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Research Prospectus

Project Title: A Landscape Indicator Approach to the Identification and Articulation of the Ecological Consequences of Land Cover Change in the Chesapeake Bay Watershed, 1970 – 2000

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A Landscape Indicator Approach to the Identification and Articulation of the Ecological Consequences of Land Cover Change in the Chesapeake Bay Watershed, 1970 - 2000.

Background

The advancement of geographic science in the area of land surface status and trends and land cover change is at the core of the United States Geological Survey (USGS) current geographic scientific research agenda (McMahon and other 2005). The dynamics of change on the earth's surface, and its causes, consequences and drivers, relate to several strategic goals of the Geographic Analysis and Monitoring (GAM) Program (GAM 2006), the Geographic Information Office (GIO) (Siderelis 2005), the Geographic Discipline (McMahon and other 2005), the Bureau (USGS 2000) and the Department of Interior strategic goals (USDOI 2006).

Of the successful scientific development of land cover related activities such as the North American Landscape Characterization (NALC) program, the Multi-Resolution Land Cover Consortium (MRLC) , the National Land Cover Data (NLCD) programs (Homer and other 2004), the development of the CART-based Land Cover mapping tools (Yang et al. 2003a), the land cover change (Yang et al. 2003b) and the land cover trends (Loveland et al. 2003) programs, perhaps the least developed or articulated aspect of USGS land cover research has been in the identification and analysis of the *consequences* of land cover change.

Research has shown clear evidence that changes in land use and land cover have significant impacts on a variety of environmental, ecological, economic and social conditions and processes. Land cover change affects the pattern and process, form and functioning of ecosystems, including their ability to provide essential ecological goods and services, which in turn affect the economic, public health, and social benefits that these ecosystems provide. The consequences of change are both direct and indirect, and also are manifested at a range of spatial and temporal scales. One of the great scientific challenges ahead of modern science is to understand and calibrate the effects of land use and land cover change, and the complex interaction between human and biotic systems at a variety of natural, geographic and political scales. Improving understanding and knowledge of consequences of land use and land cover change is an important goal of the science strategy for geographic land use and land cover change research and the USGS mission..

Understanding the dynamics of land surface change requires an increased understanding of the complex nature of human-environmental systems and will require a suite of scientific tools that include traditional geographic data and analysis methods, such as remote sensing and Geographic Information Systems (GIS) as well as new and innovative approaches to understanding the dynamics of complex systems. One such approach that is gained much recent scientific attention is the Landscape Indicator, or Landscape Assessment approach that has been developed with the emergence of the science of Landscape Ecology.

The Landscape Indicator Approach

Because of the increasing need to monitor ecosystem health and because of the traditionally high costs associated with field-based monitoring, alternatives to and adaptations of the traditional monitoring approach have been developed using high resolution remotely sensed data, standard geographic data and derivative products. Termed the "landscapes approach," this alternative applies a combination of concepts from landscape ecology, hydrology, and geography in conjunction with remotely sensed and other spatial data and geographic information system technology to the assessment landscape and ecological condition (Jones et al., 2000, Pitchford et al. 2000, O'Neill et al., 1997). Figure 1 shows the concept design of a landscape indicator project.

The landscapes approach relies on:

- Geographic analysis of spatially explicit patterns of ecological characteristics (e.g., riparian zones near streams) to interpret ecological conditions;

- Concepts from the field of landscape ecology, relating changes in landscape patterns to changes in ecological processes;

- Hierarchy theory that analyzes the consequences of landscape change on ecosystems at multiple scales;

- Spatially explicit digital data and maps of biophysical characteristics and human use to interpret landscape patterns relative to ecological condition; and

- Inclusion of humans as part of the environment.

Typically a landscape indicator project for any given area, starts with the acquisition an/or development of a series of base, geographic data in a GIS format. These typically include:

- Land Use/Land Cover in raster format representing one or more time periods

- Streams and Hydrology in a vector format.

- Roads and transportation in a vector format

- Normalized Difference Vegetation Index (NDVI) derived from satellite imagery

- A digital elevation model

- *In situ* monitoring data from field sampling or a monitoring network, such as USGS Stream gauges

- Any other special GIS data layers targeted for a specific ecological endpoint.

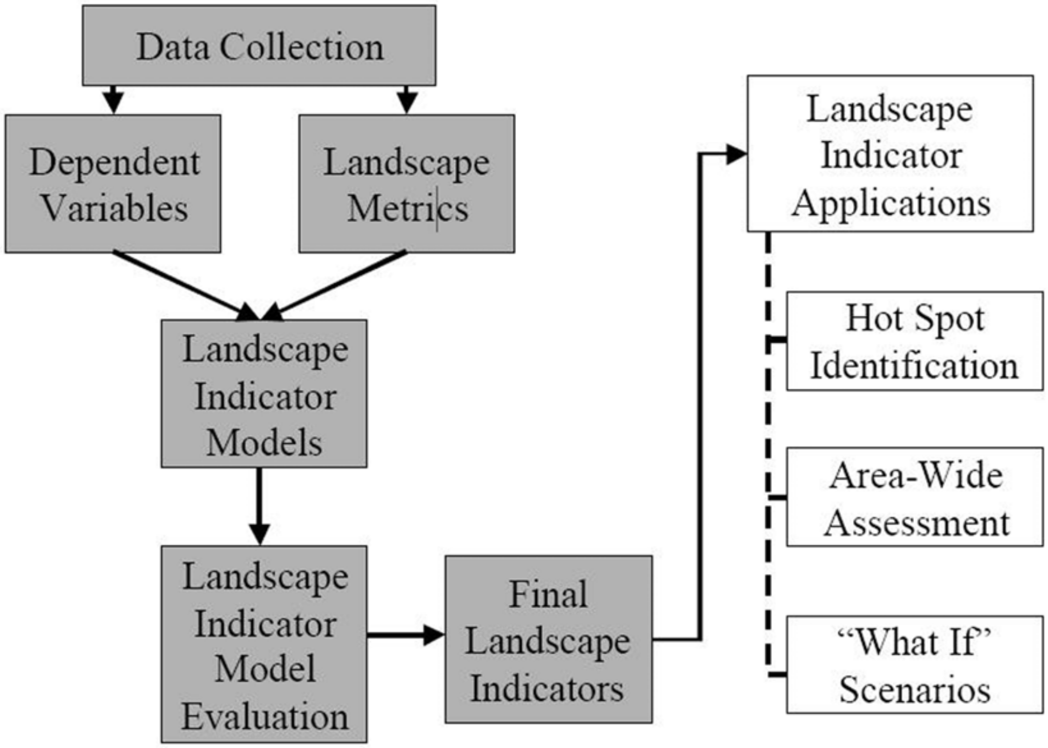

Figure 1. The conceptual components and processing sequence of the general landscape indicator model. From Pitchford et al. (2000).

These data layers are then used to compute a series of **landscape metrics** and **landscape indicators** for each of the analytical units in the study area, typically watersheds. For sake of clarity, landscape metrics are defined here as numerical values based on a single GIS data layer such as ***forest area,*** or ***total road miles***. Landscape indicators are numerical values that are derived from two or more other data layers and some analytical operation, such as ***agriculture on steep slopes*** or ***riparian forest buffers.*** There are a number of software packages and extensions that will compute these metrics and indicators from the base GIS data layers. One such program, known as ATtILA (Analytical Tools Interface for Landscape Assessment) is an Arcview 3.x (ESRI, Redlands California) extension and is available free for download at:

http://www.epa.gov/nerlesd1/land-sci/attila/regform.htm

Although new indicators can be developed at any time, ATtILA computes a standard suite of Landscape Metrics and Indicators and these are listed in Appendix A.

After the landscape metrics and indicators have been computed, the general approach is to develop a statistical model for a particular ecological endpoint, such as sediment loading to streams. A set of measured values for that particular endpoint is treated as a dependent variable and all of the landscape metrics and landscape indicators are hypothesized to be important factors contributing to the variability of the conditions measured and become independent variables. A "weight of evidence" approach based on statistical tests is used to determine which independent variables explain the most variation in the dependent variables. Statistical techniques are then used to identify promising multivariate and hierarchical relationships. The result of this analysis becomes the initial landscape indicator model, which relates a specific dependent variable to the independent variables.

That model is then tested through independent data verification, field work or statistical cross validation. Typically, after a set of refinements, a final set of landscape indicators and a landscape model is finalized and then used in a number of spatial analytical scenarios such as area wide assessments and rankings of individual subunits, such as sub-watersheds or administrative boundaries, identifying critical hot spots, potentially requiring near-term corrective action or developing 'what if' scenarios in anticipation of changing ecological or climate conditions.

The Chesapeake Bay Watershed

Nowhere is the need to understand landscape level ecosystems stress greater than in the Chesapeake Bay watershed. The Nation's largest estuary, the Chesapeake Bay, has been degraded due to the impact of human-population increase, which has doubled since 1950, resulting in degraded water quality, loss of habitat, and declines in populations of critical biological communities (Phillips 2005). Since the mid-1980s, the Chesapeake Bay Program (CBP), a multi-agency partnership which includes the Department of Interior (DOI), and the U.S. Environmental Protection Agency (USEPA) has worked to restore the Bay ecosystem. However, after over 20 years of restoration activities by the CBP, there is growing concern at all levels of government, and by the public, that ecological conditions in the Bay and its watershed have not significantly improved, and many desired ecological conditions will not be achieved by 2010. There is an acute need for enhanced science to better document the reasons for the lack of significant ecosystem improvement, assess the types and potential locations of restoration activities that will provide the greatest benefit, and forecast changes in human activities and their potential impact on the ecosystem so policy makers can adapt longer-term strategies to achieve ecologically sustainable development in the Bay watershed (Phillips 2005).

We propose here that landscape indicators and landscape pattern metrics represent a new analytical approach that could be especially appropriate for the identification and analysis of consequences in the Chesapeake Bay Program and in larger USGS Land Cover program. The status of current ecological restoration efforts in the Chesapeake Bay watershed indicate that few if any, of the restoration goals will be achieved by the 2010 target schedule under the Chesapeake 2000 Program (Phillips 2005). New analytical approaches to the causes and consequences of ecosystem decline in the Chesapeake Bay Watershed are sorely needed in order to develop a more comprehensive understanding of the ecological stressors and likely methods for successful ecosystem restoration.

Hypothesis and Literature Review

This proposal tests the hypothesis that the key, policy-relevant consequences of land cover change can be identified and articulated through a multi-scale analysis of landscape indicators and a landscape pattern analytical approach.

> ***Are the consequences of land cover change to water quality and wildlife habitat identified and articulated based on the integrated analysis of Landscape Indicators, as derived from USGS remote sensing, land cover and other national geo-spatial data applicable at the local scale where land use decisions are made?***

The landscape indicator analytical approach is derived from the relatively new field of Landscape Ecology which began to emerge as a specific scientific discipline in the late 1980s (Golley 1987). Landscape ecology is defined as the interdisciplinary study of spatial variation in landscapes at a variety of scales and includes the biophysical and societal causes and consequences of landscape heterogeneity. The conceptual and theoretical core of landscape ecology links natural sciences with related human disciplines through its core themes:

The spatial pattern or structure of landscapes, ranging from wilderness to cities,
The relationship between pattern and process in landscapes,
The relationship of human activity to landscape pattern, process and change,
The effect of scale and disturbance on the landscape

The need to monitor environmental conditions at a variety of scales, coupled with the relatively high cost of collecting environmental data in the field has limited the implementation of regional- and national-scale monitoring programs but has also given rise to the development of alternatives to and adaptations of the traditional in situ monitoring approaches. This 'landscape approach," described earlier, combines critical analytical concepts from the disciplines of geography, landscape ecology, and hydrology in conjunction with remotely sensed and other geographic data in a spatially-explicit geographic information system analytical framework (Jones et al., 2000, Pitchford et al. 2000, O'Neill et al., 1997). The emergence of the landscapes approach coincided with two other important technological developments that were promoted by the USGS geographic science; 1) the widespread availability of GIS technology, and 2) the availability of moderate resolution, synoptic land use and land cover data.

The concept of landscape is deeply rooted in the history and tradition of geographic inquiry. From its origins as a systematic science, geographers often embraced landscapes as a unit of study. Early German *Landschaftkunde* (landscape geography) studies often focused on small unique areas and thematic regions (Holt-Jensen 1988) and Carl Sauer once proposed landscapes as a basic unit of geographic inquiry (Sauer 1925). In his classic essay "The Beholding Eye, D.W. Meinig (1979) captured the essence and richness of the landscape concept by outlining the many ways that any one landscape may be perceived: as nature, as habitat, as artifact, as system, as problem, as wealth as ideology, as history, as place and as aesthetic. The many meanings of landscape reveal and important aspect of the term that translates to its scientific usage as well: although landscape connotes a geographic area, the extent of such an area is not strictly defined, and the term can be used to reflect a perspective from very localized to regional scales (Norton and Slonecker 1990).

This scale flexibility translates to one of the strengths of analytical approach for landscape indicators. Landscape indicators are a particular category of ecological indicators that are determined for a predefined area, which can be geographic, biogeographic (watershed, ecoregion) or political (State and county boundaries, Federal regions). They are usually based on remotely sensed data or other geographic information, and like ecological indicators, they can be based on a single measure or a combination of measures and can be aggregated or re- computed based on the appropriate scale of analysis. The landscape indicator development and testing approach has evolved from the general approach to landscape indicators first used in early landscape monitoring and assessment research (U.S. EPA, 1994; Kepner et al., 1995; Jones et al., 1997) to the sophisticated landscape indicator model and statistical methods, including Classification And Regression Tree (CART) methods, that were used in pesticides loading and land cover change monitoring applications of Pitchford et al. (2000) and Jones et al. (2000). Landscape indicator analysis has a number of unique features that make it especially appealing as an alternative analytical approach to the analysis of consequences in the Chesapeake Bay watershed:

- ability to look past artificial boundaries and fit specific areas into a larger natural context;
- coverage of 100 percent of selected area, consistent with available data;
- adjustability of resolution of results, from fine to coarse scales;
- ability to test applicability of concepts from hierarchy theory; and
- ability to evaluate the importance of landscape features especially spatial pattern and adjacency metrics to stream conditions.
- ability in incorporate new data, models or statistical methods

These characteristics distinguish the landscapes approach from the more traditional field or site-based monitoring programs. We hypothesize that the integrative landscape approach could become integral to the USGS assessment of the vulnerability and sustainability of ecosystem processes and functions.

Successful Applications of the Landscape Indicator Model Approach

The use of landscape indicators and landscape approaches to ecosystem monitoring has been successfully applied by a number of researchers and organizations. The 2003 Report of the Environment, by the U.S. Environmental Protection Agency (USEPA 2003) uses a suite of landscape indicators, as does the 2005 Heinz Center report: The State of the Nation's Ecosystems (Heinz Center 2002). Landscape metrics and landscape analyses have proven useful in formal ecological risk assessments (Graham et al., 1991, Hunsaker et al., 1990). Wascher (2004) applied landscape indicators to European-wide 'Landscape Character Assessment'. Jones et al (1997) performed a comprehensive landscape analysis of the watersheds in the Mid Atlantic and created an Atlas of regional ecological condition.

Hunsaker and Devine (1995) showed that landscape metrics of land cover percentages and spatial pattern were effective at explaining variability in water quality at the watershed scale. Smith et al. (2001) showed that by utilizing land cover indicators, water bodies that may be at risk of fecal coliform contamination may be identified. Land cover information derived from the Multi-Resolution Land Characterization (MRLC) project, 14-digit hydrologic unit code (HUC) watersheds of the state, a digital elevation model, and test point data were used to develop a landscape indicator model for potential fecal coliform contamination. Proportions of the various land covers were identified within the individual watersheds and then analyzed using a logistic regression. The results reveal that watersheds with large proportions of urban land cover and agriculture on steep slopes had a very high probability of being impaired. Jones et al. (2001b) evaluated the relationship between landscape metrics and USGS nutrient and sediment data acquired from 148 monitoring stations in the Chesapeake Bay watershed. They found that landscape indicator models consistently explained a large percentage (65-85%) of the total variation in nitrogen, phosphorous and sediment loads for the major watersheds but also suggested the there were significant differences in landscape-stream relationships between ecoregions and biophysical settings. Mehaffey et al.(2005) performed a landscape indicator analysis of 32 upstate watersheds that comprised the drinking water supply for New York City. Two landscape indicators, percent agriculture and percent urban development, were positively related to water quality and consistently present in all regression models. Together these two land uses explained 25 to 75% of the regression model variation.

Heilman et al. (2002) showed that landscape pattern analysis could be effective at monitoring forest fragmentation at the ecoregional level and for promoting meaningful planning for biodiversity conservation at multiple spatial and temporal scales. Wade et al. (2003) used landscape indices to map global forest cover from Global Land Cover Characteristics (GLCC) database as derived from Advanced Very High Resolution Radiometer (AVHRR) satellite imagery. Modeling fragmentation in natural and anthropogenic components, they were able to determine that over half of the temperate broadleaf and mixed forest biome and nearly one quarter of the tropical rainforest biome have been fragmented or removed by humans.

In terms of consequences research, a key application of landscape indicators was performed by Jones et al (2001a). Land cover and land cover change was calculated for the Mid-Atlantic region from NALC, LUDA and NLCD datasets for the 1973 – 1993 time periods. Typical landscape applications compute landscape metrics and indicators based on natural or administrative (watershed or county) reporting units and attempt to explain variability in the dependent variable based on multiple regression. In this application, land cover data were aggregated and re-sampled into 120 meter pixels and land cover statistics, metrics and indicators were computed on a per pixel basis throughout the study area. Using specific models of ecological endpoints of bird habitat and nitrogen loading, the landscape data sets were used to calculate changes in land cover, landscape metrics and indicators and to statistically relate these to the bird habitat and nitrogen loading model inputs. Results of the model outputs were calculated in spatially explicit 25 km^2 grid cells for the study area. Using spatial analysis and statistical clustering techniques, indicator values were developed for positive and negative changes for habitat and nitrogen individually and in combination. Figure 2 shows an example of the results of landscape/nitrogen loading model and shows positive and negative statistical relationships and their spatial pattern across the Mid-Atlantic region.

What is most interesting about this approach is that it reveals patterns and relationships that are not intuitive or readily apparent from our a priori knowledge of the landscape phenomenology. In the example in Figure 2, southern New York, western Pennsylvania and north-central West Virginia all show significant improvement in nitrogen loading while south central Pennsylvania and north central Maryland show declines.

For this research effort, we propose expanding on the work by Jones et al., (2001a) by: 1) updating the analysis to cover the historic period from 1970 through 2001 using the 2001 National Land Cover Dataset; 2) applying the indicator approach to forecasted land cover data derived from the Chesapeake Bay Land Change Modeling System; and 3) acquiring high resolution imagery of areas in the target time periods to determine the *detailed translation* of land use and land cover change and potential causal factors that are the focus of any decision support scenario. Articulation of very specific land use changes is central to the understanding of overall consequences and to the likely paths to effective corrective action.

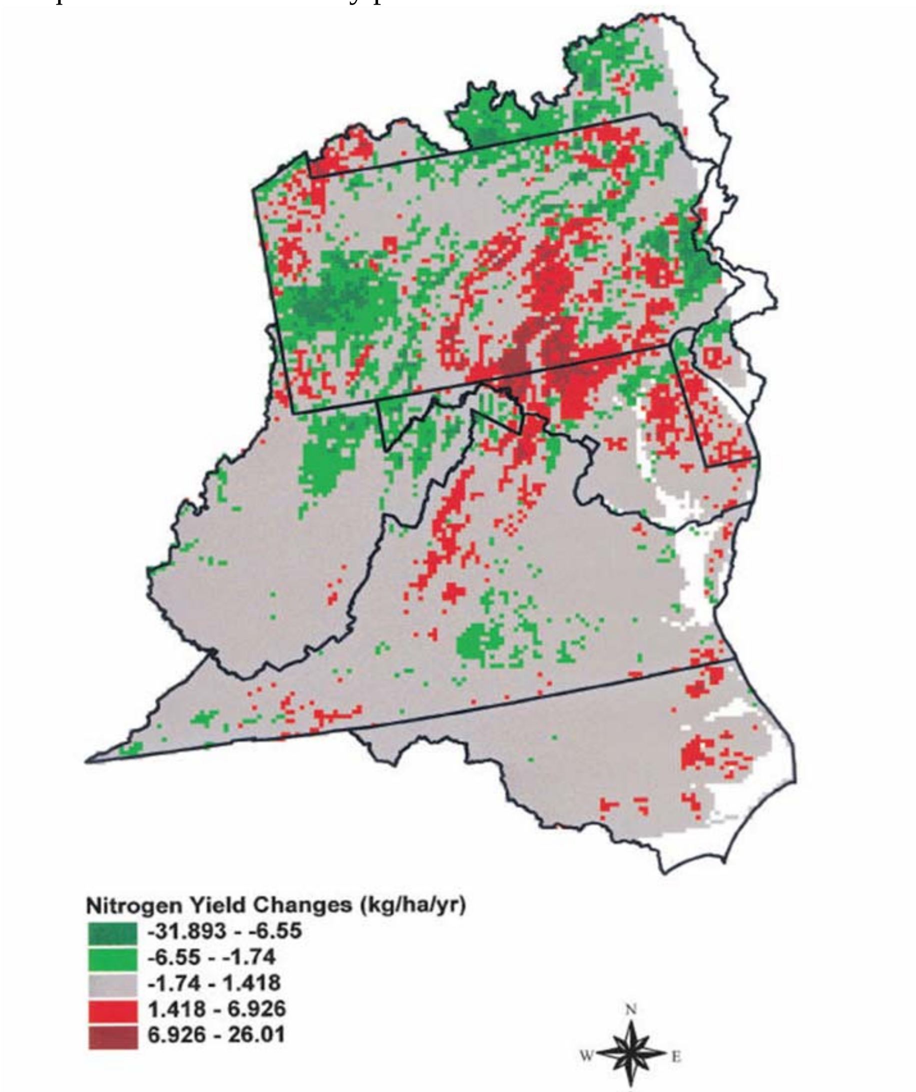

Figure 2. Landscape Level Changes in Nitrogen Yield from 1973 – 1993.
From Jones et al. 2001a.

Objectives and Approach

The objective of this research is to develop and test a spatial analysis methodology to identify and articulate the consequences of land cover change in the Chesapeake Bay Watershed. To do this we will utilize a general *Landscape Indicator* Model framework which utilizes synoptic land cover data to compute landscape metrics and landscape indicators as independent variables to explain to spatial relationship with a dependent variable representing and ecological consequence (e.g., nutrient and sediment loads). We will modify the landscape model approach based on Jones et al (2001) by expanding the historic analysis through the year 2000, and by analyzing high-spatial resolution imagery to articulate the specific land use and land cover changes and potential causal factors that relate to the significant consequence of ecological change being evaluated.

In this spatial analytical model, consequences will be developed by integrating key spatial data sets in a GIS environment and by developing a suite of per-pixel landscape indicators at an aggregate and more synoptic scale of analysis from two or more temporal land cover data sets. These landscape indicators will then be run through endpoint-specific models to identify increases or decreases in the quality of specific ecological characteristics (i.e. animal habitat or pesticide loading). The range of modeled statistical values will be mapped into a range of classified values and displayed in a spatially-explicit GIS environment.

General Processing Sequence

1. Acquire and compile base land use and land cover data and Landsat satellite imagery for the Chesapeake Bay Watershed for the 1970, 1990, and 2000 time frames

2. Acquire and compile AVHRR-based NDVI maps for each of the three historic time frames.

3. Perform Literature Review and Identify and Coordinate with Other Federal Agencies/Programs of interest.

4. Develop land cover change data layers for the 1970 – 2000 and the 1990-2000 time periods. (The EROS Data Center will be funded to develop a NLCD-based 1990-2000 land cover change data layer for the entire Chesapeake Bay)

5. Calculate a complete suite of per-pixel landscape indicators for the entire Chesapeake Bay Watershed for each of the three historic time periods.

6. Research likely topic areas for ecological consequences research from the Chesapeake Bay Program and stakeholders and identify appropriate models and *in situ* data sources to serve as dependent variables in the Landscape Indicator Models.

7. Run Landscape and statistical analyses for individual consequences of interest and create GIS data layers showing areas of statistically significant improvement or decline over the historic record and forecast significant improvements or declines over the future period.

8. Research the validity, accuracy and phenomenology of the specific ecological change by acquiring high-resolution imagery of the area in the specific time frames mapping the detailed (Anderson Level 3) land use change, field work, and/or determining other social, economic or policy issues were likely contributors to the land cover change and ecological consequences scenario.

Data Sources and Software

1. Land cover data and Landsat Imagery Data will be acquired from the North American Landscape Characterization (NALC) and the National Land Cover Data (NLCD) databases. Additional 1970-era land use data will be derived from the LUDA data set as required. Other geospatial data will be acquired from regular USGS data sets such as the NHD and the NED.

2. Water quality and sediment data will be acquired from a variety of sources including the USEPA, NAWQA and other USGS monitoring programs, other Federal Agency and State and local monitoring programs where available and appropriate.

3. AVHRR data will be acquired from NOAA.

4. Primary software packages to be utilized are ArcGIS 9.3, Arcview 3.3, ATtILA, Erdas Imagine, ENVI, SAS and SEE5 and Cubist, all of which are available in house.

5. High resolution imagery will be acquired from a variety of sources including the Advanced Systems Center. Aerial photographs will be purchased when necessary.

Expected Results/Products/Schedule

FY07: Q2. Research Plan: Testing A Landscape Indicator Approach for Identifying and Articulating the Consequences of land Use Change in The Chesapeake Bay Watershed 1970-2000.

Q3. Preliminary Data Analysis (Open File Report)

Q4. Website, Fact Sheets, Poster

FY08: **Q2**. Symposium Paper: Evaluating Consequences of Land Cover Change in The Chesapeake Bay Watershed using a Landscape Indicator Approach.

Q3. Journal Article: Evaluating Consequences of Land Cover Change in The Chesapeake Bay Watershed using a Landscape Indicator Approach.

Q4. Final Project Report.
Additional Symposium Papers/Journal Articles as appropriate.

Significance to the USGS Mission

This project relates directly to the core mission responsibilities of the Department of the Interior, The U.S. Geological Survey and the Geographic Discipline

The Chesapeake Bay is one of the most important natural resources in the United States and the steady decline in its ecological health is a cause of serious and ongoing concern to public officials and citizens at all levels. The research proposed here represents an attempt to apply innovative geographic methods to a serious natural resource issue; identifying and articulating the land management actions necessary to improve the health of the Chesapeake Bay Ecosystem

The goals of this research project and the ecological health of the Chesapeake Bay are integral to all four of the key Government Performance Results Act (GPRA) goals of the draft Department of Interior GPRA Strategic Plan: Resource Use, Resource Protection, Recreation and Serving Communities (USDOI 2006).

Similarly, this research effort to identify and articulate the ecological consequences of land cover change in the Chesapeake Bay relates directly to the USGS Strategic GPRA Goals to: 1) describe and understand the Earth, 2) manage water, biological, energy and mineral resources; and 3) to enhance and protect our quality of life.

This research effort also supports some of the key goals and Strategies of the National Geospatial Program Office: A Plan for Action (Siderelis et al.2005):

1. *Toward matters and places of national importance*: Improvement of the ecological health of the Chesapeake Bay is of national importance.

2. *Identify interagency investment strategies*; working with and cost-sharing with the U.S. Environmental Protection Agency to achieve common scientific research objectives, and

3. *Institutionalize a process for developing new and innovative services:* if successful, this research will lead to innovative Geospatial analysis methods that not only serve to identify key bio-geographical relationships, but also serve to extract critical, but latent geospatial metrics from current and archival USGS data, enhancing the value and importance of temporal Geospatial data archives.

References

Ebert, D.W, and Wade, T.G. 2004. ATtILA User's Guide. U.S. Environmental Protection Agency, Washington D.C. EPA/600/R-04/083, p. http://www.epa.gov/nerlesd1/land-sci/attila/manual/userman.htm#app4

GAM, 2006. Draft Geographic Analysis and Monitoring Program, 5 – Year Program Plan, August 11, 2006, U.S. Geological Survey, Reston, Virginia

Golley, F.B. 1987. Introducing Landscape Ecology. Landscape Ecology, v. 1 (1): p. 1-3.

Graham, R.L., Hunsaker, C.T., O'Neill, R.V., and Jackson, B.L. 1991. Ecological risk assessment at the regional scale. Ecological Applications v. 1, p. 196-202

Heilman, G.E., Jr., Strittholt, J.R., Slosser, N.C. and Dellasala, D.A. 2002. Forest Fragmentation of the Conterminous United States: Assessing Forest Intactness through Road Density and Spatial Characteristics. BioScience, v. 52 (5), p. 411-422.

Holt-Jensen, A. 1988. Geography History and Concepts. Totowa, New Jersey, Barnes and Noble. 186 p.

Homer, C, Huang, C., Yang, L., Wylie, B and Coan, M. 2004. Development of a 2001 National Land-Cover Database for the United States. Photogrammetric Engineering and Remote Sensing, v. 70(7), p. 829-840.

Hunsaker, C. T., Graham, R. L., Suter, G. W. II, O'Neill, R. V., Barthouse, L. W., and. Gardner R. H. 1990. Assessing ecological risk on a regional scale. Environmental Management 14: 325-332.

Hunsaker, C. T. and Levine D.A. 1995. Hierarchical Approaches to the Study of Water Quality in Rivers, BioScience v. 45, (3), p. 193-203.

Jones, K.B., Neale, A.C., Wade, T.G., Wickham, J.D., Cross, C.L., Edmonds, C.M., Loveland, T.R., Nash, M.S., Riiters, K.H., and Smith, E.R. 2001a. The Consequences of Landscape Change on Ecological Resources: An Assessment of the United States Mid Atlantic Region, 1973-1993. Ecosystem Health, v. 7, p. 229-242.

Jones, K.B., Neale, A.C., Nash, M.S., Van Remortel, R.D., Wickham J.D., Riitters K.H., and O'Neill RV., 2001b. Predicting nutrient and sediment loadings to streams from Landscape metrics: A multiple watershed study from the United States Mid-Atlantic Region. Landscape Ecology, v. 16. p. 301-312.

Jones, K.B, Williams, L.R., Pitchford, A.M., Slonecker, E.T., Wickham, J.D., O'Neill, R.V., Garofalo, D., Riitters, K.H., Kepner, W.G,. and Goodman, I.A 2000. A national assessment of landscape change and impacts to aquatic resources, a 10-year research strategy for the landscape sciences program. U.S. Environmental Protection Agency, EPA/600/R-00/001.

Jones, K.B., Riitters, K.H., Wickham, J.D., Tankersley, R.D. Jr, O'Neill, RV., Chaloud, D.J., Smith, E.R. and Neale, A.C. 1997. An ecological assessment of the United States mid-Atlantic region: A landscape atlas. Washington (DC): US Environmental Protection Agency. USEPA/600/R-97/130.

Kepner, W.G., Jones, K.B., Chaloud, D.J., Wickham, J.D., Riitters, K.H., O'Neill, R.V. 1995. Mid-Atlantic landscape indicators project plan, Environmental Monitoring and Assessment Program. EPA620/R-95/003, U.S. Environmental Protection Agency, Washington, D.C

Loveland, T.R., Sohl, T.L., Sayler, K., Gallant, A., Dwyer, J., Vogelmann, J.E., and Zylstra, G.J. 2001. Land Cover Trends: Rates, Causes, and Consequences of Late-Twentieth Century U.S. Land Cover Change, EPA journal, 1-52.

McMahon, G., Benjamin, S.P., Clarke, K., Findley, J.E., Fisher, R.N., Graf. W.L., Gunderson, L.C., Jones, J.W., Loveland. T.R., Roth, K.S., Usery, E.L., and Wood, N.J. 2005. Geography for a Changing World – A Science Strategy for the Geographic Research of the U.S. Geological Survey, 2005-2015, Sioux Falls SD. U.S. Geological Survey Circular 1282, 76 pages.

Mehaffey , M. H., Nash, M. S., Wade T. G., Ebert, D. W., Jones, K. B. and Rager A. 2005. Linking Land Cover and Water Quality in New York City's Water Supply Watersheds. Environmental Monitoring and Assessment, v. 107, p. 29-44.

Meinig, D.W. ed. 1979. The Interpretation of Ordinary Landscapes. New York, Oxford University Press.

Norton, D.J. and Slonecker, E.T. 1990. Landscape Characterization: The Ecological Geography of EMAP. Geo Info Systems, v. 1 p. 32-43.

O'Neill, R.V., Hunsaker, C.T., Jones, K. B., Riitters, K.H. , Wickham, J.D., Schwartz, P.M., Goodman, I.A., Jackson, B.L. and Baillargeon, W.S. 1997. Monitoring environmental quality at the landscape scale. Bioscience, v. 47(8) p. 513-519.

Phillips, S. W. 2005. U.S. Geological Survey Chesapeake Bay Science Plan, 2006-2011. U.S. Geological Survey Open-File Report 2005-1440. Reston, Virginia. 52 p. http://chesapeake.usgs.gov/USGSChesapeakeBayplan.pdf

Pitchford, A.M., Denver, J.M., Olsen, A.R., Ator, S.W., Cormier, S. Nash, M.S. and Mehaffey, M.H. 2000. Testing Landscape Indicators for Stream Condition Related to Pesticides and Nutrients: Landscape Indicators for Pesticides Study for Mid-Atlantic Coastal Streams (LIPS-MACS). U.S. Environmental Protection Agency, EPA/600/R-00/087. 87 p.

Sauer, C.O. 1925. The Morphology of Landscape, *Land and Life: A Selection of the Writings of Carl Ortwin Sauer*. Berkley, University of California Press p. 315-330.

Siderelis, K., DeLoatch, I., DeMulder, M., Garie, H., Naftzger, M., Pierce, R. and Ponce, S. 2005. The National Geospatial Programs Office: A Plan for Action. U.S. Geological Survey Open-File Report 2005-1379. 58 p.

Smith, J.H., Wickham, J.D., Norton, D., Wade, T.G. and Jones, K.B., 2001. Utilization of Landscape Indicators to Model Potential Pathogen Impaired Waters. Journal Of The American Water Resources Association, v. 37 (4), p. 805-814

USDOI. 2006. U.S. Department of Interior GPRA Strategic Plan Fiscal Year 2007-2012: August 2006 DRAFT. U.S. Department of the Interior, Washington D.C. 80 p. http://www.doi.gov/ppp/Strategic%20Plan%20FY07-12/strat_plan_fy2007_2012.pdf

USEPA. 1994. Landscape Monitoring and Assessment Research Plan. U.S. Environmental Protection Agency, Washington, D.C. EPA 620/R-94/009.

USGS. 2000. U.S. Geological Survey Strategic Plan 2000 – 2005. U.S. Geological Survey, Reston, Virginia. 25 p. http://www.usgs.gov/stratplan/stratplan_rev.pdf

Volgelman, 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, v. 67(6), p. 650-662.

Wade, T.G., Riitters, K.H., Wickham, J.W., and K.B. Jones. 2003. Distribution and causes of global forest fragmentation. Conservation Ecology 7(2): 7. http://www.consecol.org/vol7/iss2/art7

Wascher, D.M., 2004. Landscape-indicator development: steps towards a European approach. In: Jongman, R.G.H. (Ed.), The new dimensions of the European landscape: Frontis Workshop on the future of the European cultural landscape, Wageningen, The Netherlands, 2002-06-10/ 2002-06-12. Springer, Dordrecht, pp. 237–252.

Wickham, J.D., Jones, K.B., Riitters, K.H., O'Neill, R.V., Tankersley, R.D., Smith, E.R., Neale, A.C. and Chaloud, D.J. 1999. An integrated environmental assessment of the US Mid-Atlantic Region. Environmental Management, v. 24, p. 553–560.

Yang, L., C. Huang, C. Homer, B. Wylie and M. Coan. 2003a. An approach for mapping large-area impervious surfaces: Synergistic use of Landsat 7 ETM+ and high spatial resolution imagery. Canadian Journal of Remote Sensing, Vol. 29, No. 2, pp.230-240

Yang, L., Xian, G., Klaver, J., Deal, B. 2003b. Urban Land-Cover Change Detection through Sub-Pixel Imperviousness Mapping Using Remotely Sensed Data. Photogrammetric Engineering & Remote Sensing Vol. 69, No. 9, September 2003, pp. 1003-1010.

Project Support

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Other Project Support:

$50,000	In Kind (EPA Labor - Slonecker)
$20,000	USGS Land Remote Sensing Program (for NLCD Change Product, 1990 - 2000)
$5K	Travel (EPA) GPS and Spectrometric equipment Supplies and laboratory analysis.

Budget

A Landscape Indicator Approach to the Identification and Articulation of the Ecological Consequences of Land Cover Change in the Chesapeake Bay Watershed, 1970 – 2000.

Principal Investigator: Peter Claggett
FY 2007 Budget Request

	COST CENTER CODE	COST CENTER CODE	TOTAL YEAR 1
	25200000		
Personnel Salary	39,997.60		39,997.60
Other Expenses (Travel, Data, Equipment, Supplies)	5,000.00		5,000.00
Extramural (SAIC Contract)	20,000.00		20,000.00
TOTAL DIRECT	**64,997.60**		**64,997.60**
Gross Assessment Rate	18.6%		
Indirect Costs Estimate	**12,089.55**		**12,089.55**
TOTAL	*77,087.15*		*77,087.15*

FY 2008 Budget Request

	COST CENTER CODE	COST CENTER CODE	TOTAL YEAR 1
	25200000		
Personnel Salary	41,367.81		41,367.81
Other Expenses (Travel, Data, Equipment, Supplies)	5,000.00		5,000.00
TOTAL DIRECT	**46,376.81**		**46,376.81**
Gross Assessment Rate	18.6%		
Indirect Costs Estimate	**8,626.09**		**8,626.09**
TOTAL	*55,002.90*		*55,002.90*

Combined FY 2007 and FY 2008 Budgets

	A	B	C	D	E	F	G	H
1	Landscape Indicators - Claggett							
2	Budget FY07 and FY08							
3		FY07	FY07	FY07		FY08	FY08	FY08
4		Request	USGS In-Kind	USEPA In-Kind		Request	USGS In-Kind	USEPA In-Kind
5								
6	Personnel Salary	39,997.60	10,000.00	50,000.00		41,376.81	10,000.00	50,000.00
7	Other Direct	5,000.00	2,000.00	5,000.00		5,000.00	2,000.00	5,000.00
8	Extramural	20,000.00						
9								
10	Subtotal	64,997.60	12,000.00	55,000.00		46,376.81	12,000.00	55,000.00
11								
12	Cost Center Indirect Rate	18.60%	18.60%	21.10%		18.60%	18.60%	21.10%
13								
14	Indiect Total	12,089.55	2,232.00	10,230.00		8,626.09	2,232.00	10,230.00
15								
16	TOTAL	77,087.15	14,232.00	65,230.00		55,002.90	14,232.00	65,230.00
17								
18	FY07 Request	77,087.15						
19	FY07 Match	79,462.00						
20	FY07 Total	156,549.15						
21								
22	FY08 Request					55,002.90		
23	FY08 Match					79,462.00		
24	FY08 Total					134,464.90		
25								
26	PROJECT TOTALS							
27	2 Year Request							132,090.05
28	2 Year Match							158,924.00
29	2 Year Total							291,014.05
30								

APPENDIX A

Landscape Metrics and Landscape Indicators Computed in ATtILA

1. 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 - water) in map units for the land cover/slope composite grid
SL_Overlap - Percent overlap between reporting unit and land cover/slope composite grid

1.1 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.

1.2 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.

1.3 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

2. 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

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

3. 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.
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

4. 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