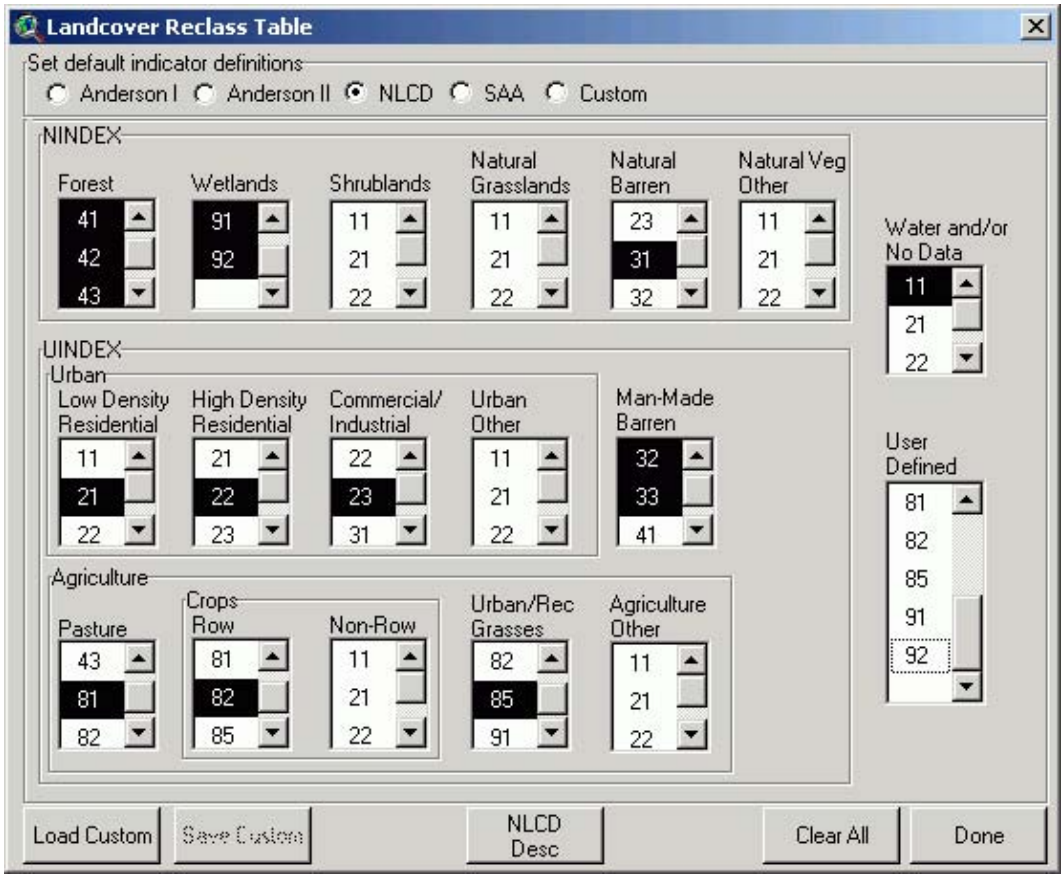
If processing is interrupted (system crash, power outage, etc.), partial results may have been calculated. It is strongly recommended that products from interrupted analyses be discarded and the analysis completely re−done.

***Land Use/Cover Classification Systems***

In three of the metric categories, land use is the core input. You must tell ATtILA what land cover is represented by each code (land cover class) in your data. Several common systems are pre−coded, including Anderson level I or II (Anderson et al., 1976), NLCD (Vogelmann et al., 2001) and Southern Appalachian Assessment (SAA; USDA, 1996). There is also a custom option.

Selecting the coding system of your land cover data tells the program what land cover is represented by each code in the grid. A description of a selected pre−coded system is available by clicking the middle button on

the bottom of the custom dialog (see below).




Selecting Custom or clicking the advanced button brings up a new dialog (shown above) that allows you to view and edit which codes represent each type of land cover. If you have data that use codes other than Anderson, NLCD or SAA, you will need to enter the codes for each land cover by clicking on the appropriate values (hold the shift key to select more than one). For example, if forest is coded as 7, 8, and 9 in your data, shift−click those values in the Forest list. This same technique can be used to modify Anderson, NLCD or SAA defaults. Shift−clicking a code toggles it from on to off or vice−versa. If any of the predefined schemas were selected before choosing custom, the previous schema values will remain. You may edit these or use the "Clear All" button to start from scratch. Clicking "Custom" again after making edits will reset to values when the dialog was opened.

User defined is a custom category that can be defined as any combination of land cover in your data.

The groupings delineated by boxes define super categories. For example, any code entered in the Pasture, Row Crops, Non−Row Crops, Urban/Rec Grasses or Agriculture Other classes are all included in total agriculture metrics (e.g. Pagt, the proportion of total agriculture).

It is extremely important that the codes for the Water and/or NoData class are selected correctly. All metrics based on land cover proportions use terrestrial area only, ignoring the codes included in the Water and/or NoData class. For example, a reported value for percent forest of 70% means that 70% of the land area in the reporting unit is covered by forest. If a water or NoData code is included in a terrestrial land cover class, the calculated land cover proportions will be incorrect. In addition, ATtILA calculates LandArea (or equivalent, depending on the metric), which is included in the output attribute table. LandArea is the total number of grid cells not classified as water or NoData within the reporting unit multiplied by the area of a single grid cell.

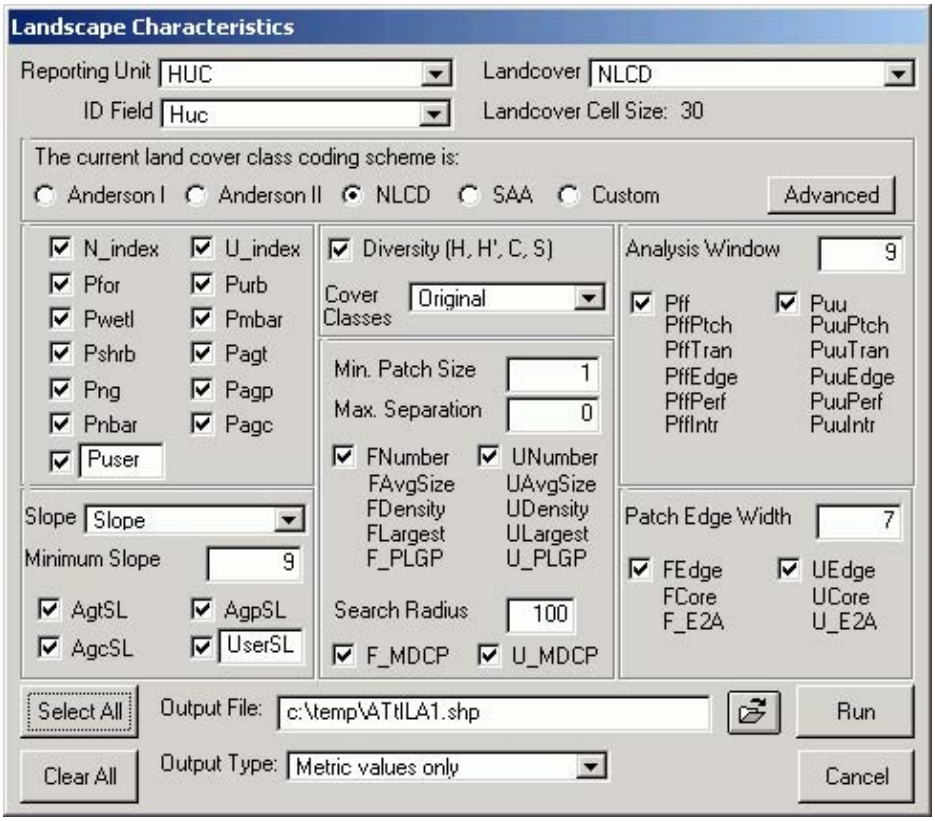
You may save a custom classification for future use with the save custom button. This will create a file with a ".cds" extension with a name and location of your choice. To recall the classification, use the "Load Custom"

button. At any time, you may select a core definition (e.g., NLCD) to reset values to that definition. When all the codes have been entered, click "Done".

*Note*: NLCD coding is based on 1992 NLCD data.

## A. Landscape Characteristics

This set of metrics deals primarily with proportions of land cover, a commonly used measurement of overall environmental quality at regional scales. The dialog box is shown below. Be sure to choose a land cover theme and coding system before proceeding. Descriptions of the metric codes discussed in this section are available in Appendix 1




***Source Data***

Check that the reporting unit and land cover themes and id field have been correctly selected. The program will search the themes in the view and attempt to make a logical choice as the default selection (see Appendix 4 for more information). ATtILA will also attempt to make an intelligent choice for the ID field.
*Tip:* By renaming your theme to contain a key word shown in Appendix 3 or by moving your theme of interest above all other similar type themes (e.g. polygon) in the View's Table of Contents, you can force ATtILA to automatically select that theme each time the metric dialogs are opened.
The ID field should contain a unique value for each area of interest (e.g., watershed name or number, FIPS code, etc.) in the reporting unit theme. It is a good idea to look at the reporting unit theme table prior to running ATtILA to choose an appropriate ID field. The land cover cell size is automatically updated when you select a new land cover theme.

*Note:* If your reporting unit theme has a larger spatial extent than your land cover, be sure and set the analysis extent to "same as {name of reporting unit theme}" in the analysis properties. This may circumvent an

inherent ArcView bug.

***Metrics***

Land Cover Proportion Metrics

Calculate the percentages and total area of any land cover type by checking the appropriate boxes. You may also generate U−index (all human use), N−index (all natural cover). If you set a user defined land cover class, you may calculate proportion and area for it, as well as change its name. Area is reported in the map units of the land cover grid. *Percentages of land cover calculations exclude water from total area*. For example, Pfor = area of forest / (total area − area of water), or the percentage of terrestrial area that has forest cover. Therefore, it is important that codes for water be entered in the Water/No Data code list and *only* that list (i.e., do not include it as part of N−index). If it is desirable to include water in the reporting unit's total area or to calculate the percentage and area of water in the reporting unit, we recommend moving the code(s) for water from the Water/No Data list to the User Defined list. For each land cover proportion metric selected, the area is also calculated and reported as {metric}_a (e.g. Pfor_a is the total area of forest in the reporting unit).

*Note:* It is possible to exclude any class from calculations by including its code in the Water/No Data list.

Slope Metrics

Amount of agriculture on steep slopes is an indicator of water quality. Steep slopes lead to higher runoff of water, soil and fertilizer. Calculating the amount of agriculture on steep slopes requires you to enter a slope grid and a threshold value. The slope grid may be in either degrees or percent slope. The minimum slope threshold uses the units of the slope grid. The default assumes percent slope, and uses a threshold of 9 percent as previous studies have shown this to be a steepness where soil erosion begins to increase (USDA, 1997). You may compute the amount of cropland, pasture, total agriculture and/or the user defined category (if specified) on steep slopes.

*Note:* Amount of agriculture on steep slopes uses two grids as input sources − a land cover grid and a slope grid. It is uncommon for the land cover grid and the slope grid to have the same cell size and grid extents and/or overlay each other perfectly. As a result, the landcover/slope composite grid created to identify areas of agriculture on steep slopes is likely to have different spatial properties than the input land cover grid. Therefore, ATtILA calculates the percent of overlap between the reporting unit and the land cover/slope composite grid (SL_Overlap) as a check for the trustworthiness of the calculated metric. For further information, see the discussion in Output Information above.

Diversity Metrics

Diversity metrics quantify landscape composition. These metrics are influenced by two components − richness, the number of different patch types present, and evenness, the distribution of area among the patch types. There are four diversity measurements available. H and H' are Shannon−Weiner diversity and Standardized Shannon−Weiner diversity, respectively, C is the Simpson index and S is simple diversity. Equations for each are in Appendix 4. You may calculate these metrics using either the original land cover codes in your data (the default), or the coding system values (e.g. NLCD). For example, in the first case, each forest class is treated separately, in the second they are treated as one class.

Patch Metrics

Patch metrics are commonly generated for forest cover and can give an indication of forest health. ATtILA calculates patch metrics for the forest or the user defined class, which allows patch metrics to be calculated for any land cover class or group of classes. You may generate number of patches (NUMBER), largest patch (LARGEST), average patch size (AVGSIZE), and proportion of largest patch area to total patch area (PLGP) by reporting unit. Metrics with an F prefix use the forest class, while metrics with a U prefix are generated

with the user defined class. Many small patches are representative of a fragmented landscape, while fewer, larger patches indicate a clumped pattern, which provides better habitat for some species.

*Note:* A complex patch that is large and continuous in the landscape may have several small pieces in the reporting unit due to reporting unit boundaries creating artificial edges. Each piece will be considered a separate patch in the reporting unit, affecting metric values.

The "Min. Patch Size" box is the minimum number of pixels required to be considered a distinct patch. The default value is one, allowing single pixels to be considered a patch. In noisy, or "salt and pepper" data, setting this value higher will eliminate isolated small patches. The "Max. Separation" is the maximum distance in pixels for disjunct patches to be considered continuous. The default is zero, requiring all cells in a patch to be continuous.

*Note:* The number entered is half the amount used in processing, due to the nature of the algorithm. For example, entering a 1 will result in patches 2 cells apart to be considered continuous. This parameter may be useful in habitat modeling, where a species may cross a certain distance of non−habitable land cover to reach the next acceptable habitat patch.

Mean distance to closest patch (MDCP) calculates the shortest edge−to−edge distance between distinct patches in map units. "Search Radius" is the largest distance (in number of cells) to search for the closest patch. PWN (patches with neighbors) and PWON (patches without neighbors) are written to the output attribute table as part of MDCP calculations. The values in the PWN field and the PWON field should add up to the total number of patches in the reporting unit (NUMBER). For reporting units that have PWON values greater than zero, you may want to increase the search radius and rerun the metric (just for those watersheds). The reason for this is a PWON value greater than zero indicates some patches in the reporting unit had no neighboring patches within the search radius (i.e., the nearest neighbor was farther away than the selected search radius). Patches with no neighbors within the search radius are not included in the MDCP calculation, so the reported MDCP value will be lower than the true value.

*Caution*: MDCP can be extremely resource intensive. You may want to run few selected reporting units as a test before using your entire data set. Start with a small search radius to reduce computational times and increase the radius only for those reporting units that have wider separated patches.

Core and edge area are commonly used in habitat suitability studies. To calculate the percentage of core and edge, as well as the ratio of edge to area, fill in the "Edge Width" field. This defines the edge width in *grid cells*, and must be an integer. The default is seven, so if you are using 30 meter data, this will define edge as 210 meters. It is up to the user to determine what defines an edge for their purposes and calculate the number of cells needed based on the cell size of the input land cover grid.

*Notes*: With the exception of the Core and Edge Area metrics, the patch metrics are calculated one reporting unit at a time. The scripts involved perform several calculations using Spatial Analyst, making one or more calls to Spatial Analyst's Grid Engine for each polygon in the reporting unit theme. If the metric calculations fail to run to completion, it is possible that exceeding the 32k call limit to the GRID engine is the likely cause for the subroutine failure. Save the project then exit ArcView. After reopening the project, try running ATtILA on subsets of the Reporting Units equal to or less than the number of completed Reporting Units in this ATtILA run. Remember to restart ArcView between runs.
While exceeding the Grid Engine limitation may be the most likely cause of the metric failure, there are other possible sources of problems (e.g., insufficient memory or disk space, spaces in pathnames, etc.).

Fragmentation Metrics

Fragmentation is classified into five categories as defined in Riitters et al. (2000). This work used forest only, but ATtILA will also calculate the classification based on the user−defined class. The following description uses forest, but the user−defined class works in an identical manner. Fragmentation metrics are more complex

than most ATtILA metrics and it is strongly recommended that you be familiar with the Riitters work before using them.

Analysis is performed using a moving window, defined in grid cells in the "Analysis Window" field. The default of nine will use a 9 x 9 cell window. Changing this value will change the scale of the analysis. Analysis is limited to windows where the center cell is forest. There are two components to the classification, $P_f$ and $P_{ff}$. $P_f$ is the proportion of forest in the window. $P_{ff}$ examines the edge between cell pairs in the window, where at least one of the cells in the pair is forest. $P_{ff}$ is the number of edges that delineate forest−forest cell pairs divided by the number of all forest cell edges. The five classes are patch, transitional, edge, perforated and interior. For $P_{ff}$, the average value across the reporting unit is written to a new field in the output attribute table. For each fragmentation class, the proportion of class area to total area in the reporting unit is written to a new field in the output attribute table.

*Notes*: Fragmentation metrics are calculated one reporting unit at a time. The scripts involved perform several calculations using Spatial Analyst, making one or more calls to Spatial Analyst's Grid Engine for each polygon in the reporting unit theme. If the metric calculations fail to run to completion, it is possible that exceeding the 32k call limit to the GRID engine is the likely cause for the subroutine failure. Save the project then exit ArcView. After reopening the project, try running ATtILA on subsets of the Reporting Units equal to or less than the number of completed Reporting Units in this ATtILA run. Remember to restart ArcView between runs.
While exceeding the Grid Engine limitation may be the most likely cause of the metric failure, don't forget to look at other possible sources of problems (e.g., insufficient memory or disk space, spaces in pathnames, etc.). Another potential source of failure for the fragmentation metrics is the 2.1 gigabyte size limit for grids in ArcView 3.x. If this limit is reached while processing intermediate grid products, the metric calculations will fail to complete. This limitation will most likely be encountered during the creation of the Pff grid. This grid is a floating point grid and can easily exceed the 2.1 gigabyte limit if the size of a reporting unit's extracted landcover grid is over 200 megabytes in size. Unfortunately there is no workaround to this problem.

***Output Options/Optional Map Products***

"Metric values only" will not save any intermediate data sets required for the calculations. Values will be added to new fields in the reporting unit attribute table, or overwrite values if the field already exists. Any fields that were overwritten will be displayed in a list when processing is complete, and be included in the metadata file. This is the default and recommended choice.

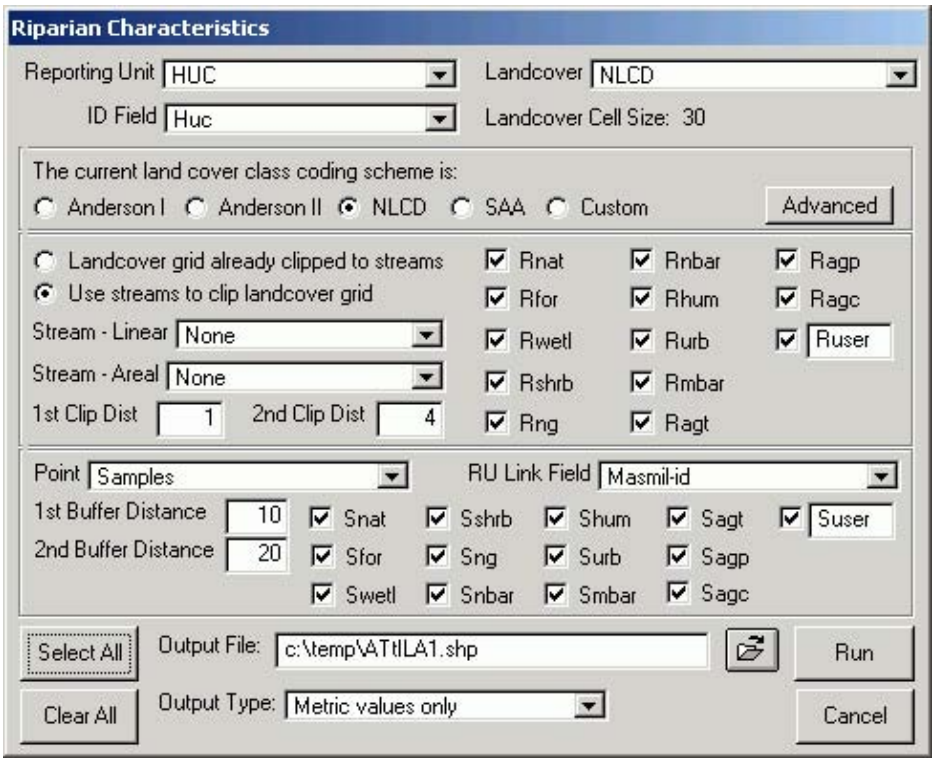
"Metric values and maps" will generate and save values as above, but will also save intermediate themes required to calculate the selected metrics (where applicable). An example for the AgtSL (total agriculture on steep slopes) metric would be a grid where a 1 represents any agriculture class on steep slopes and a zero represents other land cover types and agriculture on slopes below the minimum slope threshold. Detailed information is available in Appendix 3.

*Notes:* The percent overlap between land cover and reporting unit is automatically calculated and written to a field named LC_Overlap. If this value is substantially below 100 for a reporting unit, you may wish to exclude it from analyses, as values may not be representative of the entire reporting unit. Likewise, the overlap between slope, land cover and reporting unit is calculated and written to a field named SL_Overlap. Land_area, the raster measure of terrestrial area (excluding water and NoData) in the reporting unit, is also calculated automatically.

## B. Riparian Characteristics

This category is very similar to the landscape characteristics metrics (see section A. Landscape Characteristics for more detailed instructions), but focuses on proportions of land cover adjacent to and near streams.

Proportions of land cover types in the riparian zone can be used to assess water quality and habitat impacts at multiple scales. Riparian zones high in forest and wetland cover are effective filters of excess runoff of fertilizer and other pollutants and provide high quality habitat for a variety of plant and animal species. Descriptions of the metric codes discussed in this section are available in Appendix 1
Required inputs are identical to those in the landscape characteristics dialog, with the addition of a streams and buffer size input. The dialog is shown below.




***Riparian Zone Land Cover Proportion Metrics***

Instead of using all the area within a reporting unit, these metrics only use the riparian zone (defined by stream buffers) within the reporting unit. If a riparian zone land cover grid exists, check the "Land cover grid already clipped to streams" button. In this case, metrics will be calculated for all area in the land cover grid. If the land cover has not been clipped to riparian areas, select the "Use streams to clip land cover grid". There are two options when using streams to clip land cover. Use "Stream − Linear" for stream themes that contains lines and use "Stream − Areal" for themes that contain polygons (e.g. lakes or wide rivers). You may select one or both of these options depending on your data. Linear streams are buffered on both sides, while Areal streams are only buffered "out", to include land area. Enter clip distances that define buffers (in number of cells) for which land cover percentages will be generated. Default values are one and four cells. You may enter up to two integer values, measured in number of cells. For example, if your land cover grid has a 30 meter cell size, entering a 2 will buffer linear streams by 60 meters on each side. Land cover adjacent to streams (buffer distance of zero) is automatically calculated. ATtILA requires a number in the first clip distance, so to calculate only proportions of land cover adjacent to streams, enter a 0 in the first clip distance, and 0 or blank in the second clip distance. The second buffer can be turned off by setting the value to 0 or blank. Percentages and total area of each selected land cover located within the buffer(s) will be calculated. Only land cover that exists within the buffer zones within the reporting unit are used for metric calculations. Buffer zones that extend beyond the reporting unit boundaries are ignored. Land area in the riparian zone is also calculated automatically. The field name is RLA{n}, where n is the buffer size.

*Notes:* The percent overlap between land cover and riparian buffer zone is automatically calculated and written to a field named RO_{n}, where n is the buffer size. If this value is substantially below 100 for a reporting unit, you may wish to exclude it from analyses, as values may not be representative of the entire riparian zone.

The riparian metrics are calculated one reporting unit at a time. The scripts involved perform several calculations using Spatial Analyst, making one or more calls to Spatial Analyst's Grid Engine for each polygon in the reporting unit theme. If the metric calculations fail to run to completion, it is possible that exceeding the 32k call limit to the GRID engine is the likely cause for the subroutine failure. Save the project then exit ArcView. After reopening the project, try running ATtILA on subsets of the Reporting Units equal to or less than the number of completed Reporting Units in this ATtILA run. Remember to restart ArcView between runs.
While exceeding the Grid Engine limitation may be the most likely cause of the metric failure, don't forget to look at other possible sources of problems (e.g., insufficient memory or disk space, spaces in pathnames, etc.).

***Near Sample Point Land Cover Proportion Metrics***

Water quality studies often relate land cover metrics near a water quality sample point to water quality measurements at the sample point. To do this in ATtILA, select a sample site cover in the "Point" input box and enter buffer distance(s). Default distances are 10 and 20 meters and will be the radius of circles centered on the points. To only use one buffer, enter a 0 or blank for the second buffer distance. Any portion of the circle that is outside of the reporting unit boundaries is removed before metric calculation. Land cover proportions within the buffer zones and total area for each selected land cover will be calculated. Land area in the sample point buffer zone is also calculated automatically. The field name is SLA{n}, where n is the buffer size.
Before calculating these metrics, the "RU Link Field" must be set. The "RU Link Field" is a primary key that identifies which reporting unit the sample point is associated with (i.e., contained within). Entries in the "RU Link Field" need to match those of the reporting unit id field although the field names do not need to be the same. All sample points for a particular reporting unit are buffered, merged, then clipped by the associated reporting unit boundary. If the "RU Link Field" is not set properly these operations will fail or produce incorrect results.

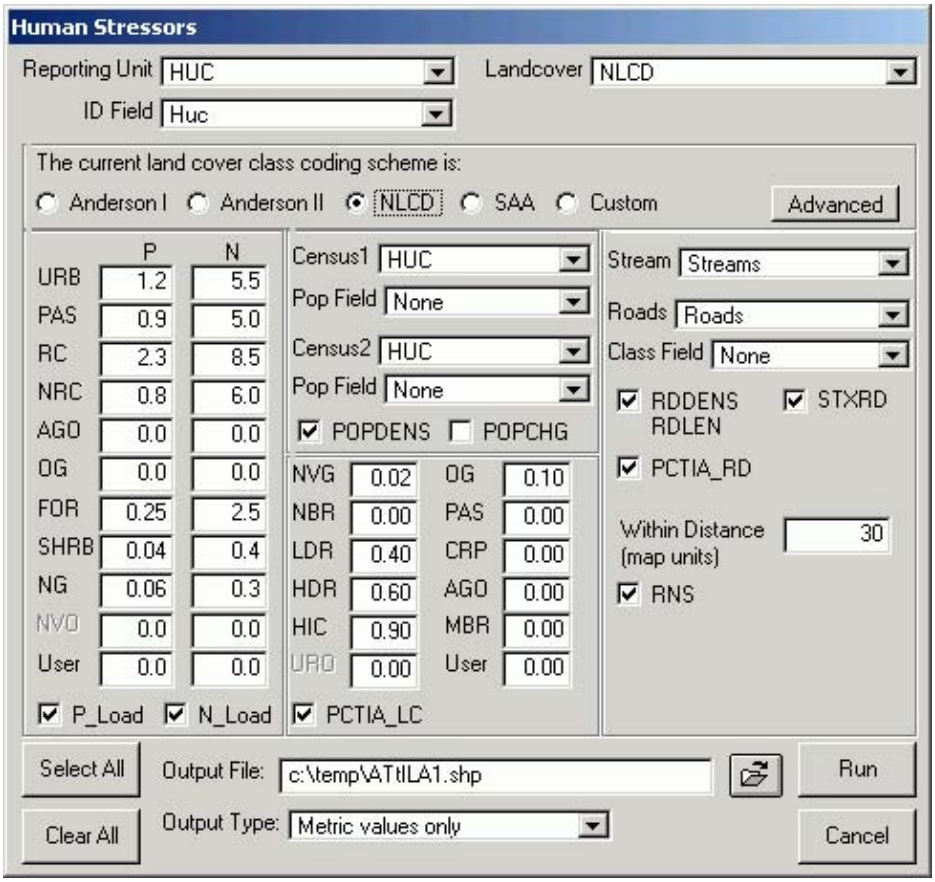
*Notes:* Users interested in this type of analysis should also see the "Modify reporting unit using point buffers..." tool available on the ATtILA main menu. This tool intersects reporting units with circular buffers created from a point theme. The buffer size (in map units) is specified by the user. A new shapefile is created that can be used as a reporting unit theme to calculate the entire suite of ATtILA metrics near the points not just the land cover proportions.
In many cases, an "RU Link Field" can be easily created in the Sample Point theme by performing a spatial join between the sample point and reporting unit themes (see spatial join in the ArcView Help Index). However, this should not be done if the reporting unit theme contains overlapping or "nested" polygons as the attributes from a different polygon than that desired may be joined to the sample point theme. Also, problems may occur using this technique if the sample point and it's associated reporting unit do not in fact overlap due to differences in the precision of the spatial data or to human error while digitizing the data.
The percent overlap between land cover and sample point buffer zone is automatically calculated and written to a field named SO_{n}, where n is the buffer size. If this value is substantially below 100 for a reporting unit, you may wish to exclude it from analyses, as values may not be representative of the entire riparian zone.

Output options are identical to those in the Landscape Characteristics dialog.

## C. Human Stressors

Human land uses (agriculture and developed) usually produce higher levels of nutrients like nitrogen and phosphorus than natural land cover. In addition, human land uses increase the amount of impervious surfaces (roads, rooftops, parking lots, etc.), and increases the volume and force of precipitation runoff. Increased runoff leads to higher risk of flooding and also carries larger amounts of pollutants and sediment into surface waters. The human stressors metrics include nutrient loadings, population density and change, amount of impervious surface, road density and length, the number of road/stream crossings and length of roads near

streams. Descriptions of the metric codes discussed in this section are available in Appendix 1




***Source Data***

Reporting unit and ID field must be entered as in previous dialogs. Land cover, population, stream, and road information are optional depending on the metrics you choose to generate.

For road related metrics, your data may include an attribute relating to road class (e.g., interstate highway or surface street). If your data does not have this information, use the "None" option. This will treat all roads as a single class when generating results. Because road length is a required component in the calculation of PCTIA_RD and RNS, ATtILA requires that RDDENS/RDLEN must be checked to calculate PCTIA_RD or RNS.

***Metrics***

Phosphorus and Nitrogen Loadings (P_Load and N_Load)

Excess export of nitrogen and phosphorus to streams leads to eutrophication of streams, lakes, bays, and other water bodies. Most of these nutrients come from non−point sources like animal waste from livestock operations and fertilizer applications on agricultural fields, golf courses, and residential lawns. Phosphorus and nitrogen loadings are based on amounts of certain land cover types. Weightings in the input boxes are measured in kg per hectare per year. For example, each hectare of urban land cover contributes 1.2 kg of phosphorus and 5.5 kg of nitrogen per year to the watershed. Default values are based on literature (see Reckhow *et al.*, 1980), but may be changed by the user. The abbreviations used are: URB = urban, PAS = pasture, RC = row crop, NRC = non−row crop agriculture (e.g., orchards), AGO = agriculture − other, FOR = forest, SHRB = shrubland, NG = natural grassland, NVO = natural vegetation − other, and User = user defined (optional). Results are in kg/ha/year.

*Note:* If you are using the User class, it should not contain land cover codes used in urban, pasture, row crop, non−row crop agriculture, or forest as that would double count those areas. If this is the case, ATtILA will notify you and end the process. You may then redefine the User class in the coding schemes using the advanced button and rerun the metric. ATtILA will also notify you and end the process if any land cover code is duplicated among any of the land cover classification boxes used for this metric.

Population Density and Change

To calculate population density, you need to enter a population theme name for Census1 and the associated field (Pop field) containing population values. When reporting units contain partial census units, population is apportioned by area−weighting. That is, if 50% of the census unit is within the reporting unit, 50% of the population is assigned to that reporting unit. A new field with the same name as the population field is written to the output theme attribute table. It contains the total area−weighted population. For the user's convenience, an alias name is created for the field that consists of the fieldname along with the population theme's name.

To compute population change, you also need to set theme and field name for Census2 (this information can be in the same theme, in different fields). Population density is reported as number of people per $km^2$. Population change is reported as percentage change in population by reporting unit.

*Note:* The population change tool is quite versatile, like many of the metrics in ATtILA, and can be used beyond its stated purpose. For example, instead of selecting population counts from different time periods, the user could select fields containing counts of male and females members of a population at a given time. The POPCHG metric could then be used to show the percentage difference between the number of males to females for the given reporting unit. Another example would be where the user used ATtILA to calculate the total area of a land cover class in a reporting unit for two different time periods. Using these two themes as inputs into the POPCHG metric, the user could then calculate the percentage change in the land cover type over the given time period.

Impervious Surface (PCTIA_LC and PCTIA_RD)

Impervious surfaces include rooftops, roads, parking lots, and compacted soil. Amount of impervious surface is an indicator of habitat loss and water quality, and is related to the urban heat island effect. Estimated impervious surface is calculated two ways. The first (PCTIA_LC) is based on percent cover of certain land cover. By default, 2% of natural vegetation (NVG), 60% of high density residential (HDR), 40% of low density residential (LDR), 10% of other grasses (OG), and 90% of high intensity commercial (HIC) are considered impervious, based on Caraco et al., (1998). Other codes initially set to 0 are urban − other (URO), natural barren (NBR), man made barren (MBR), pasture (PAS), crop (CRP), and agriculture − other (AGO). These values may be altered manually. Total impervious surface by reporting unit is calculated by multiplying the percentages by amount of area for each associated land cover, then summing over all land cover. Results are reported both as total area, as well as percent impervious cover.

Road density can be highly correlated with population density. Therefore, high road density generally corresponds to larger amounts of developed land cover and increased amounts of impervious surface. PCTIA_RD uses road density as the independent variable in a linear regression model to calculate impervious surface (see May, et al., 1997). Road density is calculated as km of road per $km^2$ of reporting unit area. Due to the nature of the regression equation used for PCTIA_RD, values below 1.8 are assigned a value of 0, values above 11 $km/km^2$ are considered invalid and will be reported as −1.

*Note*: If you are using the User class for the PCTIA_LC metric, it should not contain land cover codes used in any of the other land cover type boxes (e.g., high density residential, other grasses, forest, etc.) as that would double count those areas. If this is the case, ATtILA will notify you and end the process. You may then redefine the User class in the coding schemes using the advanced button and rerun the metric. ATtILA will also notify you and end the process if any land cover code is duplicated among any of the land cover classification boxes used for this metric.

Road Density Metrics

Total road length (RDLEN) is reported in map units (usually meters). Road density (RDDENS) is reported as total road length in km divided by area of reporting unit in square kilometers. Stream/Road crossings (STXRD) calculates two metrics, the total number of stream/road crossings in the reporting unit (STXRD_CNT) and the density as number of crossings per stream kilometer in the reporting unit (STXRD). If a road class field is provided in the Human Stressors Dialog, ATtILA will also calculate each road density metric described above as well as the RNS metric described below for each road class found within the roads theme. For example, if there are two road classes coded within the roads theme and the STXRD metric is selected, ATtILA will calculate the number of roads/stream crossings per kilometer of stream within the reporting unit as well as the number of road/stream crossings per kilometer of stream for road class 1 and for road class 2. The output field name will have "C[CLASS]" appended. In this example, for road class 1, the road/stream crossings per kilometer of stream field name will be STXRDC1. For road class 2, the field name will be STXRDC2.

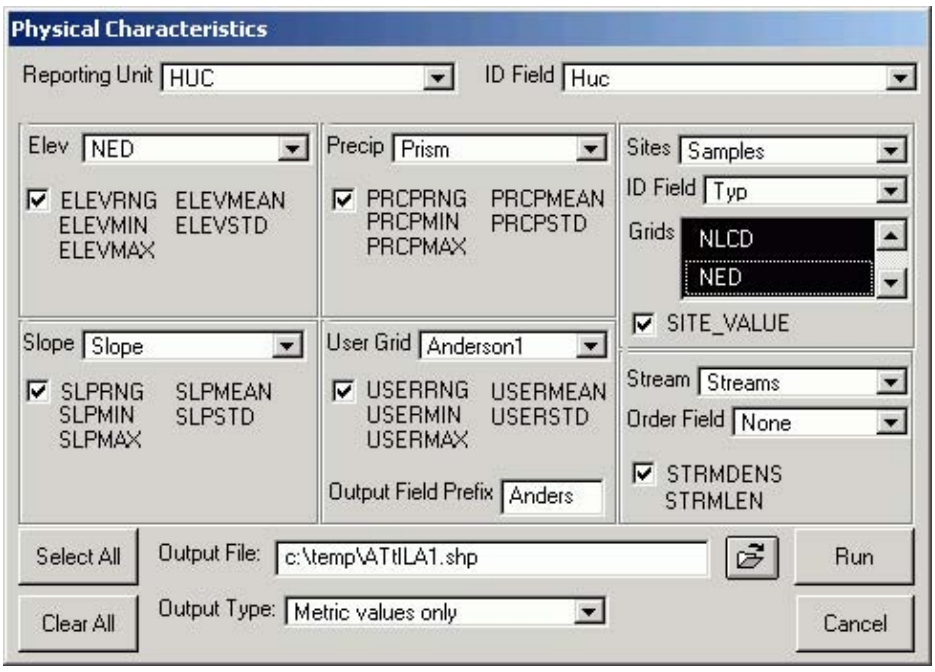
Due to the impervious nature of roads, petroleum products, antifreeze and other vehicle related chemicals, as well as road salt and sediment are washed away in storm runoff. When roads are near streams, very often this runoff enters surface water directly. Roads near streams (RNS) requires a buffer distance, measured in projected map units if the view is projected, or native map units if not. In most cases, map units will be meters. This metric measures the total length of roads within the buffer distance divided by the total length of stream in the reporting unit, both lengths are measured in map units (e.g., m of road/m of stream).

*Caution:* RNS can be extremely computationally intensive. You may want to run a few selected reporting units as a test before using your entire data set.

Output options are identical to those in the Landscape Characteristics dialog.

## D. Physical Characteristics

These metrics provide general physical descriptions of reporting units. Required inputs are Reporting Unit and ID Field. Optional inputs are elevation, slope, streams, stream order, and a point theme, which will usually be sample site locations. Descriptions of the metric codes discussed in this section are available in Appendix 1



Common statistical measurements such as range, minimum, maximum, mean and standard deviation, may be calculated for precipitation, elevation, slope and/or a user selected grid. The field names for the user grid metrics will begin with the first six letters of the user grid name as the default. You may change this by typing a new string into the "Output Field Prefix" box. To be meaningful, the user grid should represent continuous data.

*Note:* It is possible for the range of values in a grid to be quite large. This can cause ArcView to crash when calculating summary statistics. To protect against this possibility, ATtILA checks the range of values, and if it is too large, will prompt the user to use an alternate process. This is highly recommended, but be aware it is significantly slower.

Checking the "SITE_VALUE" box will identify the value of one or more grids at each location in the point theme selected in the "Sites" input box. All grids in the table of contents are included in the dropdown list. Shift−click to choose more than one grid. Output is stored in a new dbf file. You are given the option of joining the new file to the original point attribute table using the ID Field.

Stream density (STRMDENS) and total stream length (STRMLEN) may be calculated for all streams or by stream order for each reporting unit. If stream order information isn't available or not desired, use the "None" option, and values will be generated using all streams in the reporting unit. Total stream length is reported in map units. Stream density is reported as total stream length in km divided by area of reporting unit in $km^2$.

Output options are identical to those in the Landscape Characteristics dialog.

### E. Metadata

Metadata is created automatically by ATtILA. A text file is created that contains information such as the date a process was run, the project in which the process was run, the input data used in the process, the coding scheme for the land cover data, any user thresholds used and the output shapefile name and location. The metadata file is given the same name as the associated shapefile with a .txt suffix. It is stored in the same location as the output shapefile. Each ATtILA run creates a new shapefile and related metadata file. Sample metadata output is included in Appendix 5.

*Note:* If the headings and text columns in the metadata file appear misaligned or jagged, it is recommended that the user change the font used to view the metadata file to Arial regular with size 10. These were the parameters used while formatting the metadata file and should alleviate the problem.

## VI. Display

There are four ways to display results in the ATtILA: quantile maps, a metric index, column charts of selected metrics, and metric histograms. The reporting unit theme must be active when selecting any of these display options. To create any type of output, metric values must be in the reporting unit attribute table. Atlas and index values are generated for all reporting units, regardless of whether any units are selected.

Create Metric Atlas

The Create metric atlas option displays a scrolling list of metrics in the active theme's attribute table. The scrolling list will contain any ATtILA generated metric found in the active theme’s attribute table. To add metrics not generated by ATtILA to the list, see "Add user field to metric list". From this list, select one or more metrics that will be used to create atlas layers. Next, you will be asked how many quantiles to use in the

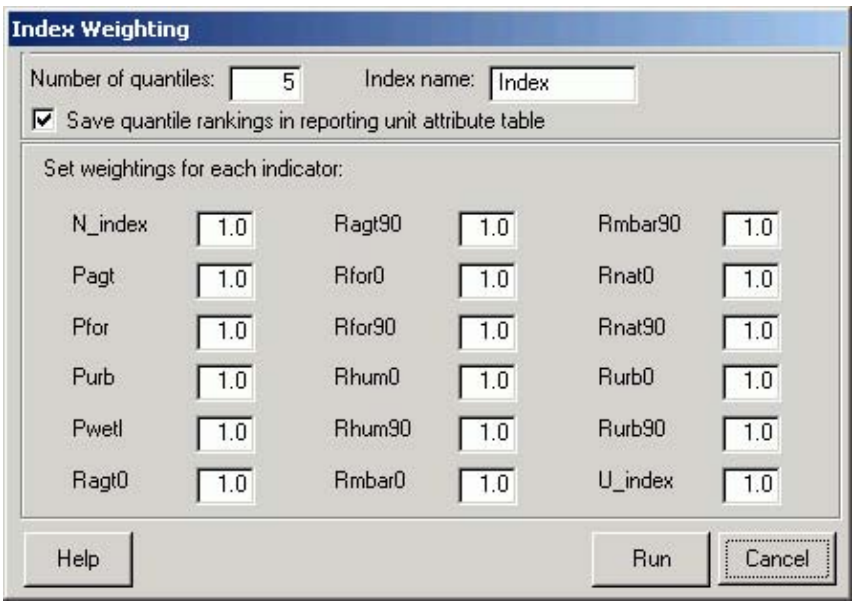
legend. The default is 5, but may be any integer from 2 to 64. The number of quantiles is the number of classes used in the legend, where each class contains the same number of features (reporting units in this case). You are then asked if you want to save the quantile rankings. Replying yes will save the quantile value for each reporting unit to a new field in the attribute table. The field will be named {metric code}_q{n}, where n is the number of quantiles used (e.g., Pfor with 5 quantiles becomes Pfor_q5).

For each metric chosen, a new theme is added to the view. Reporting units are ranked based on their metric values and displayed using colors from red (worst condition, quantile 5) to green (best condition, quantile 1). Rankings are *relative*. A low ranking does not necessarily represent poor conditions, just worse conditions than other areas in your data. Conversely, a high ranking may not represent good conditions, but better than other areas in the reporting unit theme.

Create Metric Index

Create metric index is a way of combining many metrics into one value. The atlas maps are valuable for viewing single metrics at a time, but it is difficult to analyze multiple metrics simultaneously. To make an index, select up to 18 metrics from a list of metrics in the active theme's attribute table. The list will contain any ATtILA generated metric found in the active theme's attribute table. To add metrics not generated by ATtILA to the list, see "Add user field to metric list". Each selected metric will have an input box in the dialog (shown below) to accept a weight, which may be any number less than 10. For each reporting unit, all metric rank values are multiplied by the related metric weight. The index is the sum of all the weighted values. A new theme is added to the view and displayed using the specified number of quantiles. Again, rankings are relative. The equation used to calculate the index is stored in the index theme properties' comments.

In the dialog, you must also enter a number of quantiles (any integer between 2 and 64, the initial setting is 5). This value is used to rank the reporting units, similar to the create atlas function, and to display the index (see Appendix 4 for details on index creation methodology).




Checking the "Save quantile rankings..." box will add two new fields to the active theme's attribute table for each metric used in the index. The quantile value for each reporting unit is saved to a field named {metric code}_q{n}, where n is the number of quantiles used (e.g., Pfor with 5 quantiles becomes Pfor_q5). The weighting used in the index is saved in a field named {metric code}_wt. Another field named Index is also added. It contains the overall index value for the reporting unit.

You may change the name of the index in the "Index name" box. By default, the name is "Index". A new field

will be added to the reporting unit attribute table with the name you enter to hold index values. If the field already exists, values are overwritten.

Create Metric Column Charts

Create metric column charts also displays a list of metrics available in the active them attribute table. The list will contain any ATtILA generated metric found in the active theme's attribute table. To add metrics not generated by ATtILA to the list, see "Add user field to metric list". A chart is generated for selected metrics that shows each selected metric grouped by reporting unit. The maximum number of columns cannot exceed 100 (i.e., number of metrics * number of reporting must be less than 100). You may need to select a subset of reporting units or only run this option on one metric at a time. This is an ArcView limitation and is maintained because charts larger than this are difficult to decipher. You may get a warning stating: CHART: There is not enough space to plot the chart; check the format parameters and/or resize the chart. Click OK on the warning dialog. Making the chart window larger will usually fix this problem.

*Note: You should use the ATtILA output when creating column charts. If the reporting unit theme has multi−part polygons, each unique reporting unit ID will only be represented once in the chart using the ATtILA output, but once for each part using the original reporting unit theme.*

Create Metric Histograms

Create metric histogram displays the same list of available metrics, but in this case, only one may be chosen. A histogram is then created for the selected metric, creating a new dbf file stored in a user selected location. The dbf file contains the metric used, the range for each histogram bin, and the number of observations in each bin.

*Note: You should use the ATtILA output when creating metric histograms. If the reporting unit theme has multi−part polygons, each unique reporting unit ID will only be represented once in the histogram using the ATtILA output, but once for each part using the original reporting unit theme.*

# VII. Other Tools

There are several tools included in the extension. All are located at the bottom of the ATtILA menu. These tools don't create metrics, but may aid in analysis or data management.

"Modify reporting unit using point buffers". This tool intersects reporting units with circular buffers created from a point theme. The buffer size (in map units) is determined by the user. A new shapefile is created that can be used as a reporting unit theme to calculate metrics near the points. It is useful for generating metrics near water quality sample points where watersheds that drain to the sample point are available.

"Summarize points by zones...". This tool gives summary statistics such as number, average, sum, minimum, maximum, standard deviation and variance for any attribute field in a point theme. Statistics are summarized by zones (polygons) and written to a new dbf table with the prefix ptsum. This summary can be useful when a reporting unit (zone) contains multiple points (e.g. water quality samples).

"Get z values at points". Make a point theme active before choosing this option. A list will display the grids in the view, select those that you want information for. The result is a permanent table of values at each point in the active theme for each selected grid. Finally, you are given the choice of joining the grid information to the point attribute table.

*Notes*: Spatial Analyst has an upper limit to the number of calls it is able to make to the Grid Engine in a single ArcView session. That number is 32,767. For this tool, one call to the Grid Engine is made for each

selected point (or all points, if none are selected) and each selected grid. If the product of the points and the number of selected grids exceeds this value, this operation will fail − usually by a segmentation violation. If this is the case, it will be necessary to process the data using subsets of either the points or the grids or both and restarting ArcView between runs. Additionally, since the number of Grid Engine calls is cumulative during a single ArcView session, the number of calls still available before beginning this operation might be much lower than 32,767 and could be as low as a single call. As such, this can cause this tool to fail at seemingly random locations in its data processing. Simply quitting and restarting ArcView before running this tool may solve this problem.

"Generate perpendicular lines...". Creates a new line theme containing lines perpendicular to selected lines in an existing selected theme. Length of the lines are defined by the user as is the spacing between lines. The user also has the option of transferring one or more attributes from the existing line theme to the new lines. This tool could be useful for generating sampling transects along a stream or road or measuring the width of a flood plain.
*Caution*: This tool can be extremely resource intensive.

"Get elevation profile along line...". You must have a line theme active, with one or more lines selected. Although the most common use of this tool is an elevation profile along a stream, you can get information along a line or transect for any grid in your view (e.g., slope, aspect, or vegetation theme). Select the grid you want to profile from the list. Next the selected line(s) in the active theme will be split into equal length segments for display in a graph. The default number of segments is 10, you may change that value in the dialog. A permanent table is created by this tool. A final dialog allows you to choose where to store this table.

"Find intersections of two themes...". This tool prompts you for two themes (any combination of line and poly) and creates a theme with points at the intersections of the two inputs. This tool is used in ATtILA to find road/stream crossings.

"Delete multiple fields from table...". Because ATtILA creates many fields in the output table, this tool allows you to efficiently remove unwanted fields. A list of all fields in the attribute table for the active theme will be displayed when you choose this tool. Select fields to delete by clicking. Consecutive fields may be selected by clicking and dragging. To unselect a field click on it again. This tool is also available when a table is active.

*Note:* Fields are permanently deleted! Do not select area, perimeter, #, or −id fields in coverage attribute tables or the coverage will be corrupted.

"Update area, length and perimeter". Recalculates area and perimeter for polygon themes and length for line themes. If you project or edit your data within ArcView, these values are not automatically updated and need to be recalculated to represent correct measurements in the new projection space.

# VIII. Table Functions

When a table document is active, the ATtILA menu changes to contain five table functions.

"Delete multiple fields" displays a dialog listing all fields in the active table. Select fields to delete by clicking. Consecutive fields may be selected by clicking and dragging. To unselect a field click on it again. This tool is also available when a view is active.

*Note:* Fields are permanently deleted! Do not select area, perimeter, #, or −id fields in coverage attribute tables or the coverage will be corrupted.

"Statistics for multiple fields" generates summary statistics for fields selected from a dialog. A new dbf table is generated in a user specified location. Statistics include count, maximum, minimum, mean, median, mode,

midrange, harmonic mean, quadratic mean, range, variance and standard deviation.

"Change field name" will rename the active field and move it to the end of the table.

"Add user field to metric list" will add the active field to the list of metrics available in ATtILA's display options (e.g. "Create atlas" or "Create index"). This allows users to display metrics generated outside of ATtILA and create indices from a combination of metrics generated within and outside ATtILA. You must know if high values are preferred over low values or vice versa and if the data is scaled from 0 − 100 or not.

"Remove user fields from metric list" will remove all metrics added with the "Add user field to metric list" tool from the display list only. Fields are not deleted from the table.

# IX. Acknowledgements

Code for the PCTIA_RD metric was written by Dennis Yankee of the Tennessee Valley Authority, Public Power Institute. We incorporated part or all of several Avenue scripts available from the ESRI ArcScripts website into ATtILA. All code was used with permission of the original authors, who we gratefully acknowledge here:
Intersec Script by Jarko Laine, Novo.
Profiler Script 1.0 by Bill Eichenlaub, National Park Service.
Two Theme Analyst Extension by Kevin O'Malley.
XTools Extension by Mike DeLaune, Oregon Department of Forestry.
Spatial.AlignedGridExtract Script by Eugene Martin, University of Washington.
Nearest Feature Analysis Tool Script by Timothy J. Fox, USGS Upper Midwest Environmental Science Center.
Table.RenameField Script by Tom Cosmas, New Jersey Department of Environmental Protection.
Bearing extension by Ron Schultz
Distance/Azimuth Tools 1.4b by Jeff Jenness, Jenness Enterprises.

We would like to offer a special thanks to peer reviewers Peter Leinenbach (US EPA Region 10), Karl Hermann (US EPA Region 8), Jim Harrison (US EPA Region 4), Dr. Roger Tankersley of the Tennessee Valley Authority, and Dr. Rick Kutz of Towson University.
We thank the many beta testers for their excellent comments and suggestions. In particular, we would like to recognize the efforts of Jim Harrison (US EPA Region 4), Angel Kosfiszer (US EPA Region 6), Dan Heggem, Megan Mehaffey, Annie Neale and Deb Chaloud (US EPA ORD) and Ed Evanson (Lockheed Corp.).

***Notice:*** The information in this document has been funded wholly by the United States Environmental Protection Agency. It has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

# X. References

Anderson, J.F., Hardy, E.E., Roach, J.T. and Witmer, R.E., 1976. A land use and land cover classification for use with remote sensor data. U.S. Geological Society professional paper 964, 28 pp.

Caraco, D., Claytor, R., Hinkel, P., Kwon, H.Y., Schueler, T., Swann, C., Vysotsky, S. and Zielinske, J. 1998. *Rapid Watershed Planning Handbook*. Center for Watershed Protection. Ellicott City, Maryland.

Loveland, T. R. and D. M. Shaw, 1996, Proceedings of the ASPRS/GAP Symposium Charlotte, North Carolina: Multiresolution land characterization: building collaborative partnerships. In Gap Analysis: A Landscape Approach to Biodiversity Planning (Moscow, Idaho: National Biological Service), pp. 83−89.

May, C.W., Horner, R.R., Karr, J.R., Mar B.W., Welch, E.B. 1997. *Effects of urbanization on small streams in the Puget Sound Lowland Ecoregion*. Watershed Protection Techniques. 2:4. pp. 483−493.

Reckhow, K.H., Beaulac, M. N., and Simpson, J. T. (1980). *Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients*. USEPA 440/5−80−011. Washington, DC: Office of Water Regulations and Standards, U.S. Environmental Protection Agency. Washington, DC, USA.

Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2000. Global−scale patterns of forest fragmentation. Conservation Ecology 4(2): 3. [online] URL: http://www.consecol.org/vol4/iss2/art3

U.S. Department of Agriculture (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE).* Agricultural Handbook 703. Washington, DC: U.S. Department of Agriculture. 384pp.

U.S. Department of Agriculture, Forest Service, Southern Region, 1996. The Southern Appalachian assessment. Series: R8−TP ; 25−29. Atlanta, GA. U.S. Department of Agriculture.

Vogelmann, J.E., Howard, S.M., Yang, L., Larson, C.R., Wylie, B.K. and Van Driel, N., 2001. Completion of the 1990s National Land Cover Data Set for the Conterminous United States from Landsat Thematic Mapper Data and Ancillary Data Sources. *Photogrammetric Engineering and Remote Sensing*, 67: 650−662.

# XI. Appendices

# Appendix 1 − Metric Glossary

The following is a list all the metric codes in ATtILA and a short description of each. The codes are used in the dialogs and as the field name that is created in the output table.

## All Metric Categories

Area − Total area in map units

Perimeter − Total perimeter in map units

## Landscape Characteristics

Land_area − Total terrestrial area in map units (total area minus water)
LC_overlap − Percent overlap between reporting unit and land cover themes
SL_LndArea − Total terrestrial area (total area minus water) in map units for the land cover/slope composite grid
SL_Overlap − Percent overlap between reporting unit and land cover/slope composite grid

### Land cover proportions

Pagc − Percentage of reporting unit that is crop land
Pagp − Percentage of reporting unit that is pasture
Pagt − Percentage of reporting unit that is all agricultural use
Pfor − Percentage of reporting unit that is forest
Pmbar − Percentage of reporting unit that is man made barren
Pnbar − Percentage of reporting unit that is natural barren
Png − Percentage of reporting unit that is natural grassland
Pshrb − Percentage of reporting unit that is shrubland
Purb − Percentage of reporting unit that is urban
Pusr − Percentage of reporting unit that is user defined class
Pwetl − Percentage of reporting unit that is wetland
N_index − Percentage of reporting unit that is all natural land use
U_index − Percentage of reporting unit that is all human land use

Each of the above will also have a field with _A appended (e.g. Pfor_A) representing total area in map units.

### Slope metrics

AgcSL{n} − Percentage of reporting unit that has agricultural crop land on slopes >= {n}
AgpSL{n} − Percentage of reporting unit that has agricultural pasture on slopes >= {n}
AgtSL{n} − Percentage of reporting unit that has any agricultural land use on slopes >= {n}
UserSL{n} − Percentage of reporting unit that has user defined class on slopes >= {n}

{n} is the slope threshold.
Each of the above will also have a field with _A appended (e.g. AgtSL_A) representing total area in map units.

### Patch metrics

General metrics:

Patch metrics will be prefixed by an F if forest was used or U if the user defined class was used to define patches.

{F or U}Number − Number of patches within the reporting unit
{F or U}AvgSize − Average size of patches within the reporting unit
{F or U}PatDens − Patch density within the reporting unit (number of patches/$km^2$)
{F or U}Largest − Size of largest patch within the reporting unit
{F or U}_PLGP − Proportion of largest patch to total area of forest or user class within the reporting unit
{F or U}_MDCP − Mean distance (in map units) to closest patch within the reporting unit

- PWN − Number of patches with neighbors within the reporting unit and search radius
- PWON − Number of patches without neighbors within the reporting unit and search radius

Based on user defined edge width ({n} in grid cells):
{F or U}Edge{n} − Percentage of reporting unit that is defined as edge
{F or U}Core{n} − Percentage of reporting unit that is defined as core
{F or U}_E2a{n} − Ratio of edge to area

Forest patch metrics based on Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2000. Global−scale patterns of forest fragmentation. Conservation Ecology 4(2): 3. [online] URL: http://www.consecol.org/vol4/iss2/art3:

Pff{n} − Average forest connectivity within the reporting unit for user defined scale
PffPtch{n} − Percentage of reporting unit that is patch forest class for user defined scale
PffTran{n} − Percentage of reporting unit that is transitional forest class for user defined scale
PffEdge{n} − Percentage of reporting unit that is edge forest class for user defined scale
PffPerf{n} − Percentage of reporting unit that is perforated forest class for user defined scale
PffIntr{n} − Percentage of reporting unit that is interior forest class for user defined scale

For each of the above metrics, uu will be substituted for ff when the user defined class is used instead of forest to define patches. User defined scale is a {n} by {n} window of grid cells.

Diversity measurements
S − Simple diversity
H − Shannon−Weiner diversity
H_Prime − Standardized Shannon−Weiner diversity
C − Simpson index

## Riparian Characteristics

RLA{n} − Land area within {n} map units of a stream
SLA{n} − Land area within {n} map units of a sample point
RO − Percent overlap of riparian zones and land cover
SO − Percent overlap of sample point buffers and land cover

Riparian zone metrics
Ragc0 − Percentage of stream length adjacent to cropland
Ragp0 − Percentage of stream length adjacent to pasture
Ragt0 − Percentage of stream length adjacent to all agricultural use
Rfor0 − Percentage of stream length adjacent to forest
Rhum0 − Percentage of stream length adjacent to all human land use
Rmbar0 − Percentage of stream length adjacent to man made barren
Rnbar0 − Percentage of stream length adjacent to natural barren
Rnat0 − Percentage of stream length adjacent to all natural land use
Rng0 − Percentage of stream length adjacent to natural grassland
Rshrb0 − Percentage of stream length adjacent to shrubland
Rurb0 − Percentage of stream length adjacent to urban
Ruser0 − Percentage of stream length adjacent to user defined class
Rwetl0 − Percentage of stream length adjacent to wetland

Each of the riparian metrics may have a number greater than 0 following the code to represent a buffer distance. For example, Rfor30 is the percentage of forest in a 30 (map units) stream buffer area. If the buffer distance was a real number, it is rounded to the nearest integer.

Near sample point metrics
Sagc{n} − Percentage of cropland within {n} map units of a sample point
Sagp{n} − Percentage of pasture within {n} map units of a sample point
Sagt{n} − Percentage of all agricultural use within {n} map units of a sample point
Snbar{n} − Percentage of man made barren within {n} map units of a sample point
Snbar{n} − Percentage of natural barren within {n} map units of a sample point
Sfor{n} − Percentage of forest within {n} map units of a sample point
Shum{n} − Percentage of all human land use within {n} map units of a sample point
Snat{n} − Percentage of all natural land use within {n} map units of a sample point
Sng{n} − Percentage of natural grassland within {n} map units of a sample point
Sshrb{n} − Percentage of shrubland within {n} map units of a sample point
Surb{n} − Percentage of urban within {n} map units of a sample point

Suser{n} − Percentage of user defined class within {n} map units of a sample point
Swetl{n} − Percentage of wetland within {n} map units of a sample point

### Human Stresses

Land_area − Total terrestrial area in map units (total area minus water)
LC_overlap − Percent overlap between reporting unit and land cover themes

P_Load − Phosphorus loading (kg/ha/yr)
N_Load − Nitrogen loading (kg/ha/yr)
POPDENS − Population density reported as population count/area of reporting unit in $km^2$

- POPFld − Population count via area−weighted redistribution. Field name in ATtILA output is same as field name in input. Field name alias is: "{input field name} − {input population theme name}"

POPCHG − Percent change in total population
PCTIA_LC − Percentage of reporting unit composed of impervious cover, based on land use
RDDENS* − Road density reported as km of roads/area of reporting unit in $km^2$
RDLEN* − Total road length in map units
STXRD* − Number of road/stream crossings per kilometer of stream in the reporting unit
STXRD_cnt − Total number of road/stream crossings in the reporting unit
XCNT_* − Number of road/stream crossings within reporting unit by road class
PCTIA_RD − Percentage of reporting unit composed of impervious cover, based on road density
RNS{n}* − Length of roads near streams (user defined distance) divided by length of streams in reporting unit

* If a road class is used in the metric computation, the output field name will have "C[CLASS]" appended. For example, for road class 1, the density name will be RDDENSC1.

### Physical Characteristics

{grid}Ovlp − Percent overlap between {grid} and reporting unit themes
{grid}MIN − Minimum grid cell value within reporting unit
{grid}MAX − Maximum grid cell value within reporting unit
{grid}RNG − Range of grid cell value within reporting unit
{grid}MEAN − Average grid cell value within reporting unit
{grid}STD − Standard deviation of grid cell value within reporting unit

For each of the above, {grid} can be ELEV (elevation), PRCP (precipitation), or SLP (slope).

STRMDENS* − Stream density reported as km of streams / area of reporting unit in $km^2$
STRMLEN* − Total stream length in map units

* If a stream order is used in the metric computation, the output field name will have "O[ORDER]" appended. For example, for stream order 1, the density name will be STRMDENSO1.

## Appendix 2 − Land−Cover Classification Systems

### Anderson level I

| Land use category | Codes included in this category |
|---|---|
| **N−INDEX** | 3,4,6,7,8 |

| | |
|---|---|
| Forest | 4 |
| Wetlands | 6 |
| Shrublands | 3 |
| Natural Grasslands | none |
| Natural Barren | 7 |
| Other Natural Vegetation | 8 |
| **U−INDEX** | 1,2 |
| Man−Made Barren | none |
| ***Urban*** | 1 |
| Low density residential | none |
| High density residential | none |
| Commercial/Industrial | none |
| Other Urban | 1 |
| ***Agriculture*** | 2 |
| Pasture | none |
| Row Crops | none |
| Non−Row Crops | none |
| Other Agriculture | 2 |
| **Water/NoData** | 5,9 |

## Anderson level II

| Land use category | Codes included in this category |
|---|---|
| **N−INDEX** | 31,32,33,41,42,43,61,62,71,72,73,74,77,81,82,83,84,85 |
| Forest | 41,42,43 |
| Wetlands | 61,62 |
| Shrublands | 32,33 |
| Natural Grasslands | 31 |
| Natural Barren | 71,72,73,74,77,83 |
| Other Natural Vegetation | 81,82,84,85 |
| **U−INDEX** | 11,12,13,14,15,16,17,21,22,23,24,75,76 |
| Man−Made Barren | 75,76 |
| ***Urban*** | 11,12,13,14,15,16,17 |
| Low density residential | None |
| High density residential | 11 |
| Commercial/Industrial | 12,13,14,15,16 |
| Other Urban | 17 |
| ***Agriculture*** | 21,22,23,24 |
| Pasture | none |
| Row Crops | none |
| Non−Row Crops | 22 |
| Other Agriculture | 21,23,24 |
| **Water/NoData** | 51,52,53,54,91,92 |

## NLCD 1992

| Land use category | Codes included in this category |
|---|---|
| **N−INDEX** | 31,41,42,43,51,71,91,92 |
| Forest | 41,42,43 |
| Wetlands | 91,92 |
| Shrublands | 51 |
| Natural Grasslands | 71 |
| Natural Barren | 31 |
| Other Natural Vegetation | none |
| **U−INDEX** | 21,22,23,32,33,61,81,82,83,84,85 |
| Man−Made Barren | 32,33 |
| ***Urban*** | 21,22,23 |
| Low density residential | 21 |
| High density residential | 22 |
| Commercial/Industrial | 23 |
| Other Urban | none |
| ***Agriculture*** | 61,81,82,83,84,85 |
| Pasture | 81 |
| Row Crops | 82 |
| Non−Row Crops | 61,83 |
| Other Agriculture | 84 |
| **Water/NoData** | 11,12 |

## Southern Appalachian Assessment (SAA)

| Land use category | Codes included in this category |
|---|---|
| **N−INDEX** | 1,2,3,4,5,6,7,8,9,10,11,14 |
| Forest | 1,2,3,4,5,6,7,8,9 |
| Wetlands | 14 |
| Shrublands | none |
| Natural Grasslands | 10 |
| Natural Barren | 11 |
| Other Natural Vegetation | none |
| **U−INDEX** | 12,13,15 |
| Man−Made Barren | none |
| ***Urban*** | 15 |
| Low density residential | none |
| High density residential | none |
| Commercial/Industrial | none |
| Other Urban | none |
| ***Agriculture*** | 12,13 |
| Pasture | 12 |
| Row Crops | 13 |
| Non−Row Crops | none |

| | |
|---|---|
| Other Agriculture | none |
| **Water/NoData** | 16,17 |

## Appendix 3 − Optional Map Products

Many metrics produce other map products from the initial data inputs necessary for the calculation of selected metrics. By default, these map products are discarded at the end of the ATtILA metric runs. Several of them, however, can be retained by selecting "Metric values and maps" from the dialog's Output Type dropdown box. The optional map products are then added to a view of the user's choice. By default, the new shapefiles are stored in the project working directory, which is the $AVHOME directory unless changed by the user. $AVHOME is usually C:\temp in Windows or your home directory for UNIX.

In addition, ATtILA can generate some output maps that were not created during the metric runs, but may be of some interest to the user. The land−cover proportion maps are a good example of this. The amount of land−cover within a reporting unit is actually determined by generating a cross−tabulation table between the land−cover grid and the reporting unit theme and performing mathematical operations on the data within the table to determine the proportion of the reporting unit that is comprised of a particular land−cover type. By selecting "Metric values and maps" from the dialog's Output Type: dropdown box for these metrics, ATtILA will generate a grid for each selected metric that reclassifies the original land−cover grid into two classes: 1) the land−cover of interest and 2) all other land−cover types.

The following is a list the optional map products available for the various ATtILA metrics and their default naming conventions.

*Note:* Many of the created filenames will have a number {n} attached to the end of the name. The value of n is generated by ArcView's MakeTmp request. The MakeTmp request will check the a directory for files that match a prefix and an extension and then creates a new FileName object with the lowest unused number in the sequence. For example, if there are no files named test1.txt in the directory, this script creates a FileName called test1.txt. If there are files test2.txt, text3.txt, test4.txt, it creates the name test1.txt. If there are files test1.txt, test2.txt, test3.txt, it creates the name test4.txt.

*Note:* Grid outputs generated by ATtILA are generally temporary grid data sets. It is the user's responsibility to make the grid a permanent data set by either saving the project or by selecting Save Data Set... from the Theme menu. All grid data sets that are still temporary in status when the ArcView project is closed are deleted from disk.

*Note:* By creating and examining the optional output maps for the various ATtILA metrics where they are available, the user can gain a better understanding how the metric calculation is conducted and of what, exactly, the metric is measuring. In addition, many of the optional output maps can, in turn, be used as input data sources for additional ATtILA runs. For example, the STXRD metric can generate a point theme identifying the locations of road stream crossings. This point theme can then be input in the SITE_VALUE metric in the Physical Characteristics dialog to obtain a record of grid values at those locations for all available grid themes. The polygon theme that uniquely identifies the various land cover patches generated by the MDCP metric can in turn be used as the reporting unit theme in any of the ATtILA dialogs to generate the entire suite of ATtILA metrics for each land cover patch. The same can be done with the sample site buffer polygons generated by the Near Sample Points Metric in the Riparian Characteristics Dialog.

***Landscape Characteristics***

Land cover proportions
Pagc, Pagp, Pagt, Pfor, Pmbar, Pnbar, Png, Pshrb, Purb, Pusr, Pwetl, N_index, U_index

Each of the metrics above will create a new grid with the following characteristics:

| | |
|---|---|
| Description | Binary integer grid highlighting a given land cover type. |
| Extent | Same as land cover grid |
| Cell size | Same as land cover grid |
| Values | 1 = selected land cover, 0 = other land cover |
| Theme Name | {metric name} |
| File Name | {metric prefix}+{n}, where metric prefix is the metric name truncated to the first six characters and n is the value generated by ArcView's MakeTmp request. |

Slope metrics
AgcSL, AgpSL, AgtSL, UserSL

Each of the selected metrics will create a new grid with the following characteristics:

| | |
|---|---|
| Description | Binary integer grid highlighting where a given land cover type coincides with grid cells of another grid (slope) with values greater than or equal to a user specified threshold. |
| Extent | Union of land−cover grid extent and the slope grid extent |
| Cell size | Maximum between land−cover grid cell size and slope grid cell size |
| Values | 1 = selected land cover on slopes greater than or equal to threshold value 0 = other areas |
| Theme Name | {metric name}+{i}, where i is the slope threshold value |
| File Name | {metric prefix}+{i}+{n}, where metric prefix + i is the metric name and appended slope threshold truncated to the first six characters and n is the value generated by ArcView's MakeTmp request. |

Patch metrics
Number, AvgSize, PatDens, Largest, PLGP

This metric group will generate a separate grid with the following characteristics for each selected reporting unit (be aware this may create many new grids):

| | |
|---|---|
| Description | Integer grid uniquely identifying individual land cover type patches within a reporting unit. Attribute table contains patch id and a count of the number of cells within a particular patch. |
| Extent | Extent of the associated reporting unit modified slightly (expanded) to coincide with the intersecting grid cell boundaries. |
| Cell size | Same as the land cover grid |
| Values | 0 = non−patch n = patch number (consecutive numbers 1 thru n) |
| Theme Name | {Forest or User} Patch Grid (+{reporting unit id}+) Example: Forest Patch Grid (6010202) |
| File Name | Patch+{n}, where n is the value generated by ArcView's MakeTmp request. |

MDCP
This metric will generate a separate polygon theme with the following characteristics for each selected reporting unit (be aware this may create many new shapefiles):

| | |
|---|---|
| Description | Polygon theme uniquely identifying individual land cover type patches within a reporting unit. Derived from a land cover grid where groups of adjacent cells of selected land cover type are assigned a unique grid code. Attribute table contains the original grid code value and a count of the number of patches with the same grid code (grid cells touching on the diagonal are |

| | |
|---|---|
| | placed into different polygons) spatially merged into a single entity. Output map for the Patch Number metric described above to obtain the patch integer grid. |
| Extent | Extent of all patches within reporting unit. |
| Cell size | n/a |
| Attributes | Gridcode = patch number derived from regiongroup request Count = number of parts to a spatially merged polygon |
| Theme Name | {Forest or User} Patch Theme (+{reporting unit id}+) Example: Forest Patch Theme (6010202) |
| File Name | {F or U}Patch+{n}.shp, where "F" or "U" is appended onto the new shapefile filename depending on if the F_MDCP metric or U_MDCP metric is selected and n is the value generated by ArcView's MakeTmp request. Example: Fpatch1.shp |

Fragmentation measurements

Pff, PffPtch, PffTran, PffEdge, PffPerf, PffIntr

For each of the above codes, Puu may be subtituted for Pff when the user defined class is used instead of forest to define patches.

This metric will generate two separate grid themes (Pff or Puu and Fragmentation Classification for Forest Land−Cover Type or Fragmentation Classification for User−Defined Land−Cover Type) with the following characteristics for each selected reporting unit:

| | |
|---|---|
| Description | Floating−point grid theme where each cell of the land−cover type of interest in the input land−cover grid is assigned the probability that one of its eight adjacent cells is the same land−cover type. |
| Extent | Extent of all land−cover cells which intersect the reporting unit. |
| Cell size | Same as land−cover grid. |
| Values | 0 through 1 |
| Theme Name | {Pff or Puu} (+{reporting unit id}+) Example: Pff (6010202) |
| File Name | P{ff or uu}+{n}, where "ff" or "uu" is appended onto the new grid filename depending on if the Pff metric or Puu metric is selected and n is the value generated by ArcView's MakeTmp request. Example: Pff2 |

Fragmentation Classification for Land−Cover Type Grid

| | |
|---|---|
| Description | Integer grid theme where each cell in the input land−cover grid is assigned a fragmentation classification code based on the connectivity of the land−cover type of interest within the user−defined analysis window and the proportion of the user−defined analysis window occupied by that land cover. |
| Extent | Extent of all land−cover cells which intersect the reporting unit. |
| Cell size | Same as land−cover grid. |
| Values | 1 = water<br>2 = other<br>3 = patch class<br>4 = transitional class<br>5 = edge class<br>6 = perforated class<br>7 = interior class |
| Theme Name | {Forest or User}+ Fragmentation Class (+{reporting unit id}+) Example: Forest Fragmentation Class (6010202) |
| File Name | |

| | |
|---|---|
| | {f or u}+class+{n}, where "f" or "u" is appended onto the new grid filename depending on if the Pff metric or Puu metric is selected and n is the value generated by ArcView's MakeTmp request. Example: fclass8 |

Diversity measurements
S, H, H_Prime, C

No output maps are generated for these metrics.

***Riparian Characteristics***

Riparian zone metrics
Ragc, Ragp, Ragt, Rfor, Rhum, Rmbar, Rnbar, Rnat, Rng, Rshrb, Rurb, Ruser, Rwetl

This metric will generate two types of output: a separate grid highlighting the land−cover type of interest for each selected reporting unit and each user−specified riparian buffer zone and polyline theme that consists of all selected linear stream segments merged with the outlines of any selected real water features within the reporting units of interest. If no water features are selected, then all the water features within the reporting units will be used. If areal stream features are used as inputs for metric calculations, two other vector themes are created: a polygon theme that merges all adjacent and/or overlapping waterbodies and a polyline theme depicting the outlines of the merged areal waterbodies.

The grid(s) will have the following characteristics:

| | |
|---|---|
| Description | Binary integer grid highlighting a given land−cover type within the riparian zone. |
| Extent | The reporting unit's extent modified slightly to coincide with the land−cover grid cell boundaries. |
| Cell size | Same as land−cover grid. |
| Values | 0 = other land−cover 1 = selected land−cover |
| Theme Name | {reporting unit id}+: {metric name}+{riparian buffer distance} Example: 6010106: Rurb120 |
| File Name | {metric name}+{n}, where n is the value generated by ArcView's MakeTmp request. Example: Rurb2 |

The polyline theme has the following characteristics:

| | |
|---|---|
| Description | A polyline shapefile that consists of all selected linear stream segments merged with the outlines of any selected areal water features (e.g., lake shorelines, river banks) within the reporting unit(s) of interest. If no water features are selected, then all the water features within the reporting unit(s) will be used. |
| Extent | The extent of linear and/or areal water features within the reporting units of interest. |
| Cell size | n/a |
| Attributes | Same as linear stream theme, if linear stream is the only input theme. If an areal stream theme is used, a SHAPE and ID field are the only output fields. The ID value is arbitrary and not used in the calculation of the metric. |
| Theme Name | Areal and/or Line Composite |
| File Name | astrms+{n}+.shp, where n is the value generated by ArcView's MakeTmp request. Example: astrm5.shp |
| Additional Theme Name | Dissolved Areal Features |
| Additional File Name | wb_dis+{n}+.shp, where n is the value generated by ArcView's MakeTmp request. |

| | |
|---|---|
| Additional Theme Name | Areal Features as Polylines |
| Additional File Name | wb_pln+{n}+.shp, where n is the value generated by ArcView's MakeTmp request. |

Near sample point metrics
Sagc, Sagp, Sagt, Snbar, Snbar, Sfor, Shum, Snat, Sng, Sshrb, Surb, Suser, Swetl

This metric will generate two types of output: a separate grid highlighting the land−cover type of interest for each selected reporting unit and each user−specified point buffer zone and a polygon theme for each reporting unit and each buffer distance that consists of all buffer areas within each reporting unit spatially merged into a single entity.

The grid(s) will have the following characteristics:

| | |
|---|---|
| Description | Binary integer grid highlighting a given land−cover type within the point buffer zone. |
| Extent | Same as land−cover grid |
| Cell size | Same as land−cover grid. |
| Values | 0 = other land−cover 1 = selected land−cover |
| Theme Name | {metric name}+{buffer distance in map units}+(+{reporting unit id}+) Example: Sfor3066 (6010203) |
| File Name | {metric prefix}+{n}, where metric prefix is the metric name + buffer distance truncated to the first six characters and n is the value generated by ArcView's MakeTmp request. |

The polygon theme has the following characteristics:

| | |
|---|---|
| Description | A polygon shapefile that consists of all areas within the buffer distance of selected points, but within the associated reporting unit. If two or more distinct buffer areas exist within a reporting unit, the buffer areas are spatially−merged into a single entity. The shapefile will contain one record for each reporting unit of interest that contains an input point feature. |
| Extent | The extent of buffer area within the reporting unit. |
| Cell size | n/a |
| Attributes | Area, perimeter, and reporting unit ID. |
| Theme Name | PtBffr+{n}+.shp ({reporting unit id}+), where n is the value generated by ArcView's MakeTmp request. Example: PtBuffr8.shp (6010204) |
| File Name | PtBffr+{n}+.shp, where n is the value generated by ArcView's MakeTmp request. Example: ptbffr8.shp |

***Human Stresses***

Nutrient loadings metrics
P_Load, N_Load

No output maps are generated for these metrics.

Population measurements
POPDENS, POPCHG

No output maps are generated for these metrics.

Impervious area measurements
PCTIA_LC

No output maps are generated for these metrics.

Road/stream metrics
RDDENS, RDLEN, PCTIA_RD

| | |
|---|---|
| Description | A polyline shapefile that consists of all roads (selections are ignored) within the reporting unit(s) of interest, clipped to the reporting unit boundary, and assigned the id of the reporting unit the road segment is located within. If a road class field is specified, the road class attribute is copied to the road feature in the new theme. |
| Extent | The extent of the road features within the reporting unit(s) of interest. |
| Cell size | n/a |
| Attributes | Length, reporting unit ID, road class code (if specified). |
| Theme Name | Roads by Reporting Unit |
| File Name | rurds+{n}, where n is the value generated by ArcView's MakeTmp request. |

STXRD

This metric will generate two separate shapefiles (Streams by Reporting Unit shapefile and Points of Crossing shapefile) with the following characteristics:

Streams by Reporting Unit

| | |
|---|---|
| Description | A polyline shapefile that consists of all streams (selections are ignored) within the reporting unit(s) of interest, clipped to the reporting unit boundary, and assigned the id of the reporting unit the stream segment is located within. If a stream order field is specified, the stream order attribute is copied to the stream feature in the new theme. |
| Extent | The extent of the stream features within the reporting unit(s) of interest. |
| Cell size | n/a |
| Attributes | Length, reporting unit ID, stream code (if specified). |
| Theme Name | Streams by Reporting Unit |
| File Name | rustrms+{n}, where n is the value generated by ArcView's MakeTmp request. |

Points of Crossing

| | |
|---|---|
| Description | A point shapefile that consists of crossing points between selected road features and all streams (selections on streams are ignored) within the reporting unit(s) of interest. If no roads are selected, then all road features are used in defining crossing points. |
| Extent | The extent of stream/road crossing points within the reporting unit(s) of interest. |
| Cell size | n/a |
| Attributes | Record number. |
| Theme Name | Points of Crossing |
| File Name | cross+{n}, where n is the value generated by ArcView's MakeTmp request |

RNS

This metric will generate two shapefiles per reporting unit of interest (Stream Buffers and Roads Near Streams) and one single shapefile for the entire study area (Streams by Reporting Unit). The characteristics of each shapefile is as follows:

Stream Buffers

| | |
|---|---|
| Description | A polygon shapefile of the buffer zone surrounding those streams with one or more road segments within the buffer distance. Only streams with roads within the buffer distance will be buffered. Selections on streams are ignored. This greatly improves the efficiency of the RNS calculations. If two or more distinct buffer areas exist within a reporting unit, the buffer areas are spatially−merged into a single entity. The output shapefile should contain just one record. |
| Extent | The extent of buffer area(s) |
| Cell size | n/a |
| Attributes | ID − arbitrary value |
| Theme Name | Stream Buffers ({reporting unit id}+) Example: Stream Buffers (6010204) |
| File Name | s_buf+{n}+.shp, where n is the value generated by ArcView's MakeTmp request. Example: s_buf4.shp |

Roads Near Streams

| | |
|---|---|
| Description | A polyline shapefile of the road segments that are within the specified distance of streams within the reporting unit (i.e., roads clipped within the buffer boundaries). Selections on both the input streams and roads are ignored. If a road class field is specified, the road class attribute is copied to the road feature in the new theme. |
| Extent | The extent of road segments within the stream buffer area(s) and within the reporting unit. |
| Cell size | n/a |
| Attributes | Length, reporting unit id, road class code (if specified). |
| Theme Name | Roads Near Streams ({reporting unit id}) Example: Roads Near Streams (6010204) |
| File Name | rdclp+{n}+.shp, where n is the value generated by ArcView's MakeTmp request. Example: rdclp12.shp |

Streams by Reporting Unit

| | |
|---|---|
| Description | A polyline shapefile that consists of all streams (selections are ignored) within the reporting unit(s) of interest, clipped to the reporting unit boundary, and assigned the id of the reporting unit the stream segment is located within. If a stream order field is specified, the stream order attribute is copied to the stream feature in the new theme. |
| Extent | The extent of the stream features within the reporting unit(s) of interest. |
| Cell size | n/a |
| Attributes | Length, reporting unit id, stream order code (if specified). |
| Theme Name | Streams by Reporting Unit |
| File Name | rustrm+{n}, where n is the value generated by ArcView's MakeTmp request. |

***Physical Characteristics***

Grid summary statistics
{grid}MIN, {grid}MAX, {grid}RNG, {grid}MEAN, {grid}STD

No output maps are generated for these metrics.

Stream measurements

STRMDENS, STRMLEN

This set of metrics will create a new polyline shapefile with the following characteristics:

| | |
|---|---|
| Description | A polyline shapefile that consists of all streams (selections are ignored) within the reporting unit(s) of interest, clipped to the reporting unit boundary, and assigned the id of the reporting unit the stream segment is located within. If a stream order field is specified, the stream order attribute is copied to the stream feature in the new theme. |
| Extent | The extent of the stream features within the reporting unit(s) of interest. |
| Cell size | n/a |
| Attributes | Length, reporting unit id, stream order code (if specified). |
| Theme Name | Streams by Reporting Unit |
| File Name | rustrm+{n}, where n is the value generated by ArcView's MakeTmp request. |

## Appendix 4 − Technical Notes

***All dialogs − Default theme and field selections in input boxes***

Most of the dialogs require some user input. For theme inputs, the program searches the names of all themes in the view and attempts to choose the most logical theme for each input. Once theme inputs have been chosen, the program searches fields within their attribute tables for logical choices for field inputs (if required). In both cases, the first pass looks only for exact pattern matches, a second for partial matches. The search strings are listed below. If no matches are found, the program selects the first valid theme in the table of contents or field in the attribute table. The user may override program choices by manually selecting from the scrolling list.

| ***Dialog(s)*** | ***Input field name*** | ***Search strings (in order of precedence)*** |
|---|---|---|
| Landscape Characteristics, Human Stresses, Riparian Characteristics | Reporting unit | huc, reporting unit, reporting, unit, watershed, wtrshd, basin, subbasin, shed |
| Landscape Characteristics, Human Stresses, Riparian Characteristics | Reporting unit field | huc, basin, subbasin, shed, −id, label, name, recno, id |
| Landscape Characteristics, Riparian Characteristics | Landcover | landcover, landcov, lndcvr, land, cover, lc, lnd |
| Landscape Characteristics | Slope | slope, slp, gradient |
| Human Stresses | Census1, Census2 | population, pop, census, blockgroup, blkgrp, block, tract |
| Human Stresses | Pop field | pop, census, count |
| Human Stresses, Riparian Characteristics | Streams | stream, streams, strm, river, rivers |
| Human Stresses | Roads | roads, road, rds, highway, hwy, trans, street, streets |
| Human Stresses | Class field | class, code, type |

***All metric categories***

When reporting units have multi−part polygons, ATtILA will perform a spatial merge based on reporting unit ID. Metrics will be calculated using this theme, and results appended back to the original reporting unit table. Each record of any multi−part reporting unit will contain metric values based on the entire reporting unit, ***not*** the individual piece.

***Landscape Characteristics***

Calculations of land use percentages use terrestrial area only. Water areas are not included in the total area for the reporting unit. This is also true for the N−index and U−index, (i.e., water should not be included in the N−index selection list).

***Diversity equations***

Shannon−Wiener (H)

$$H = -\sum_{i=1}^{m} P_i * \ln P_i$$

Shannon−Wiener (H')

$$H' = \left(-\sum_{i=1}^{m} P_i * \ln P_i\right) / \ln m$$

Simpson (C)

$$C = 1 - \sum_{i=1}^{m} P_i^2$$

Simple (S)

S = *m*

For all of the above,

*m* = the number of different land cover types
$P_i$ = the proportion of land cover type *i*

***Create Metric Atlas and Create Metric Index***
If you are working with a small number of reporting units (create metric atlas) or a small number of metrics (create metric index), there may be very few unique metric/index values. The number of quantiles cannot exceed the number of unique values. If you choose more quantiles than are valid, the program automatically uses the number of unique values instead. When this occurs, a message box will inform you and the resultant theme will have fewer quantiles than you requested. This may be a concern in creating an index, as metrics may not all have the same range of values (values are equal to quantile ranks in index creation).

***Create Metric Index***

The index calculation process is best described using an example. A reporting unit has a large amount of total forest cover, but also has a large amount of riparian zone agriculture. We create an index with percentage of forest (Pfor) and percentage of agriculture within 30 meters of streams (Ragt30), using 5 quantiles. Weights of 1.0 and 2.3 are assigned to Pfor and Ragt30, respectively. Given the high amount of total forest and riparian zone agriculture, this reporting unit would likely be assigned a rank of 1 (best), for Pfor, but a 5 for Ragt100. The index value for this unit would be calculated as follows:

1 (Pfor rank) * 1.0 (Pfor weight) + 5 (Ragt30 rank) * 2.3 (Ragt30 weight) = 1 + 11.5 = 12.5

Index values for all other reporting units would be calculated in the same manner, and those values would then be used to rank the reporting units in the index display. Note that because of the weights chosen in the example, riparian agriculture has much more impact on the index value than forest cover.

## Appendix 5 − Metadata

This is a sample metadata output from a simple landscape characteristics ATtILA run. Note that the land cover was NLCD and woody wetlands was moved to the forest class and transitional was moved from natural barren to mining/other barren in the U−Index superclass. A subset of reporting units was selected, so metrics were only calculated for the selected set.

```
ATtILA v4.00 WEMAP (Analytical Tools Interface for Landscape Assessments)
LANDSCAPE CHARACTERISTICS

Output File:            c:\temp\attila1.shp
Project Name:           d:\hucmetric.apr
Date and Time:          Thu Oct 23 08:45:50 2003

Reporting Unit Name:    Huc8
Reporting Unit Src:             d:\huc8
Reporting Unit ID Field:        Huc
Number of Units:                350
Number Selected:                142

Landcover Grid:         Nlcd
Landcover Grid Src:     d:\data\nlcd
Cellsize:                       30 m

Landcover Coding Scheme:        Custom
          Row Crops                { 82 }
          Non−Row Crops                { 61 }
          Pasture               { 81 }
          Urban/Recreational Grasses                { 85 }
          Low Density Residential               { 21 }
          Commercial/Industrial               { 23 }
          High Density Residential                { 22 }
          Mining/Other Barren               { 32 33 }
          Natural Barren               { 31 }
          Wetlands               { 92 }
          Forest               { 41 42 43 91 }
          Shrublands                { 51 }
          Water and/or No Data               { 11 }

Landcover Grid Projection:
          Projection                ALBERS
          Datum                     NAD83
          Zunits                    NO
          Units                     METERS
          Spheroid                  GRS1980
          Xshift                    0.0000000000
          Yshift                    0.0000000000
          Parameters
           29 30                0.000 /* 1st standard parallel
           45 30                0.000 /* 2nd standard parallel
          −96               0  0.000 /* central meridian
           23               0  0.000 /* latitude of projection's origin
          0.00000 /* false easting (meters)
          0.00000 /* false northing (meters)

Analysis Properties:
          Mask:               none
```

```
          Cell Size:               30 m
          Extent:               Union of Inputs

View Projection:                None

Multiple-Part Polygons: Multiple-part polygons were found in Huc8.
          ATtILA performed a spatial merge on the reporting units based on their ID value.
          Polygons with the same ID value will now be treated as a single entity for all
          subsequent operations including total area calculations.
          Please refer to 'Merge Operations' in the ArcView Help Index for more information
          on the spatial merge operation.

          Number of Reporting Units after merge: 80

-----------------Landcover Proportions----------------
Selected Metrics:               Pfor Pwetl U_index

Beginning metric run...
Metric run completed.

------------------------------------------------------------
Processing Time:                1.36667 minutes
```

## Appendix 6 − Troubleshooting

| Error message | Solution |
|---|---|
| Unable to allocate memory | 1) This error frequently occurs when there is a "bad" polygon in the reporting unit theme. Possible problems are an unclosed polygon, a polygon missing a label, or a polygon with multiple labels. Try running the metrics on selected sets instead of the entire reporting unit theme at once.<br>2) Another possibility is your C: drive may not have sufficient free space to store temporary working files. You may be able to delete files to clear space.<br>3) A third cause of this error is using an ID field that contains values over $2^{31}-1$, or approximately 2 billion. Use a numeric field with smaller values or a character field to avoid this problem. Converting the original field values to characters will also work. |
| MSW call KillTimer failed | This is usually a conflict with Lotus Notes in ArcView versions 3.2 and before. The only solution is to shutdown Notes while running ArcView. |
| MSEEK: Invalid argument while accessing file (seeking to position −2147483648 of ... | This is caused by an output grid or other file exceeding an inherent 2.1 GB file size limit. The only solution is to work with smaller areas. |
| MSEEK: No space left on device while accessing file (writing (−1) bytes... | This error indicates a full disk. Delete files to make space or write output to another disk. |