New Interoperable Tools to Facilitate Decision-Making to Support Community Sustainability

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Introduction

Communities, regional planning authorities, regulatory agencies, and other decision-making bodies do not currently have adequate access to spatially explicit information crucial to making decisions that allow them to consider a full accounting of the costs, benefits, and trade-offs of alternative decisions. Decisions made at multiple scales (ranging from communities to States to regions to national policies and regulations) impact quality of life at the community scale. Decisions are also influenced at multiple scales; individuals write letters and get involved, the media influences the public, science informs the public and policy-makers, voters influence politicians and therefore policy-makers and regulators (figure 1). Better information is needed to support decision analysis at all of these scales -- information that characterizes: the variations in biophysical characteristics that predispose communities towards a particular response to changes in conditions; the distribution of stressors that affect community sustainability; the distribution of both vulnerable resources and populations, and; the opportunities for multiple benefits or unintended consequences associated with management actions.

Although every decision is based on some form of a decision analysis, a true decision analysis (hereafter, decision analysis) attempts to consider all of the important factors. A decision analysis is a complex process and is often not done effectively, or at all, due to a lack of information, a traditional tendency to make decisions in a stove-piped fashion rather than considering the entire system, inadequate representation of all the factors that contribute to desired goals, and the absence of a transparent process for structuring and assessing the decision objectives. Communities' decision processes vary by specific decision, community culture, the individual decision-maker, the ability to synthesize available information that could be used to inform the decision, and the degree of understanding of the linkages between actions and changes in community environmental, economic, and social health and well-being.

Decision analysis is needed to 1) fully identify and understand issues or problems 2) assess sustainability, 3) enable future visioning and goal setting, 4) evaluate alternatives to enhance sustainability, 5) track progress towards goals and 6) develop adaptive responses. However, for decision analysis to be widely used in real decision-making, the necessary data and tools must be packaged in broadly accessible and easy-to-understand and use applications.

The technology available today is unprecedented and continues to improve in leaps and bounds. It has only recently become possible to serve massive amounts of spatially explicit data (e.g., Google Earth, ArcGis.com) or to create mobile phone applications and web applications allowing large numbers of users to submit data instantly to data collection sites (e.g., Cornell University's eBird, mobile phone apps for pothole and roadkill reporting). It is this technology that will drive the development of webtools of the future; webtools that will help communities become more sustainable leading to a higher quality of life. One of the biggest issues with community decision-making is the lack of full accounting of the goods and services provided by nature. This has led to innumerable unintended consequences, such as loss of wetlands that help buffer against hurricanes, or that filter pollutant runoff from agriculture and disproportionate impacts of chemical pollutants on vulnerable populations. There has been little accounting for the more implicit, less easily quantified benefits we receive from nature such as the value of green space for human health and wellbeing, or the cultural significance attributed to aspects of the natural environment by communities, tribes, and different ethnic populations.

Example of Emerging Webtools from Environmental Protection Agency Research

The U.S. Environmental Protections Agency's (EPA) Sustainable and Healthy Communities Research Program (SHCRP) is developing web tools that are 1) interoperable (i.e., they work together, are able to exchange and use information), 2) use common data to the degree possible, 3) make use of emerging technologies in areas of information technology, visualization, and modeling, and 4) resonate with users such that changes in behavior and new business-as-usual approaches result. New metrics (i.e., a standard of measurement) and indicators (i.e., a metric that indicates the condition or level of something) are being developed to reflect and communicate the linkages between human well-being and environmental changes and to measure progress. Communication and engagement of communities throughout the development of decision support is considered crucial – it is needed to ensure we are meeting communities' needs, to effectively communicate the results of our research, and to ensure ongoing use of our tools.

EPA's SHCRP intends to improve access to information, tools, and decision frameworks that allow community decision-makers to understand how specific actions affect community well-being, weigh the full consequences of alternative management actions, track progress towards goals, and allow the creation of innovative solutions to community problems. It is also the goal to empower communities to effectively improve social equity and access to the full benefits of a sustainable future. This goal will be supported by research that quantifies the supply and demand of ecosystem services (i.e., all the things humans receive from their natural environment such as clean water and food), quantifies the supply and demand of the services provided by our build environment, establishes linkages between human health and well-being and changes in environmental conditions, promotes improvement of tools through better understanding of the processes that are used by decision-makers, and provides improved approaches that empower communities to move towards a more sustainable future, The suite of tools under development by the SHCRP will allow insights into the implications of alternative decisions on community resilience and quality of life, and promote the creation of innovative solutions to problems faced by communities.

The SHCRP is capitalizing on a vast amount of research the EPA has already conducted on ecosystem services and on integrated assessments. Two of these efforts, the Regional Vulnerability Assessment (ReVA) and the National Atlas of Ecosystem Services and the ongoing visioning to combine these two efforts and to add to them in an interoperable platform will be described below.

EPA's work in integrated assessment

Since 1998, EPA's Regional Vulnerability Assessment (ReVA) has been developing and demonstrating approaches to conducting integrated assessments (figure 2). Recognizing the importance of information at a variety of spatial scales, ReVA emphasizes a broad spatial perspective while allowing thorough exploration of data from many perspectives including changes in scale. Combining existing data that was collected for many different purposes can be problematic as metric scales vary, distributions often don't meet statistical requirements (i.e. most statistical analyses require a normal, bell-shaped distribution of data), or available data is unbalanced in terms of having large amounts focused on specific areas while lacking in others. Thus much of the past research effort within the ReVA program has focused on the mechanics of how disparate data and model results can be integrated into meaningful indices designed to address specific assessment questions posed by environmental decision-makers.

It is also common for GIS-based applications today to allow users to overlay many different spatial coverages, e.g. to identify where high levels of pollutants come in contact with vulnerable ecosystems or populations. While this can provide a satisfactory means of screening data and identifying where things converge on the map, it is problematic if data are correlated and the user is trying to prioritize areas for management or protection. Data correlation means that 2 or more metrics move in the same direction simultaneously, i.e. a change in one metric also shows up as a change in another related metric. An example is population data from the census. Areas of high poverty often coincide with low education levels, high levels of minority groups that could be linguistically isolated, and poor access to health care. Yet how much one of these metrics influences the others is difficult to discern. Another example of high levels of correlation among metrics includes data derived from satellite imagery and classified into different landuse / landcover classes, (e.g. agricultural land versus urban land with high levels of impervious surface), and likewise the landscape metrics derived from these data (e.g. the degree to which forests are fragmented, or the amount of riparian buffer that is in natural cover). Clearly a change in the amount of agricultural land results in a change in other land use classes, so these metrics are correlated, and metrics derived from a single land use land cover map are also correlated.

Statistics shows us that when metrics are highly correlated, it means that the variation in one metric is similar in some part to the variation that occurs in another. Correlation matrices illustrate how much the change in one metric relates to another (figure 3). When the amount of correlation is given as 0.90 this means that 90% of the information gained from looking at one metric is already covered by the correlated metric and the new metric contains only 10% new information. When GIS applications do overlays of these metrics, without considering the correlation among metrics, it introduces bias as each metric is counted equally even though subsequent metrics don't add as much new information. So if 2 metrics correlate 90 %, yet they are mapped in an additive way, then the result is basically weighted by 1.9 as the common information is effectively counted twice.

One of the accomplishments of the ReVA program has been to develop a method that corrects for bias among metrics by weighting each metric according to the amount of correlation each individual metric introduces. This method, developed by Liem Tran, uses a shift in multivariate state space approach, meaning that we can quantify the difference a set of metrics has moved from some reference condition (Tran et al., 2006). In the ReVA web-based Environmental Decision Toolkit (EDT) (figure 4), it is thus possible to map how far away from an ideal reference watershed other watersheds in the region are. Similarly for human population metrics, it is possible to define the reference population as one without poverty, without disease, and with no linguistic isolation and then see how far away other counties or census blocks are from this ideal human population, without introducing bias from correlated metrics by correcting for this correlation.

Another result from ReVA research over the years has been the identification of how different ways of combining data into indices addresses questions. For example, the integration method described above (the Tran distance), can be used to look at overall conditions by comparing reporting units to the best or worst conditions found in the region, giving an overall ranking of each individual unit compared to the reference. Other methods can be used to identify reporting units that are the most vulnerable in terms of where conditions are likely to change for the worse in the shortest amount of time. In terms of potential losses, this can be accomplished by looking at areas that have both a combination of resources that society does not want to lose (e.g. clean water for recreation and drinking, habitat that supports a biodiverse wildlife population), and a number of stressors that can harm these resources. As both of these numbers increase simultaneously across the map, so does the environmental vulnerability. This measure of vulnerability is illustrated by a 2-dimensional matrix that has relative amount of stressors present as columns, and the relative amount of valued resources by row (Figure 6). Vulnerability increases along the diagonal as resources and stressors both increase.

ReVA methods also guide the development of "what-if" scenarios; these scenarios permit inspection of likely future changes in environmental vulnerabilities from anticipated regional changes in population growth, economic conditions, land use, transportation infrastructure, etc. ReVA can improve the environmental decision-making process by permitting more realistic inputs for environmental decision-making and by expressing results of multiple factors at a regional spatial scale. This approach allows an evaluation of *net* change, so that the user can visualize how both positive and negative changes affect future conditions and vulnerabilities.

As its name implies, ReVA is based on vulnerability assessment. ReVA's web-based Environmental Decision Toolkit (EDT) allows examination of a broad range of information across a region, and can help identify areas where as-yet-unidentified resources, ecosystems, or populations might be vulnerable. ReVA accomplishes this objective by applying environmental indicators (or descriptive metrics) to represent important changes in conditions and examines the co-occurrence of valued resources and stressors to represent vulnerability to potential harm. The techniques used to examine how stressors and resources combine seek to reveal threats that are often not clearly identifiable or quantifiable, and allow the users of ReVA output to explore complex interdependencies of related issues.

The National Atlas of Ecosystem Services

The National Atlas of Ecosystem Services (Atlas) represents a comprehensive approach to quantifying and visualizing the current and future demand and provision of valued ecosystem services needed by communities to sustain human life and well-being (figure 6). As an interactive, publicly available webtool, the Atlas will also present the distribution of drivers of change (population, multiple stressors, climate changes, etc.) as well as forecast future trends for each of these drivers with the associated changes in the supply of, and demand for ecosystem services. It will provide information about the implications for human health and well-being. Where feasible, the Atlas will provide information about the social and economic costs of various decisions, such as the trade-offs between grey (i.e., built such as culverts and drains) and green infrastructure (i.e., using natural features). Data and model results will be available at multiple scales, i.e. wall-to-wall summarized information at a relatively coarse scale (approximately 83,000 basins or catchments) for the conterminous U.S., the underlying national data layers at a much finer scale (30 m^2) and then very fine-scaled analyses for selected communities across the country. The multiple scales of information can be used in combination which will allow decision-maker insights into issue context, e.g. clarifying the role of upstream watersheds for protection of community water quality, and regional pollutant sources for community air quality, as well as information relevant to regional and national policy alternatives.

Until very recently, the data that will be available in the Atlas were only available to expert users with Geographical Information Systems (GIS) skills and access to powerful computing resources. The Atlas, using the newest technology, allows users with no more than an internet browser and some healthy curiosity to access a wealth of spatially explicit data and analysis tools. The National scale data will allow users to easily view and analyze information like the numbers of threatened and endangered species in each catchment, the number of harvestable species in a given catchment, point sources (e.g., sewage treatment plants, industries, animal operations) and non-point sources (e.g., runoff from agriculture, lawn runoff) of pollution in the catchments upstream of drinking water intakes), availability of recreation resources. Users will also be able to view how well connected naturally vegetated patches of land are, the condition of stream buffers, and the protection status of all lands contained within the US. Taken in isolation, each one of these pieces of information can help answer important questions about the use of resources but linked together in an easy-to-use tool creates an incredibly powerful means to enable better decision-making.

The fine-scaled community analyses (urban Atlas) in the Atlas will provide information linking human health and well-being to environmental conditions such as urban heat islands, near-road pollution, wise use of resources, access to recreation, drinking water quality and other quality of life factors. In addition, the urban Atlas will facilitate the analysis of who pays and who benefits through characterization of populations that are disproportionately impacted due to limited access, low levels of opportunity, and lack of community empowerment to effect positive changes. The urban atlas will facilitate site-specific problem solving and provide support to individual communities by allowing identification of places that are further along towards finding innovative solutions to sustainability challenges. The urban Atlas will rely heavily on foundational land cover data that will be characterized from aerial imagery at a 1 to 3 meter pixel resolution. This high resolution land cover classification will also be made available through the Atlas tool.

The categories of ecosystem services to be included in the Atlas include clean water for drinking; clean water for recreation and to support aquatic habitat; recreation, cultural, and aesthetic amenities; clean air; flood protection; climate regulation; habitat and the maintenance of biodiversity; food, fiber, and fuels; and water supply and timing. Eventually, it is likely that the U.S. will adopt a National Classification System for ecosystem service and when this happens, the Atlas will change its framework to adopt that classification standard. The Atlas will include multiple tools to allow users to analyze the data from simple graphical analysis, to a tool to allow users to navigate up and downstream from any point on the map, to tools that will eventually allow complicated models to be run.

An important component of the Atlas will be user participation: encouraging users to provide critical feedback, allowing users to incorporate their own data, including tools for users to register conservation or best management practices information and being able to view associated benefits, and embracing the concepts of social networking. Initially, the Atlas will participate in the Ecosystem Commons (www.ecosystemcommons.org), a recently launched networking tool for ecosystem services practitioners and interested parties to exchange information. Eventually, the Atlas will become part of a larger interoperable decision platform which will include social networking. **SHCRP's interoperable decision platform**

Integration of ReVA/Atlas

The Atlas will serve as a foundation for SHCRP decision support tools and sustainability assessment capabilities, providing both basic landscape information (e.g. soils, land cover) as well as modeled output that represents the distribution of specific ecosystem services (e.g. water supply, air quality, agricultural yields, biodiversity) and human populations served . These data, both static (e.g. soils data) and modeled (e.g. estimated air pollution deposition), will inform analyses of what-if questions that are reflective of decision-maker needs at the individual, community, regional, and national scales. This will be accomplished through the development of empirical relationships that build on the vast information available from the Atlas and the spatial and temporal linkages among those factors that influence changes in environmental condition and human well-being. In addition, this research will be interfaced with research in other federal agencies including the US Geological Survey, National Oceanographic and Atmospheric Administration, and the National Aeronautics and Space Administration.

Engaging Communities

We cannot physically meet with every community that has decision support needs, yet we recognize the need to engage communities in processes that foster good decisions. EPA's experience and history demonstrate that stakeholder involvement is proportionate to decision buy-in and ultimately successful environmental outcomes. Not to mention, multilateral dialog ensures that EPA receives feedback for ongoing development and improvement of useful tools. Several existing social media websites, such as Facebook and LinkedIn, offer examples that can inform our ability to engage stakeholders in environmental problem solving and sustainability planning. We plan to partner with universities, non-profits, and the private sector to harness the power of social media technology, framed by an online architecture that allows communities and stakeholders to participate in problem solving processes.

Future Visions

Information technology is moving more quickly than ever – where capability builds upon itself – requiring more agile approaches to doing business. This is especially true for communities, where emerging IT could be harnessed to have tremendous impact on real-time, in-situ sustainability planning. We plan to creatively extend our outreach efforts and engage in online social networking culture to achieve our ends as efficiently as possible. For data needs and integration of our existing and future tools, we plan to transition to a modular and interoperable IT business model, similar to the building block model involved in creating a Blackberry. For example, one block controls the camera, another converts pictures to .mpeg files, and another manages how such files are sent to other smart phones. The "block" analogy shares commonalities with several other business models – for example, those of Drupal.org and WordPress.org. Drupal programmers create building "blocks" that are interoperable – referred to as "modules." Website developers then use those blocks to build their website (e.g., the Whitehouse site). One block includes the code for a "log-in" page, whereas another is a tool for viewing a gallery of images. Just as millions of people publish and peer review WikiPedia articles, millions of programmers from around the world now publish and peer review Drupal modules for free. We plan to extend that analogy to the development and maintenance of sustainability tools, and the tools that build on another. This approach is aimed at using software that's already out there (open source) and harnessing a virtual workforce of programmers to help us develop and maintain the code necessary to help communities solve problems and achieve sustainability (however they may define it). EPA SHCRP plans to continue the enhancement of these tools over time while continuously providing updated information and analysis capabilities. Some of the planned enhancements include:

- Ability to change broad environmental conditions (weather, buffers next to streams, the number and type of pollution point sources) basically allowing users to turn up and down these conditions and see implications for communities and human health and well-being

- The ability to delineate an area of land use or land management change and evaluate resulting impacts over both the local and the broader regional area
- The ability to identify where the user is on the map, and how that area compares to other areas
- Automated reporting on conditions for a variety of reporting areas, e.g. congressional districts, large watersheds
- Screening of areas to identify communities that are disproportionately impacted by pollution, waste management problems, or lack of access to public transportation
- The ability to bring in real-time data (e.g. weather, land use, air pollutant levels) and map changes in things like runoff, human health vulnerabilities, etc.
- Add the capability to answer the question "what can I do? to reduce impacts from environmental stressors such as air pollution, etc.
- Allow users to ask a series of "what-if?" questions such as what is the benefit/cost of different activities for mitigating problems, restoring ecosystems or community resiliency, and protecting things people care about.

The EPA SHCRP intends these tools to be widely available and easily accessible as well as continuing to take advantage of new technologies and communication tools. We recommend checking EPA's website for updates on the SHCRP webtool , e.g. the website www.epa.gov/ecology will include links to these future tools, along with updates as to new features as they are added.

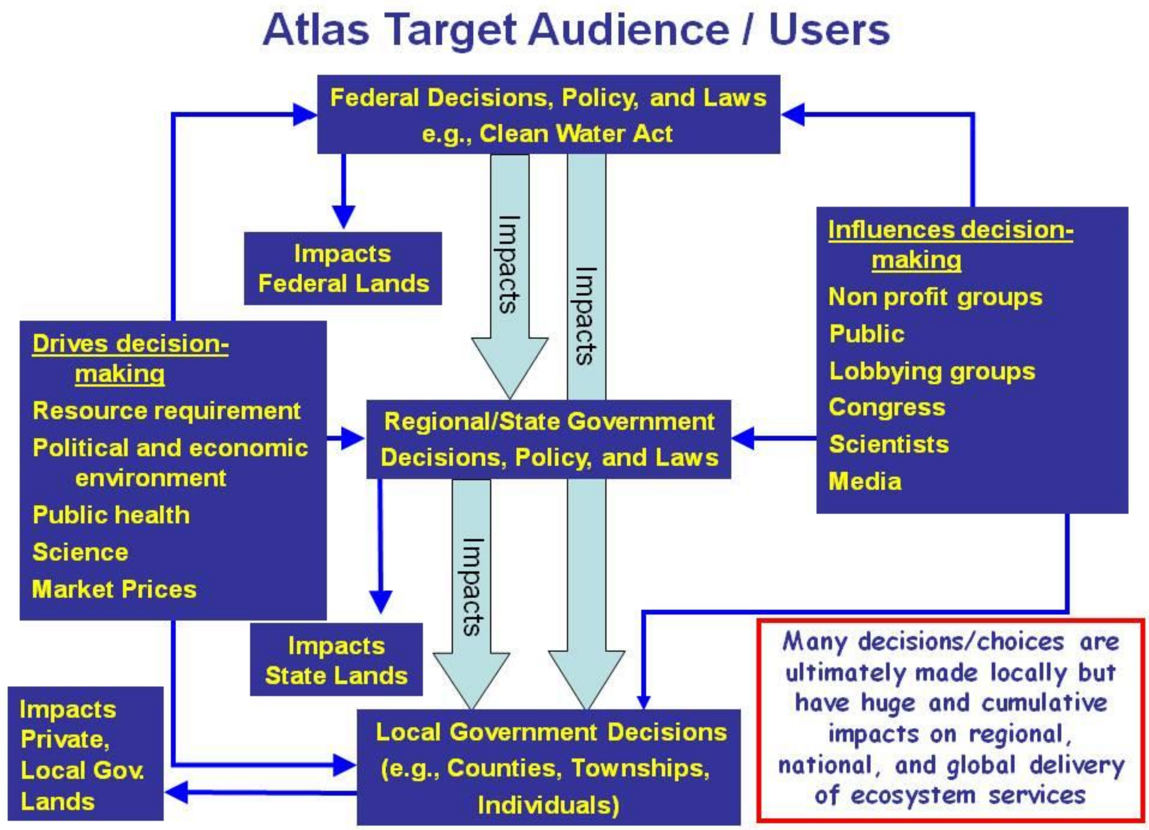

Figure 1. How decisions relate across scales

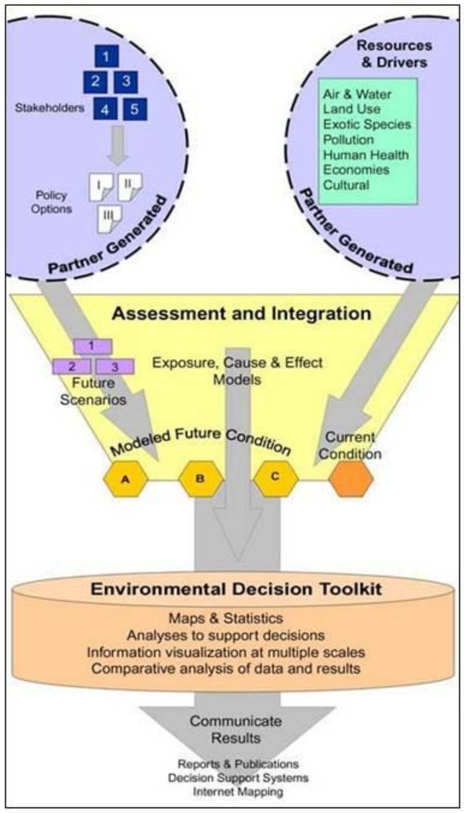

Figure 2. Graphic depicting the Regional Vulnerability Assessment (ReVA) Program process.

Region 4 population and health vulnerability data correlation matrix (partial)

1	_NAME_	MULT_RACE	HISPANIC	AGE_UNDER5	AGE_5_17	AGE_65_UP	Per_Pvty	HS_Diploma	Unemployed
8	MULT_RACE	1.0000	0.8791	0.9139	0.9233	0.8617	-0.1649	0.9301	0.9560
9	HISPANIC	0.8791	1.0000	0.6961	0.7158	0.6500	-0.0512	0.8111	0.8496
10	AGE_UNDER5	0.9139	0.6961	1.0000	0.9978	0.8865	-0.2652	0.9464	0.9322
11	AGE_5_17	0.9233	0.7158	0.9978	1.0000	0.9025	-0.2624	0.9582	0.9444
12	AGE_65_UP	0.8617	0.6500	0.8865	0.9025	1.0000	-0.2449	0.9209	0.8961
13	Per_Pvty	-0.1649	-0.0512	-0.2652	-0.2624	-0.2449	1.0000	-0.2192	-0.1594
14	HS_Diploma	0.9301	0.8111	0.9464	0.9582	0.9209	-0.2192	1.0000	0.9701
15	Unemployed	0.9560	0.8496	0.9322	0.9444	0.8961	-0.1594	0.9701	1.0000
16	Lead_NonAt	0.0672	0.0133	0.2257	0.2243	0.1240	-0.0112	0.1737	0.1599
17	Ozone_NonAt	0.1876	0.0579	0.3601	0.3474	0.2352	-0.2140	0.2656	0.2300
18	PM_NonAt	0.0350	0.0063	0.0852	0.0926	0.1017	-0.0310	0.0937	0.0596
19	NEI_COUNT	0.4178	0.2125	0.6318	0.6151	0.5142	-0.2842	0.5785	0.4723
20	EI_PNTDENS	0.2727	0.0868	0.4805	0.4582	0.3744	-0.3201	0.4201	0.3270
21	PPlaceExp	0.8315	0.6590	0.8780	0.8793	0.7986	-0.1728	0.8800	0.8550
22	RSEI_risk	0.3927	0.3447	0.4831	0.4877	0.4108	-0.1639	0.5218	0.4740
23	NATARiskCan	0.2545	0.1369	0.3774	0.3731	0.3160	-0.2343	0.3455	0.3083
24	NATAHQNeuro	0.0492	0.0245	0.0881	0.0869	0.0621	-0.0667	0.0785	0.0765
25	NATAHQResp	0.4308	0.2715	0.5210	0.5196	0.4601	-0.3301	0.4571	0.4324
26	CMortRMale	0.0720	0.0261	0.1211	0.1205	0.1074	-0.1530	0.1145	0.0992
27	CMortRFem	0.0639	0.0248	0.0992	0.0981	0.0892	-0.2138	0.0947	0.0836
28	CanMort05	0.9090	0.6823	0.9918	0.9936	0.9257	-0.2676	0.9545	0.9331
29	nCMortAgAj	-0.2370	-0.1375	-0.2810	-0.2863	-0.3519	0.4162	-0.2589	-0.2332
30	No_Uninsur	0.9692	0.8298	0.9717	0.9789	0.8982	-0.1938	0.9742	0.9778
31	Per_Unins	-0.0376	0.0374	-0.1253	-0.1258	-0.1350	0.8606	-0.1114	-0.0485
32	HPSA	-0.1232	-0.0598	-0.1826	-0.1838	-0.1715	0.2680	-0.1764	-0.1510
33	R_Drug_Use	0.9149	0.6942	0.9887	0.9929	0.9391	-0.2670	0.9632	0.9419

People within 10 km of a point source is 88% correlated with population under 5 years old. This means that 88% of the information you get from one coverage is redundant with the other. **Combining these 2 coverages effectively weights the common information by 1.88**.

Figure3. An Example correlation matrix for human health vulnerability metrics for the Southeastern United States.

Placeholder – the server is down this weekend but will be back online soon.

Figure 4. Screen shot from the ReVA Environmental Decision Toolkit showing counties in the Southeast with the best and worst conditions and those that are most vulnerable to future changes.

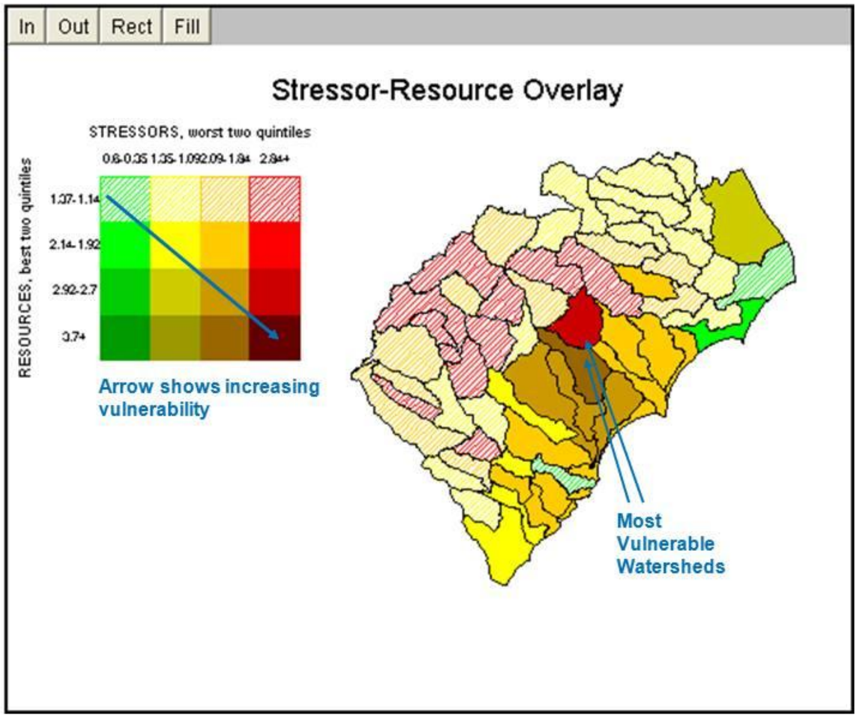

Figure 5. Illustration of the stressor – resource overlay that identifies where the greatest urgency is to protect resources that are vulnerable. Watersheds that have few resources or low amounts of stressors are not considered as vulnerable as areas that have both high numbers of resources and high numbers of stressors present.

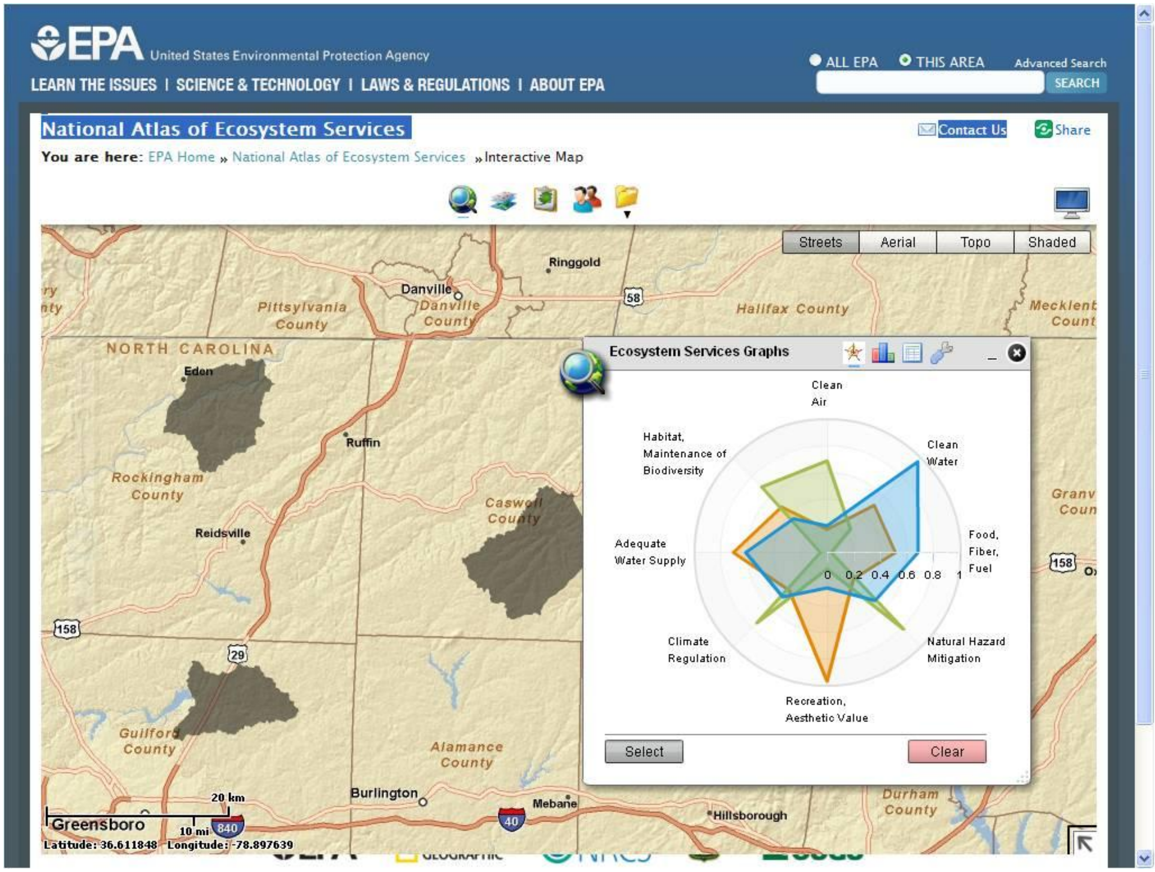

Figure 6. Screenshot from the National Atlas of Ecosystem Services depicting the relative supply of ecosystem services (inset graphic) for 3 watersheds (in gray).