FORMULATING KEY INDICATORS FOR SUSTAINABLE WATER RESOURCES DEVELOPMENT
PART II: SCALE ISSUE AND GEOGRAPHIC PATTERNS

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ABSTRACT

Agenda 21 of the 1992 UN Earth Summit on Environment and Development called for the development of new ways to measure and assess progress toward sustainable development. The nation needs a framework for tracking and understanding changes to the health of its fresh and coastal waters, surface and groundwater, wetlands and watersheds. It also needs a methodology for understanding the implications of these long term changes for ecosystems, communities and businesses.

When considering key questions about water sustainability, some important technical problems such as scale and geographic patterns immediately arise. Certain kinds of measures and indicators may be good for tracking national level phenomena, but questions may arise about how this kind of data relates to smaller geographic areas within the nation. The first paper in this publication series entitled "*Formulating Key Water Quality Indicators for Sustainable Water Resources Development*" (Smith and Zhang, 2004 and 2004a) emphasizes the application of water sustainability framework to the water quality field. The objective of this second paper is to address the importance of scale issue and geographic patterns and how they may influence the formulation of key water sustainability indicators. By presenting statistics from which indicators are developed to be shown in graphical form, the paper highlights several available studies that have proved to be promising in generating concrete results for developing water sustainability indicators at various scale and geographic patterns.

It certainly appears that geographic scale has an influence on what kind of water indicators is used. Indicators that ensure sustainability at a national scale may or may not be effective at regional or local scales. The implications for further work in developing indicators would then be to continue to seek commonalities across geographic lines that can help to define the national level water indicators, and also to continue to examine in detail the various regional characteristics that may lead to developing water indicators unique to each region. Overall, the sustainable solutions to water resources problems can be found if people thoroughly understand the issues and how each aspect of the society contributes to them.

KEYWORDS
Sustainable development, water sustainability, indicator, water resources, water quality, sustainable water resources management, Sustainable Water Resources Roundtable

INTRODUCTION

Agenda 21 of the 1992 UN Earth Summit on Environment and Development called for the development of new ways to measure and assess progress toward sustainable development. The nation needs a framework for tracking and understanding changes to the health of its fresh and coastal waters, surface and groundwater, wetlands and watersheds. It also needs a methodology for understanding the implications of these long term changes for ecosystems, communities and businesses.

Perhaps the key questions to ask at the outset are how can we define the most important **water issues**, and how can we determine indicators suitable for tracking these issues over time? If it is possible to observe the behavior of the entire system, then we may have a better chance of deciding whether or not the system is acting in a stable or an unstable manner. This certainly seems to be an important clue about sustainability. The Sustainable Water Resources Roundtable (SWRR, http://water.usgs.gov/wicp/acwi/swrr/) has been engaging this problem, and much of this paper reflects the results of these efforts.

Water issues come in many forms, but the great majority fall into just a small number of issue areas, which are the subject of most day-to-day work. **Water quality** issues include a large number of physical, chemical, and biological concerns that are familiar to anyone attempting to improve the condition of surface or ground water. **Water availability** issues are even more basic, since they can include everything beginning with water budgets for very large regions, and move progressively to include surface and ground water supplies at the local level. The extreme hydrologic events represented by floods and droughts also fall into this category, although they are usually treated as natural hazards. **Water use** issues are closely related, and illuminate not only the competition between such familiar uses as agriculture and public water supply, but also how all such uses compare with in-stream uses required by fish and wildlife.

Water sustainability solutions are characterized by certain systems analysis properties that may indicate the overall stability of the system. It is important for sustainability that solutions to problems should be viable for long durations; that the system should not be required to undergo extreme change in short periods of time to reach the desired solution; that the solution sought is often a compromise of available options, and not some extreme case; and, is not overly complex. Even with these precautions, the most successful solutions often possess the additional property of reversibility; only actual experience can tell us if we are on the right track, and if not we must be able to make changes. Whether the geographic scale is a local water problem or a national system, these rules tend to produce sustainable solutions.

METHODOLOGY

This paper presents the continuous inter-agency collaboration efforts by Sustainable Water Resources Roundtable (SWRR), which has begun to examine the problem of developing indicators for sustainability of water resources. The purpose of the Roundtable is to provide an open forum for exchanging ideas and information to foster collaboration on ways to manage water resources in such a way that the resource and its uses may be sustained over the long term.

Roundtable discussions and activities focus in part on criteria, indicators, and methods for assessing the sustainability of water resources, as well as exploring, promoting, and improving how this information is used to promote sustainable water resource management.

The paper starts by raising a key question in developing water sustainability indicators "*how can sub-national indicators be developed, and how might they relate to the national picture*". Generally speaking, we know a great deal about the condition of the nation's waters at the regional, state, tribal, and local levels, but we may not have enough information to provide a comprehensive picture at national level. However, some of available studies have proved to be promising in generating concrete results for developing water sustainability indicators at various scale and geographic patterns.

Statistics from which indicators might be developed can be shown in graphical form in many ways. By presenting statistics from which indicators are developed to be shown in graphical form, the paper highlights several available studies that have proved to be promising in generating concrete results for developing water sustainability indicators at various scale and geographic patterns.

RESULTS AND DISCUSSION

Developing Sustainability Indicators

If we now wish to track water issues over time, to ascertain whether they are becoming better or worse, other problems arise. How can a set of indicators be developed that is large enough to be comprehensive, but small enough to be readily understandable and practical? Clearly, data gaps exist in order to answer these questions comprehensively, if the available statistics are compared to conceptual models of what is really needed to understand water resources as it relates to human and ecosystem requirements. However, it is now possible to begin to address the key problem of how to create measures of tracking by using analytical and statistical tools on the voluminous data about water resources.

Given these thoughts, and perhaps daunted by the possibility of unreasonably long lists of water indicators, we might then think about how to prioritize the indicators. Possibly we do not have to consider them all simultaneously. This of course implies that we are somehow prioritizing the issues associated with the indicators, both by topic and geographically. Thus far our system of government has not developed any single way to deal with this problem. Indeed, public policy issues sometimes seem to have life cycles of their own, sometimes springing from a seminal book, like *Silent Spring*, and sometimes brought forward by some charismatic political leader. We can think of issues that have seemed to occur, pass through a maximum, and then decline or die out, to be replaced by some other issue. Unlike organisms, however, issues can indeed rise again, and sometimes do so in some poorly understood evolutionary way. Perhaps the indicators associated with the public policy issues are therefore arranged by implication in a similar hierarchy. If this is the case, we might think that indicators of point source water pollution have a lesser priority than those for non-point source pollution, and that traditional indicators of water quality like dissolved oxygen have a lesser priority than indicators about endocrine disruptors or pharmaceuticals. We should emphasize that these conclusions are not stated as undisputed facts, but are rather to illustrate the complexity of the problem.

Assuming that issues and their associated indicators do indeed come and go in some Darwinian fashion, the current practice in which agencies and others develop indicators from almost any set of statistics may actually embody a useful process. By throwing out this large collection of so-called indicators, the sorting process of history would determine which is used at any given time. This would depend on the current popularity of a given issue, which might well vary enormously in the way described above. If this process is true, it probably makes our job actually harder; if we do not know which issues, indicators, and thus statistics will be needed with any certainty, it will be very difficult to maintain adequate data collection programs (which are very costly). This would certainly be the case once some issue drops out of fashion, and would make life interesting for those who might worry that it might again become important at some later time.

Number: In starting to consider this set of questions, some technical problems arise upon even cursory consideration. When we envision the ubiquitous nature of water, for example in simply delineating the hydrologic cycle, it is very easy to make a long list of possible indicators, all of which seem necessary. A key problem therefore is determining how many indicators are needed. Too many will lead to inability to comprehend the sustainability problem, and to make tradeoffs that may be necessary between various parts of the system in order to improve its functioning. Some thinking along these lines shortly leads to the other problem, that is if too few indicators are selected it will be impossible to achieve a comprehensive picture of water resources. Finding a balance between such competing needs is one technical problem to be solved.

Scale: Those who have thought about sustainability have noted that there is also a problem associated with geographic scale. Sustainability at the national scale does not assure that it will also exist at other scales. This problem reminds us of classic systems analysis cases, in which the sum of a set of optimal results may only accidentally yield an optimal result for the whole. In more concrete terms, this kind of problem has been described as the tragedy of the commons, and quite a bit has been written about the problems of water resources between upstream and downstream users. It appears that some water indicators may be nested geographically, somewhat the way employment may be used as an economic indicator at many scales. But other indicators may not have this property. If it is true that water indicators are somehow connected to public policy issues, then we may have local issues with associated indicators that are relevant at the community level in many parts of the nation; even this may depend on regional variations in physical conditions, as between the humid East and the arid West. When the national scale is considered, the water resources issues that seem important may be quite different, and thus require different indicators to measure change for national decision makers.

Duration: When the idea of sustainability is considered, it clearly implies the notion of time. How long should a time span be for a system to be considered sustainable? We note that whole civilizations come and go over time spans of hundreds or thousands of years. Those time spans seem to be connected to the longevity of institutions, like governments, that can maintain some degree of management over their water resources sufficient to be self-sustaining. On this time scale, water resources seems to be a topic embedded within even larger considerations that have to do with how nations maintain their existence. We should recognize this fact, although these larger concerns are beyond the scope of this paper. However, time remains an important factor to be considered.

Rate of Change: When looking at a system, we should ask how quickly can it change. Systems are very sensitive to rate of change, especially the rate of change of inputs. Too great a change in too short a time mostly leads to undesirable system behavior, i.e., it becomes unstable. Examples show that a sudden spike or step function will lead to unexpected results. This holds true for changes in both directions. A sudden upswing or drop in prices can be undesirable in either case. We may call the results inflation, or depression, but they are just names for a whole set of unwanted effects. Just as we work hard to avoid such effects, this means that sustainability implies gradual and progressive change that allows the system time to adjust.

Conceptual Framework by Integration and Synthesis Group

But our work in the field of water resources does not exist apart from the larger society. In the first paper of this series entitled "*Developing Key Water Quality Indicators for Sustainable Water Resources Management*" (Smith and Zhang, 2004a), we referred to water indicators being used by seven other studies, including those by EPA, the USGS, and the Heinz Center. Among these are three other Roundtables; they concern forestry, rangeland, and minerals respectively.

As work has proceeded it has become ever more apparent that all these efforts need a way to link together their work into a more seamless whole that better describes the function of their respective interests within society as a whole. To move in this direction the Integration and Synthesis Group (ISG) was formed, with at least some representation from most of the studies noted here. The ISG was formed by the Roundtable Network, composed of the Co-chairs and other leaders of the Roundtable on Sustainable Forests (RSF), the Sustainable Minerals Roundtable (SMR), the Sustainable Rangelands Roundtable (SRR) and the Sustainable Water Resources Roundtable (SWRR) as well as leaders of other indicator projects such as the *EPA Report on the Environment* and the Heinz Center Report on *the State of the Nation's Ecosystems*. For more information, see http://roundtablenetwork.cnr.colostate.edu.

The Integration and Synthesis Group therefore has the purpose of developing a conceptual framework based on systems models, within which to place indicators of sustainability. It is fair to say that the models developed to date are still in a state of flux. Especially when one considers that they begin from such different points as water and minerals, although we know there are interrelationships, it is far from simple to specify what these may be, let alone to reduce them to some agreed upon set of indicators. Therefore, the flowchart presented in Figure 1 for water resources is best regarded as a work in progress, and certainly not as a final diagram that relates water resources to the larger society.

One can note even on casual inspection that some of the properties in this figure are familiar to water resource experts, but certainly not all. While it seems conceptually clear that some of these characteristics must be related as they are shown, it is far from evident how one would go about measuring them, or how to develop anything resembling a statistic that could be used in a professional manner. It seems we are pushing the edge of the envelope. Thus, only some of the important system properties can be represented as indicators.

Selecting Key Issues and Indicators

It will come as no surprise that the result of efforts to date has been an enormous list of potential indicators. If one refers to the paper from Smith and Zhang (2004a), the work described there covers very comprehensive sets of possible statistical information, which could be turned into indicators if appropriate time series of data exists. When one attempts to place water resources in its proper place within society as a whole, as the ISG model tries to do, the situation becomes even more intractable. Some of the properties in the ISG model seem to be more qualitative than quantitative. At this point we have a conceptual framework that is intellectually rich, but poorly adapted for use in public policy making.

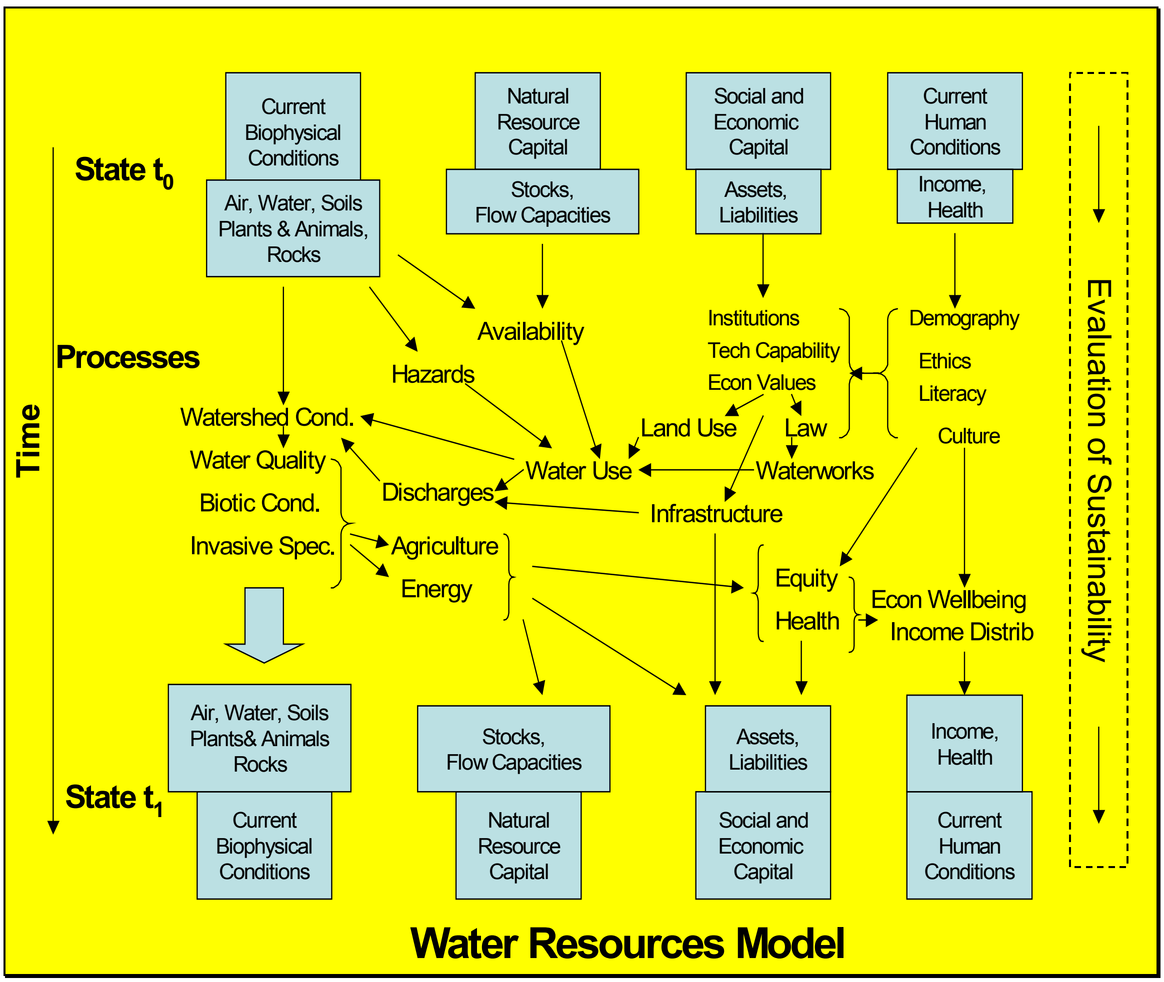

Figure 1: Integration and Synthesis Diagram for Water Resources

A major problem facing SWRR is how to select a number of indicators that is sufficiently large to be reasonably comprehensive, but small enough so as not to be overwhelming. It appears that policy makers may need just enough summary information to grasp the big picture, but additional detail would depend on their particular interests.

A second problem is how to obtain the necessary staff work to develop the presentations for any such indicators that may be selected. One way is to choose at least some indicators from those that are currently supported by some major organization, usually a Federal agency that collects the data. There may be additional indicators that are highly desirable for which no organization now collects data, or for which insufficient data now exists. Such indicators could also be reported as needing further attention in the future.

With these thoughts in mind a small number of indicators have been shown in the following list, along with the rationale for their selection and the organization that supports the specific indicator (Table 1). Each indicator is linked to a public policy issue area, e.g., *water quality*, as noted at the beginning of this paper. In all cases it may well be possible to find updated time series for these statistics in the literature; some graphs of existing data are shown in Smith and Zhang (2004a) on this subject.

Table 1: List of Sample Indicators Category and Their Significance for Water Sustainability

Sample Indicators	Significance	Selected Data Period
Water Quality Indicators		
Oil Spills in U.S. Water - Number and Volume (Coast Guard)	This highly visible indicator commonly shows major problems.	1997 to 2000
National Ambient Water Quality in Rivers and Streams --- Violation Rate (EPA)	Several common water quality parameters are compared to their accepted criteria, thus showing trends: fecal coliform bacteria, dissolved oxygen, total phosphorus, lead, cadmium.	1980 to 1995
Contaminated Sediments (EPA)	Substances that contaminate sediments can remain for many years and continue to impact the ambient water and ecosystem. Remediation is difficult and expensive.	1980 to 1993
Water Quantity Indicators		
Severe to Extreme Drought and Wetness in the Conterminous United States (NOAA)	The trends of percent impacted over many years are shown, which may imply future conditions.	1900 to 1997
Water Supply (USGS)	The water budget for the nation includes precipitation, surface-and ground water budgets, all leading to amounts available for withdrawal and consumptive use by society.	1950 to 2000 (every 5 years)
Water Use Indicators		

U.S. Water Withdrawals and Consumptive Use Per Day by End Use (USGS)	This set of indicators shows what components of society consumes water according to amount. Long term trends can be examined.	1950 to 2000 (every 5 years)
Landscape Indicators		
U.S. Wetland Resources and Deepwater Habitats by Type (USDA-FWS)	The acreages and trends are shown for types throughout the nation, making it possible to see what problems may be occurring.	1986 and 1997
Index of Agricultural Runoff Potential (USDA-NRCS)	Receiving water may be impacted by runoff due to pesticide, nitrogen, and sediment constituents. This important effect illustrates a link between agriculture and water quality via land use.	1990 to 1995

Developing Sub-National Indicator System

Once having addressed the basic problem at the national level, i.e., avoiding the inundation of the policy making process with a flood of indicator data, it may be possible to focus on just a few of the key issues and indicators as noted above. But this is only at the national level. While such a move may be suitable for Federal action of a certain kind, there are many more actions, plus those at the state and local level, that require more finely tuned geographic data.

How is such information to be provided, without compiling a large and unwieldy information base ahead of time? It has become reasonably clear that one has little success in anticipating the needs of policy makers, and for this reason it is not very likely that one can expect to know what indicators one might need at some sub-national scale. In perhaps a majority of cases the long lists of indicators are attempts to outguess the dynamic give-and-take of the public policy making process, which no one can really anticipate. It seems the best course of action is to have in place a mechanism that is designed to provide the best available quantitative and qualitative information for geographical areas that are identified on an *ad hoc* basis.

At the present time one of the best candidate systems that can be used in this fashion is the Watershed Information Network (WIN), a cooperative endeavor that involves EPA, the USGS, and support from the USDA. There are multiple points of Internet entry for this system, but two good ones are:

http://www.epa.gov/win/

http://water.usgs.gov/wsc/

Figure 2 shows an example of State water quality data; in this case we retrieved 2002 Maryland water quality data as reported by EPA 305(b) records.

It is important to realize that by far the best use of the WIN system can be made once one has full knowledge of the watershed location of interest. This means finding the hydrologic unit, which can go up to eight digits for a reasonably small area. Most information is coded in the system according to this two-to-eight-digit format. Figure 3 shows the location map for Chesapeake Bay using this approach, since later in this paper we will be looking at this geographic region more closely.

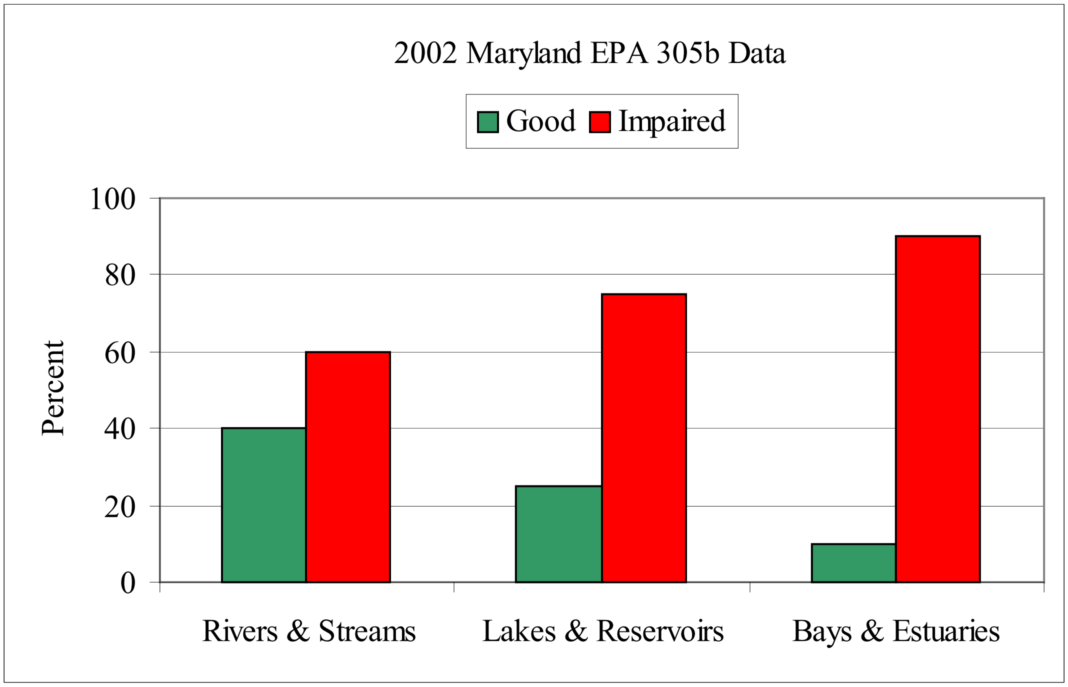

Figure 2: 2002 Water Quality Data for Maryland from EPA 305(b) Monitoring and Assessment Report

Using the eight-digit code with WIN one can access a great deal of quantitative and qualitative information for the watershed of interest. Furthermore, the information is dynamic, and continually updated by agency staff. When one is faced with an inquiry on an *ad hoc* basis about some geographic area that may be unfamiliar, WIN offers a quick way to access data that can help to form indicators for that area, as well as background qualitative information that may be otherwise difficult to locate. The bar along the left-hand side of Figure 3 is a rapid guide to some of the information that is coded in this way.

Now having this background in considerations at the national and sub-national level, it is time to put together a consistent picture that begins at the top level and proceeds to small areas. For this we have chosen the example of Chesapeake Bay, and in the following sections we will demonstrate the cascading effect of developing indicators that follow national and sub-national political boundaries, sub-national watershed boundaries, and finally focus on Chesapeake Bay as a specific example.

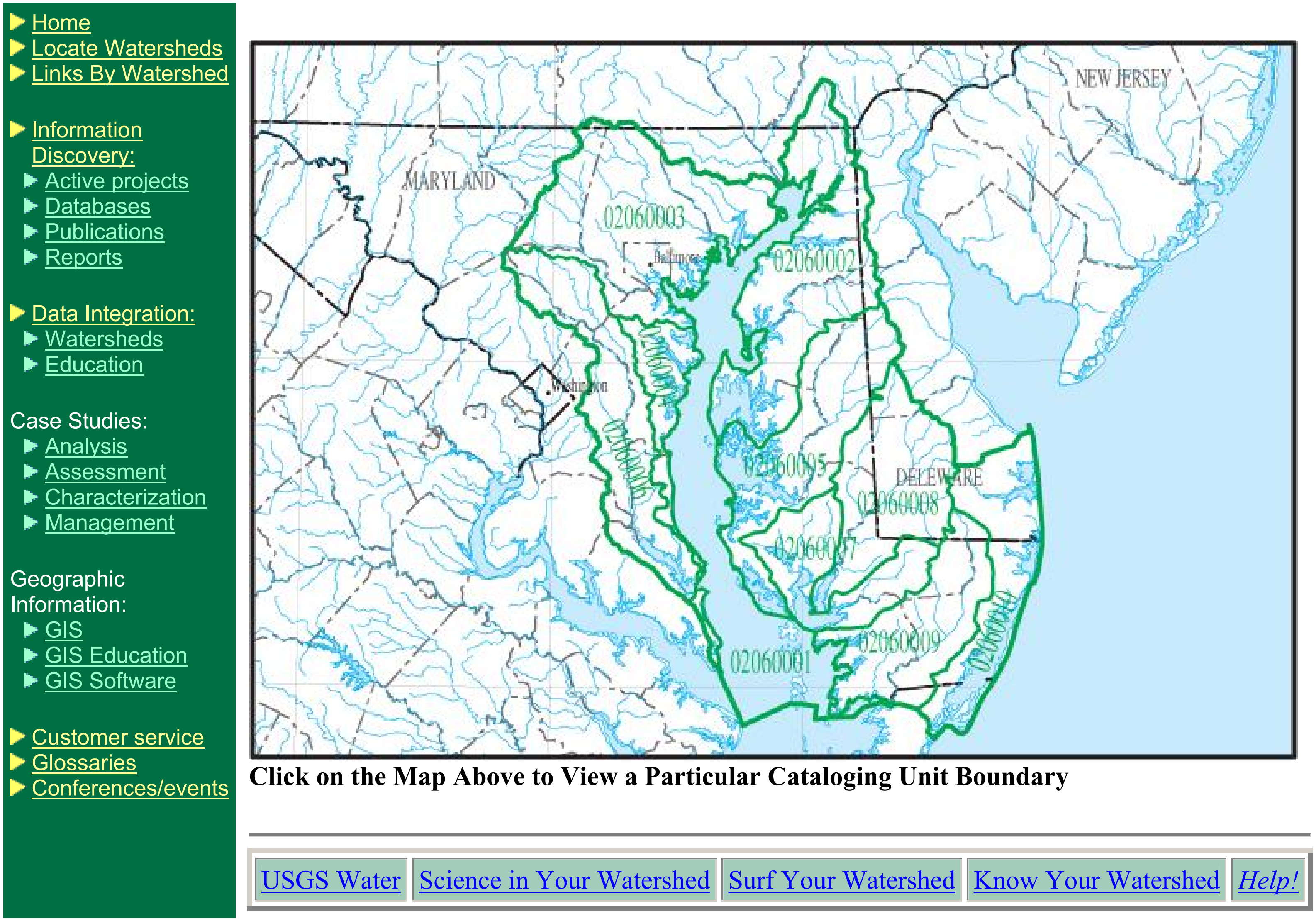

Figure 3: Water Information Network Locator Map Showing Hydrologic Units for Chesapeake Bay.

Geographic Patterns and Developing Water Indicators

Statistics from which indicators might be developed can be shown in graphical form in many ways. For example, national water use statistics are familiar in the form shown in Figure 4. While this kind of measure may be good for tracking national level phenomena, questions may arise about how this kind of data relates to smaller geographic areas within the nation. The question to ask would be "*How can sub-national indicators be developed, and how might they relate to the national picture*".

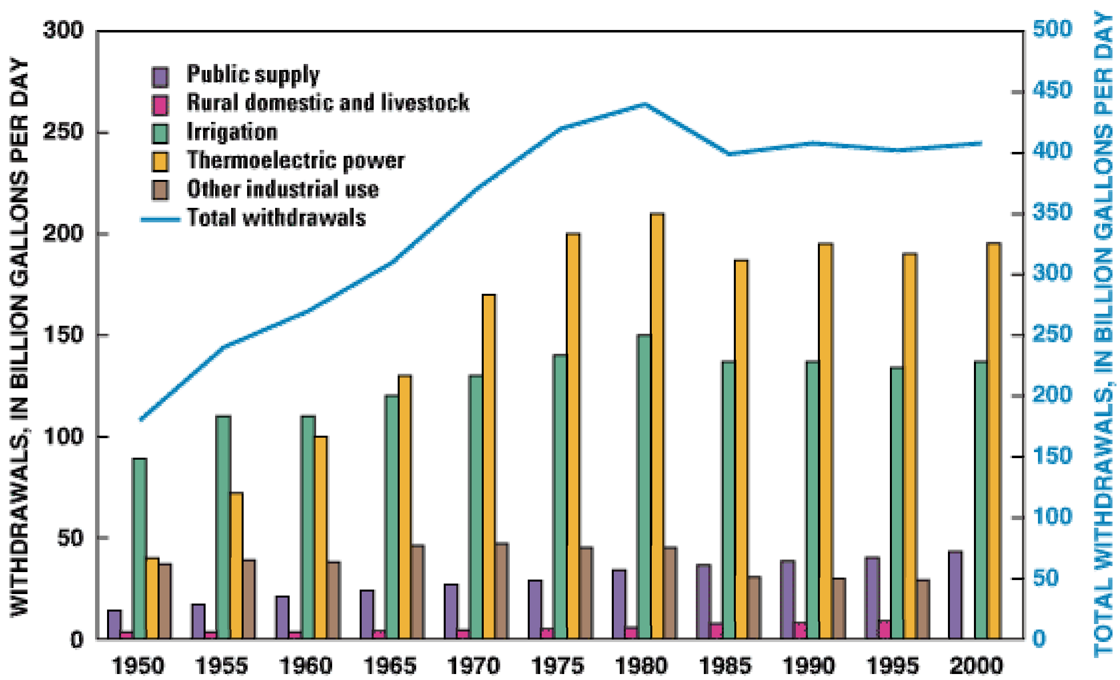

Figure 4: Trends in Total U.S. Water Withdrawals by Water-use Category, 1950-2000 (Source: http://water.usgs.gov/watuse/)

One way that has a lot of merit is shown in Figure 5. This is a choropleth map of the nation, showing the same statistics, but broken down by State. Such a display makes it possible to show the statistics by political jurisdiction, which can be useful if policy is to be developed at that level, in this case the State level. This kind of variable is additive, i.e., the data sum to the national level. Also, the issues that make the indicator important are very similar at the State and national levels. Relevant policy issues might include, for example, the amount of water being used for competing purposes, the relationship of this amount to the quantity available from the ambient environment, and trends in these statistics. Government at the Federal and State levels might reasonably be expected to take action on these issues.

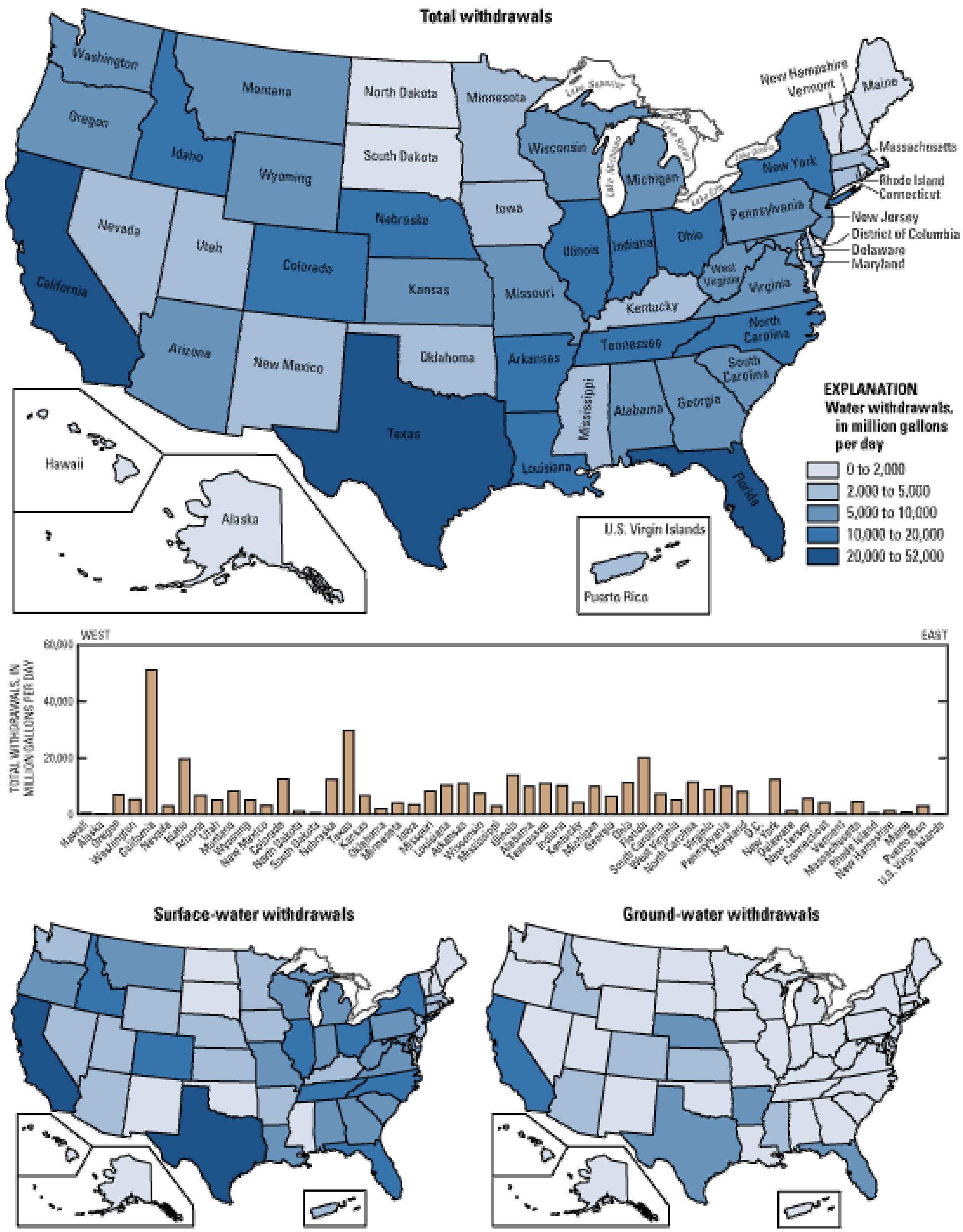

Figure 5: Total, Surface-water, and Groundwater Withdrawals for the United States, 2000 (Source: http://water.usgs.gov/watuse/)

However, there are other geographic breakdowns that do not follow political boundaries, but which may be very useful in developing water indicators. The EPA Index of Watershed Indicators is shown on the map in Figure 6.

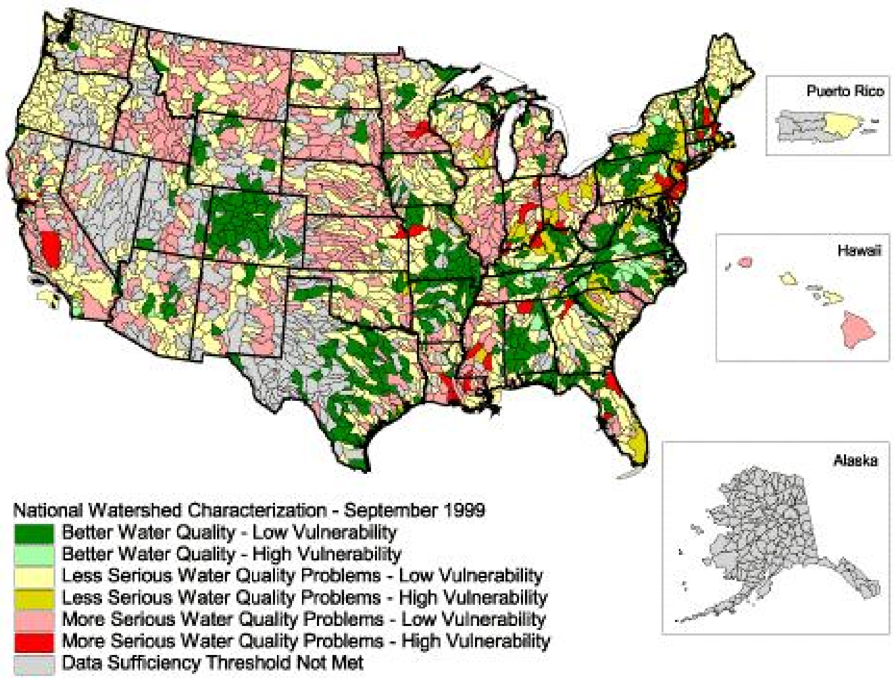

Figure 6: EPA National Map of Index of Watershed Indicators (Source: http://www.epa.gov/wateratlas/geo/maplist.html)

The Index of Watershed Indicators characterizes the condition and vulnerability of aquatic systems in each of the watersheds in the United States. The watersheds as shown in Figure 6 are based on USGS hydrologic units. This involves an assessment of condition, vulnerability, and data sufficiency.

By using this geographic breakdown, it is possible to follow the boundaries of natural systems, but this means that a wholly different relationship must exist with the geography of political jurisdictions, i.e., the means by which policy is developed. At the **Federal level**, policy can be developed for the entire nation, and thus water indicators for watersheds are useful at this level. However, at the **State level** there is a complex combination of watersheds that may be within the jurisdiction of a State, and those that may be interstate in nature. Making policy on an interstate basis has always been a much more difficult undertaking. **Local level** governments, like counties and cities, tend to have better defined geographic relationships with their associated watersheds; their issues of interest, however, may not be the same as those at the State or Federal levels. An important new kind of institution can occur at the watershed level: this is the watershed association, which is typically non-governmental or quasi-governmental. Because of the varying nature of issues that can occur at these different geographic scales, the water indicators of interest can also exhibit complex relationships. For example, the quantity of water flowing past a city may be of great concern for local water supply, but the same river may appear as a minor element in State or Federal water issues.

The approach to develop Figure 6 is as follows. First, indicators of the condition of the watershed are scored and assigned to one of three categories: better water quality, water quality with less serious problems, and water quality with more serious problems. Second, indicators of vulnerability are scored to create two characterizations of vulnerability: high and low. These two sets of indicators are then combined to create the pattern shown in Figure 6.

The Index of Watershed Indicators shows that about 15% of the watersheds in the country have better water quality and of these, about one in 10 has high vulnerability; 36% have some water quality problems and of these, about one in 14 have high vulnerability; 23% have more serious water quality problems with about one in 16 of these exhibiting high vulnerability; and, 26% of the watersheds do not have enough information on the component indicators to make an overall assessment.

The information provided by the Index of Watershed Indicators can help focus the attention of water quality managers and decision makers on areas with problems in need of restoration, on areas with good water quality in need of protection, and on areas where additional data is needed. But to make the connection between policy relevance and statistics, it is necessary to show what kind of monitoring data is used to construct the map. The data layers used by EPA for this purpose are shown in Table 2. State water quality assessments (305(b) designated use data) were given special consideration. First, when State 305(b) data were present, this data layer was weighted six times more heavily than other data layers. Where they were absent, the data from other condition indicators were weighted more heavily to compensate for this missing information.

Table 2: Data Layers for the Index of Watershed Indicators Map

Source of Data Layers	Period of Records
Percent of Assessed Rivers, Lakes, and Estuaries Meeting All Designated Uses	1994, 1996, & 1998; latest state information reported
Fish and Wildlife Consumption Advisories	1998; new data and maps
Indicators of Source Water Condition for Drinking Water Systems	1990 – 1999; new data and maps
Contaminated Sediments	1980 – 1993
Ambient Water Quality Data - Four Toxic Pollutants	1990 – 1998
Ambient Water Quality Data - Four Conventional Pollutants	1990 – 1998
Wetland Loss Index	1780s – 1990s
Aquatic / Wetland Species at Risk	1996
Toxic Loads Over Permitted Limits	1999; new data and maps
Conventional Loads Over Permitted Limits	1999; new data and maps
Urban Runoff Potential	1990
Index of Agricultural Runoff Potential	1990 – 1995
Population Change	1980 – 1990
Hydrologic Modification Caused by Dams	1995 – 1996
Estuarine Pollution Susceptibility Index	1989 – 1991
Atmospheric Deposition Estimates for Total Nitrogen	1996

Maps like Figure 6 have been developed by EPA for the various data layers, and can be viewed and used independently. Figure 6 shows how many such indicators can be combined into a synthesis that is relevant for creating water resources policy, which might take the form of laws or regulations. Therefore, this is an example of how water indicators can contribute to policy development at local, State, and Federal levels of government. As noted, the way in which this happens is mediated by the particular issues that are important at each geographic scale. Some are relevant over the whole geographic range, and others are specific (or at least most important) at some particular geographic scale. This is exactly the reason why some data collection programs are more important at one geographic scale or another, or for certain geographic regions, and why it is quite hard to make unchallenged statements about one single set of water indicators that is universally useful at all scales and for all regions.

Case Study: Chesapeake Bay

The Chesapeake Bay Program is an important effort that combines characteristics of local geographic scale in a unique water resources region of the nation. See http://www.chesapeakebay.net/ for more information about this program, from which the information has been taken for this paper (Figure 7).

The 64,000 square mile Chesapeake Bay watershed extends from New York to Virginia, and from West Virginia to Delaware. Many of the issues throughout this watershed are somehow related to water quality, and for that reason the indicators chosen as important tend to reflect this concern. For example, the Chesapeake Bay Program conducts analyses from provisional data collected by Maryland's Department of Natural Resources (DNR) and Old Dominion University (ODU) for surface temperature, bottom dissolved oxygen, water clarity and surface salinity. The program also tracks average monthly river flow data provided by the United States Geological Survey (USGS).

In order to discuss the relationships among water indicators for this region, it is necessary to simplify the complex patterns that exist in the area. For example, for the purposes of this paper the concentration is on those indicators that have a very direct bearing on water, and thus related topics like land use are omitted. Similarly, there is a significant difference between the tidal and non-tidal portions of the bay, but again there will be no real attempt to illuminate the details.

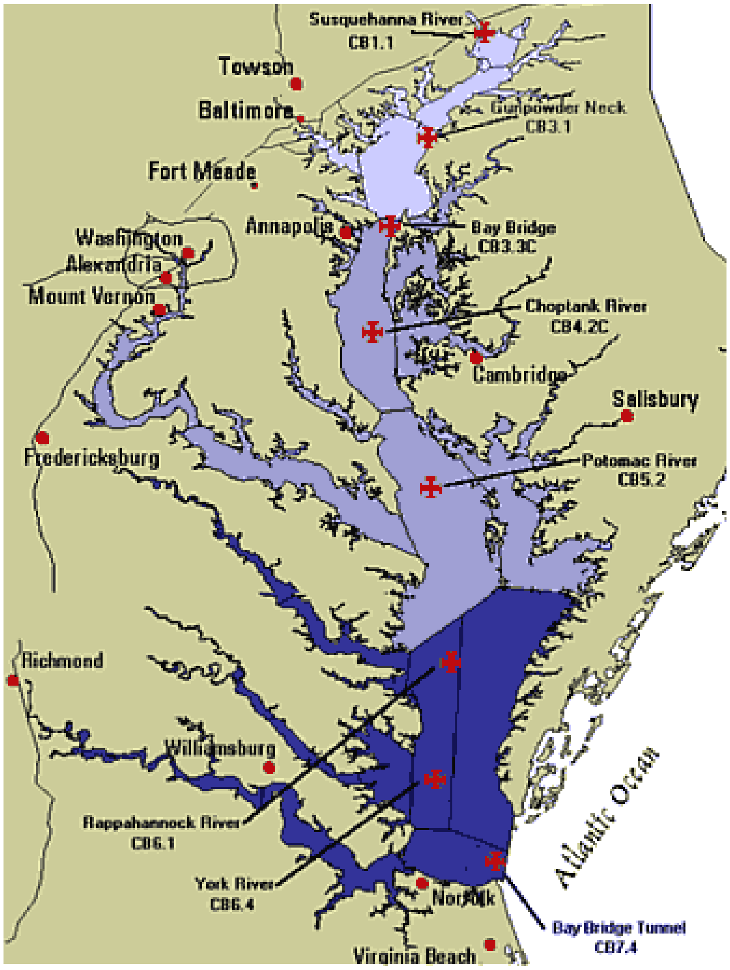

Figure 7: Chesapeake Bay with Main Tidal Rivers (Water Quality is Collected at Representative Stations Shown)

Bearing these facts in mind, Table 3 is an attempt to summarize at least the most important of the water indicators that have been developed for the bay. They are organized along the lines of the major categories used in the program: **Animals & Plants, Habitat, Water Quality, and Pollutants**. As noted above, there are additional categories not described here.

Table 3: Selected Generalized Water Indicators Used in the Chesapeake Bay Program, by Category

Animals & Plants	Pollutants
Bay Grasses Birds Crabs & Shellfish Fish Benthos	Air Pollution Nutrient & Sediment Loads Wastewater Flows Population
Habitats	**Water Quality**
Stream Miles for Migratory Fish Wetlands Protection Oyster Bed Restoration	River Flow Chlorophyll *a* Secchi Depth Dissolved Oxygen Nitrogen Phosphorus Sediment Suspended Solids Submerged Aquatic Vegetation Area Temperature Salinity Chemical Contaminants

Table 3 shows only a list of indicators. It often helps to examine some actual statistics that have been used to develop indicators, if only to obtain a deeper understanding of how numerical measures can contribute to understanding real-world conditions. With this in mind, four of the indicators from Table 3 have been selected for detailed description, which follows (Figure 8, 9, 10 and 11):

(1) Trends in Blue Crab Commercial Harvest

The Chesapeake Bay is the largest producer of crabs in the country; it's estimated that more than a third of the nation's catch of blue crabs comes from Bay waters. Commercial harvests in a good year can yield close to 100 million pounds of crab annually. There is concern about the blue crab fishery due to increased harvest pressure. The 2003 harvest of approximately 48 million pounds is below the long term average and near historic lows. The 2003 fishing mortality rate did not exceed the overfishing threshold but is above the desired target.

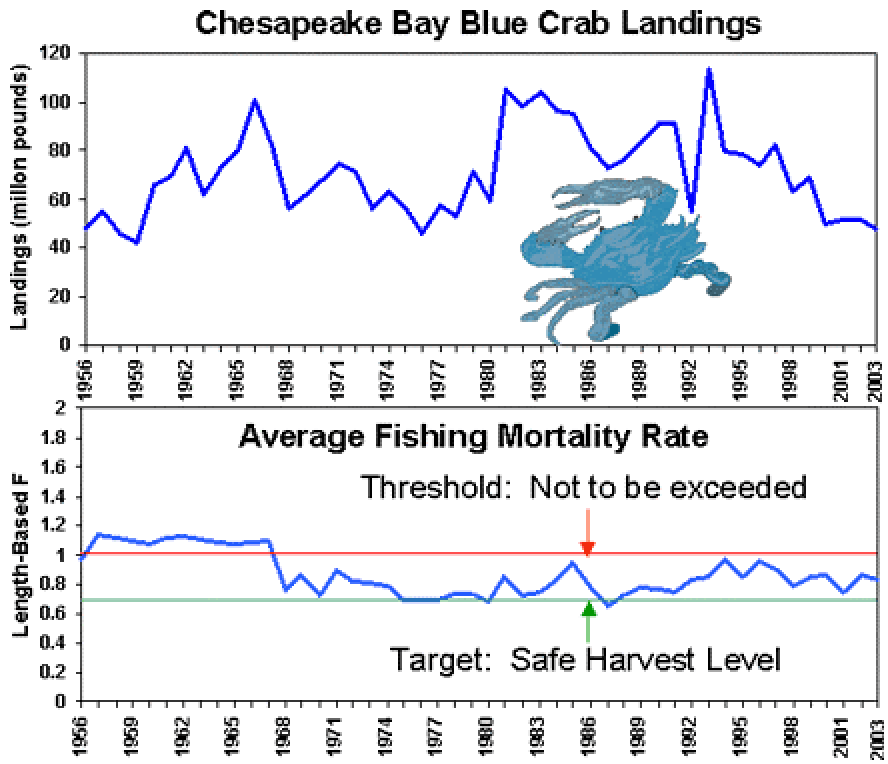

Figure 8: Blue Crab Harvest Statistics in Chesapeake Bay

(2) Trends in Finfish: Striped Bass

Striped bass have formed the basis of one of the most important commercial and recreational fisheries on the Atlantic coast. A major factor in the striped bass decline was overharvesting, which disrupted the balance of the spawning stock. Other factors included contaminants in spawning grounds and loss of habitat. Moratoriums in Maryland and Virginia followed by conservative harvest limits allowed the stock to rebound. The stock was declared restored in January 1995 by the Atlantic States Marine Fisheries Commission. The striped bass success story is due to interagency cooperation and management at the federal and state levels.

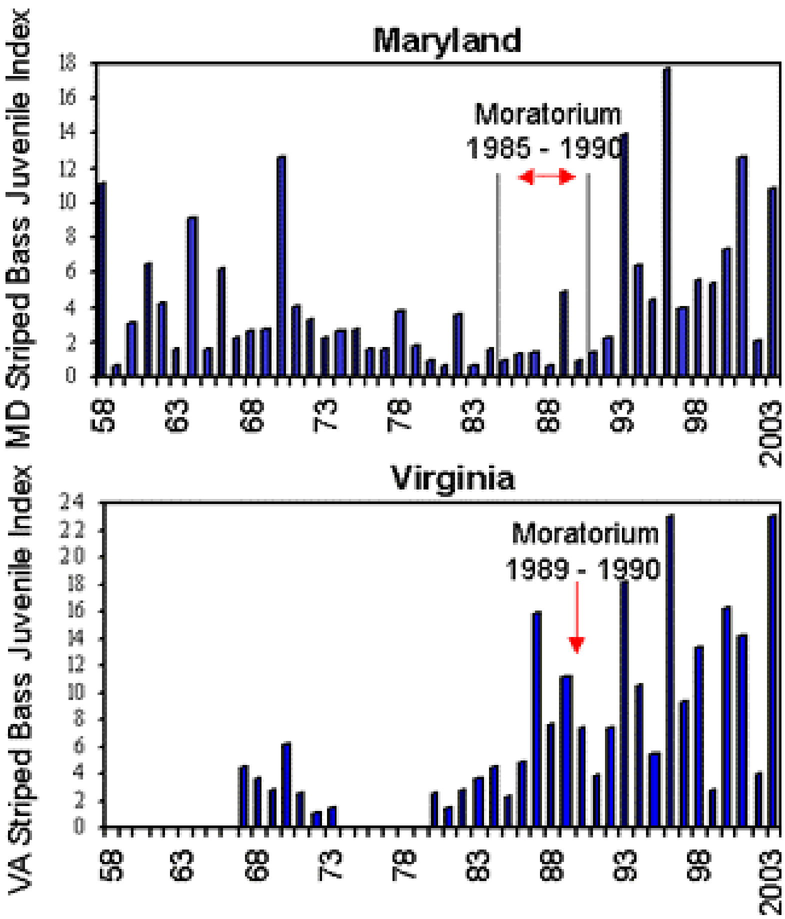

Figure 9: Striped Bass Statistics for Maryland and Virginia

(3) Wetlands Protection, Restoration, and Enhancement

Wetlands are vital habitats for many plants and animals. Wetlands directly benefit people by improving water quality, reducing flood and storm damages, minimizing erosion and supporting tourism and the hunting and fishing industries. Since 1998, 14,317 acres were restored. In order to achieve program goals, 10,683 additional acres need to be restored by 2010. During this time, an additional 1,312 acres were gained in the regulatory programs.

One of the most important functions of wetlands is that they help restore and maintain water quality in our nation's rivers and streams. Wetlands are capable of minimizing sediment loads and absorbing pollutants such as nitrogen and phosphorus. They also help to recharge aquifers.

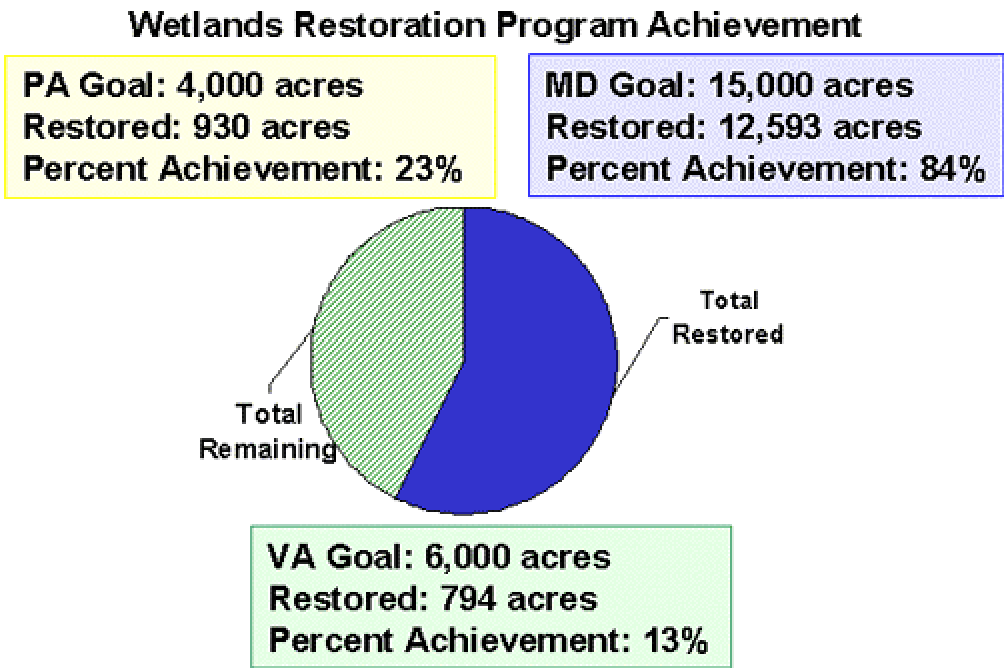

Figure 10: Wetlands Restoration Statistics for Pennsylvania, Maryland, & Virginia.

(4) Mainstem Bay Summer Dissolved Oxygen Concentrations

During the summer, dissolved oxygen (DO) levels become dangerously low in about half of the Bay's deeper water. The lower layer of water is critical habitat for fish, shellfish and other Bay life. If they cannot move out of these areas of low or no oxygen, they may become stressed or die. There are recent indications of an improving trend since 1985. In 2003, there was a relatively large volume and area of hypoxia (low oxygen), with a small volume of anoxia (no oxygen). There were no occurrences of anoxia in mainstem Bay waters in 2002. Hypoxic conditions are stressful for aquatic life and sometimes lethal if severely hypoxic. If no oxygen is present in bottom water, nutrients tied up in sediments are released to overlying waters, fueling eutrophication.

The amount of DO in water is affected by temperature, salinity, the timing and amount of freshwater river flow, the delivery of nutrients from the basin, the amount of mixing of Bay waters, and anything that affects the processes of oxygen production and consumption. The bar chart illustrates year to year variation in hypoxic volume in several concentration categories. The largest volumes of anoxic waters usually occur in the years of greatest river flow, and vice versa.

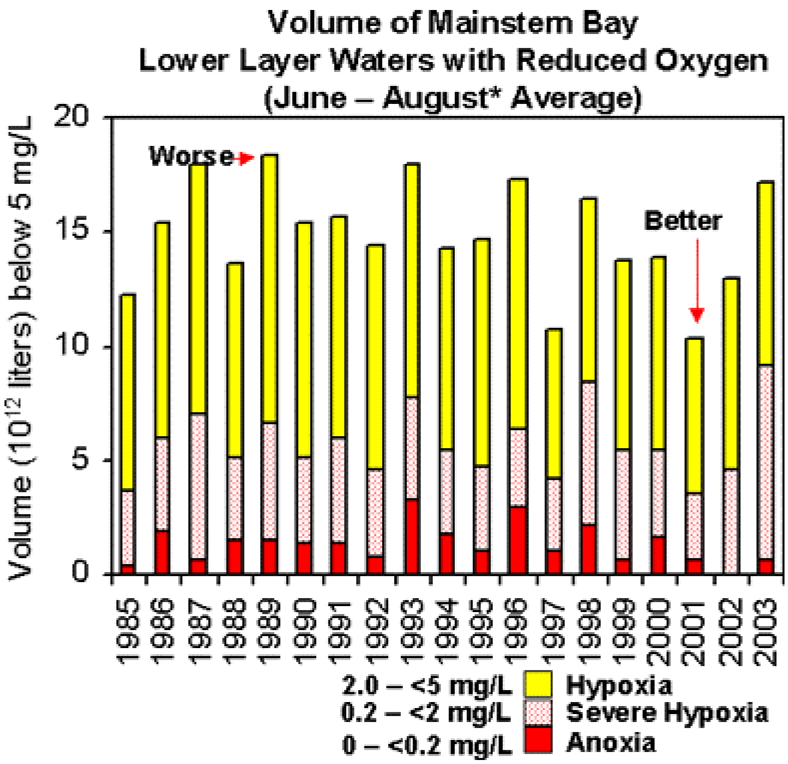

Figure 11: Dissolved Oxygen Statistics in Chesapeake Bay

CONCLUSIONS

It certainly appears that geographic scale has an influence on what kind of water indicators are used, based on these examples. It's hard to escape the idea that the nature of policy issues is the most important factor in selecting indicators. As noted, some issues are national in nature, while some are purely local or regional. Therefore, some indicators tend to recur at multiple scales, like water use, nitrogen, phosporus, flow, and dissolved oxygen. But many more indicators appear when one studies a local or regional situation like Chesapeake Bay. It may be that the latter are seen as more human-scale in nature, and those involved can perceive more numerous concerns, which eventually manifest themselves in policy issues for that particular region. This may be similar to the way environmental impact statements for some local project tend to produce long lists of issues that must be addressed.

If these conclusions are true, it may mean that there will eventually be a relatively limited set of national level water indicators that can be agreed upon as relevant for all regions and all geographic scales. The EPA Index of Watershed Indicators seems to be an attempt to move in this direction. But there may also exist a number of additional indicators, that are developed for specific regions like Chesapeake Bay, the Everglades, the Great Lakes, and unique regions like the arid Southwest. Such indicators might be expected to be particular for the region, and may not recur elsewhere. An example of this kind of indicator might be the Blue Crab statistics for the Chesapeake Bay.

The implications for further work in developing indicators would then be to continue to seek commonalities across geographic lines that can help to define the national level water indicators, and also to continue to examine in detail the various regional characteristics that may lead to developing water indicators unique to each region. It is likely that such work will take many years to complete, will help to rationalize current data collection programs, and will also provide the logical basis for expanding some data collection in areas not presently covered.

REFERENCES

Heintz, H. T. (2004). Applying the Concept of Sustainability to Water Resources, *Water Resources Update*, 127: 6-10

H. John Heinz III Center for Science, Economics and the Environment (2002). The State of the Nation's Ecosystems, http://www.heinzctr.org/ecosystems/index.htm

Hutson, S.S., Barber, N.L., Kenny, J.F., Linsey, K.S., Lumia, D.S., and Maupin, M.A., (2004). Estimated use of water in the United States in 2000: U.S. Geological Survey Circular 1268, 46 p. http://water.usgs.gov/watuse/

Kranz, R., Gasteyer, S. P., Heintz, H. T., Shafer, R. And Steinman (2004). Concetpual Foundations for the Sustainable Water Resources Roundtable, *Water Resources Update*, 127: 11-19

Moffatt, Ian, Nick Hanley, and Mike D. Wilson (2001). *Measuring and Modelling Sustainable Development,* Parthenon Publishing, New York

Smith, E. T. (2004). Water Resources Criteria and Indicators, *Water Resources Update*, 127: 59-67

Smith, E. T. and Zhang, H. X. (2004). How Do We Know It's Sustainable? Measuring Water Sustainability Effectively is Challenging, *Water Environment and Technology*, June 2004, 37-41, http://water.usgs.gov/wicp/acwi/swrr/Rpt_Pubs/index.html

Smith, E. T. and Zhang, H. X. (2004a). Formulating Key Water Quality Indicators for Sustainable Water Resources Development, *WEFTEC'04*, October 2-6, New Orleans, LA, http://water.usgs.gov/wicp/acwi/swrr/Rpt_Pubs/index.html

U.S. Census Bureau (2004). *Statistical Abstract of the United States,* Section 6, Geography & Environment, http://www.census.gov/prod/www/statistical-abstract-us.html

U.S. Department of Energy (DOE) (2003). *Environmental Quality Statistics*, Section 6: Aquatic Resources, http://ceq.eh.doe.gov/nepa/reports/statistics/aquatic.html

U.S. Department of Interior (DOI) (2003). *Water 2025: Preventing Crises and Conflict in the West,* http://www.doi.gov/water2025/

U.S. Geological Survey (USGS) (2002). Report to Congress - Concepts for National Assessment of Water Availability and Use, *USGS Circular 1223*, http://water.usgs.gov/pubs/circ/circ1223/

U.S. Environmental Protection Agency (EPA) (2003). Index of Watershed Indicators: National Maps, http://www.epa.gov/wateratlas/geo/maplist.html

U.S. Environmental Protection Agency (EPA) (2003). Draft Report on the Environment, http://www.epa.gov/indicators/