Developing National and Sub-National Sustainable Water Resources Indicators

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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. The Sustainable Water Resources Roundtable (SWRR, http://acwi.gov/swrr), continues to work on these problems.

The paper begins by describing the conceptual foundations that have been developed to aid in understanding sustainability. We recognize the importance of the 1987 Brundtland Commission definition, which relies on maintaining equity between generations to help define terms. 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.

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. One objective of this paper is to address the importance of scale issues and geographic patterns and how they may influence the formulation of key water sustainability indicators. By presenting statistics from which indicators are developed 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 scales.

The Future Imperative

We now face progressively stronger and more imperative interrelationships among both familiar water disciplines and with economic and cultural elements. At the same time our institutional arrangements among hundreds of organizations are designed for past conditions and focus on physical, chemical, engineering, and other traditional water concerns. Although our institutions have served us well, they are pressed to cope with a future in which water quality and availability, freshwater and coastal waters, surface and ground water, water and land use, and physical, chemical, and ecological characteristics must be considered simultaneously in geographical settings of wetlands, watersheds and habitats. This great variety of water-resources topics also must be related not only to other environmental and natural resource subjects, but also to all the aspects of our national economy and culture.

The Sustainable Water Resources Roundtable

The Sustainable Water Resources Roundtable was developed to address the above problems. The Roundtable was created in 2001 as a subgroup of the Advisory Committee on Water Information under the Federal Advisory Committee Act, to promote exchange of information among representatives of government, industry, and environmental, professional, public interest, and academic groups. The Roundtable is intended to provide a venue open to those who wish to examine some aspect of the many interrelationships noted above, and the future implications for the nation. History shows us that the long-term survival of a civilization depends greatly on its ability to manage its land and water resources in conjunction with its economy and culture. The web site of the Roundtable is http://acwi.gov/swrr/, and this site contains descriptions of all Roundtable activities, as well as its reports and publications to date.

Water Issues and Systems Properties

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.

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.

Figure 1 was developed to help focus on how many disparate elements of water resources might be related. As one moves along the time path from one point to the next, we have tried to depict at least some major interrelationships that involve water and the rest of the physical-economic-cultural system. This flowchart may not be complete, and indeed other such depictions might be created. Some of the pathways shown can be quantified, but certainly not all of them. This figure does however convey the complexity of the system we are trying to describe, how hard it will be to maintain sustainable conditions over time, and why we believe it will take many years to really understand the system (Smith, E.T., and Zhang, H.X., 2005).

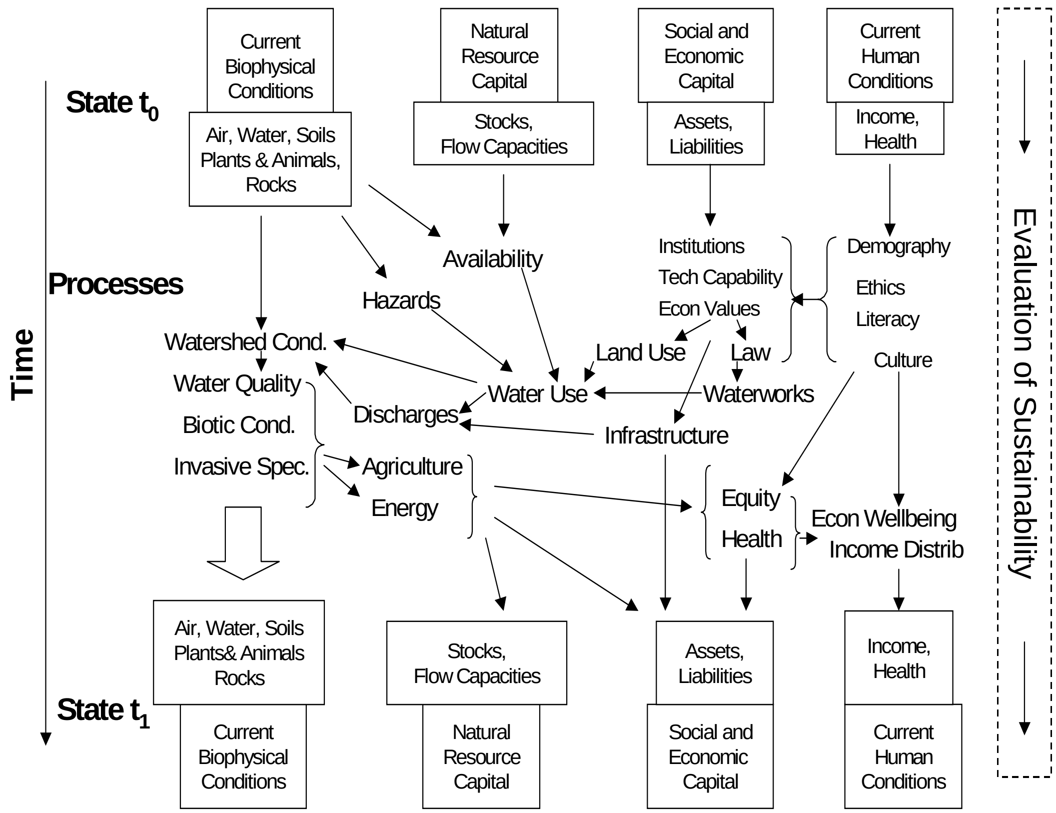

Figure 1. Water resources in the physical-economic-cultural system. (Smith, E.T., and Zhang, H.X., 2005)

Using Information Systems to Develop Indicators

How is indicator 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.

In the current technological environment, the first reaction is to use one of the popular search engines that are readily available on the world wide web. While this certainly has merit, the approach often results in a large collection of links, only some of which have the sort of information we desire. Something more selective may be necessary.

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/

Using 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.

There are other information systems that can help us too. For example, the USGS National Water Quality Assessment Program (NAWQA) Data Warehouse integrates data (more than 11 million records) on water quality, ecology, and hydrology across the nation, providing one of the largest nationally consistent on-line collections of water-quality data and associated information that is available (accessible at: http://water.usgs.gov/nawqa/data).

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 beginning at the national level, then proceeding to a regional geographic scale that focuses on Florida, and ending at a local scale that includes the area surrounding Tampa Bay.

Example National-Regional-Local Water Indicators

Having seen how water indicators might be developed, and how information systems might be used to locate information for abstract areas, it is now possible to give some specific examples to show how the process would work. Because we are at an early stage of development, in which we must use off-the-shelf products both for information systems and for the indicators themselves, the results are far from perfect. Still, we can see the power this kind of approach can have when used skillfully, pooling information from various sources, and how this might facilitate improved public policy management at the different geographic scales.

The range of geographic scales is important, because as we have seen indicators can be quite different as one scans up or down scale, even when examining the same general issue. For example, the policy audience for national scale issues is likely to be at the national government level, and be concerned with laws or regulations for the whole country. At the regional level (which is loosely defined here), we might be concerned with state government, which is focused on balancing conditions for its own area. At the local level, there may be metropolitan centers or counties that have still more focused concerns about, for example, water quality. At the local level one can imagine people fishing and swimming, worrying about drinking water quality, and seeing direct conflicts between uses like agriculture and public supply. At this level “acting locally” becomes more than a slogan.

Water Quality Indicators

Water quality issues fall into many categories, as has been noted above. For the examples shown here only a limited set is used. It must be realized that even the more traditional data and statistics that are routinely collected can include dozens of water quality parameters, which may well vary according to details of the issues under consideration. This does not even contemplate the newer topic of emerging contaminants, which may well drive much of the water quality issue process in the coming years.

National Water Quality Indicators. Bearing in mind that there may be dozens of water quality parameters that could be developed as indicators, for both surface and ground water, the present discussion will be limited to nitrates in ground water, to illustrate the process. A number of water quality issues have been associated with this indicator, and it is also the water quality indicator used in the SWRR 2005 Preliminary Report (see figure 4.4.1 in Sustainable Water Resources Roundtable, 2005).

Figure 2 shows a national map of nitrogen input and ground-water vulnerability, with statistical classes of contamination. This is from a report of the USGS National Water Quality Assessment Program (Nolan et al, 2001). Areas in the United States with the highest risk of nitrate contamination of shallow ground water (shown in red on the map) generally have high nitrogen input, well-drained soils, and less extensive woodland relative to cropland.

Nitrate is the form of nitrogen most related to human health. In 4 of 33 major drinking-water aquifers sampled, the U.S. Environmental Protection Agency (USEPA) drinking-water standard for nitrate was exceeded in more than 15 percent of samples collected. These aquifers, all of which underlie intensive agricultural areas, are in vulnerable geologic settings in the Central Valley of California, the Great Plains, and parts of the Mid-Atlantic region.

The most prevalent nitrate contamination was detected in shallow ground water (less than 100 feet below land surface) beneath agricultural and urban areas, where about 15 percent of all samples exceeded the USEPA drinking-water standard. This finding raises potential concerns for human health, particularly in rural agricultural areas where shallow ground water is used for domestic water supply. Furthermore, high levels of nitrate in shallow ground water may serve as an early warning of possible future contamination of older underlying ground water, which is a common source for public water supply (USGS Fact Sheet 116-99, 1999).

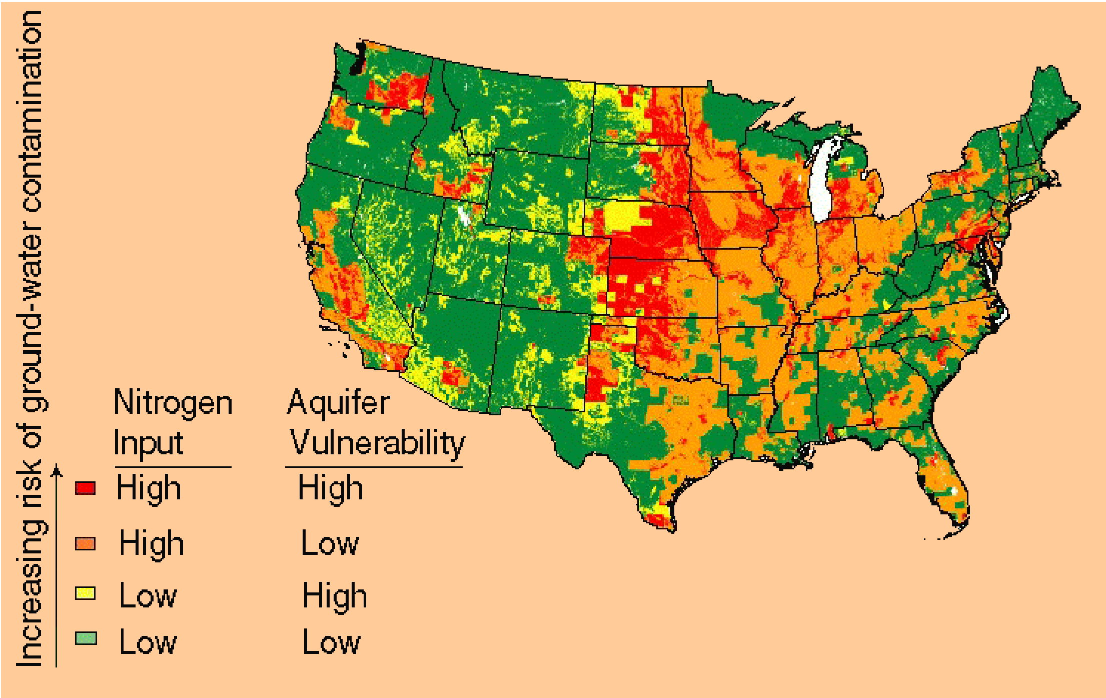

Figure 2. Nitrogen Input and Aquifer Vulnerability (Nolan et al, 2001).

Regional Water Quality Indicators. To illustrate how the process can progressively home in on smaller geographic areas, we have chosen to look at the region located partly in northern Florida and partly in southern Georgia. This region is convenient both in terms of surface and ground water delineation, and will aim us toward our local goal (see below) of the Tampa Bay area. To be sure, some idea of regional characteristics can be seen in Figure 2, but more detail is available.

Figure 3 shows nitrate concentrations in water from the surficial aquifer by land use in the three land resource areas of the Georgia-Florida Coastal Plain study unit. The data is from the USGS National Water Quality Assessment Program for this region (Berndt, Marian, 1990).

The median nitrate concentrations in water from the surficial aquifer system differed among various categories of land use near the well site and, to a lesser extent, by land resource area. This preliminary assessment of available nitrate data for ground water in the Georgia-Florida Coastal Plain study unit indicates a possible relation between land use and nitrate concentrations. Further studies might consist of data-collection activities, such as random sampling of ground-water within selected land- use areas of interest in the Georgia-Florida Coastal Plain study unit. Analysis of these ground-water samples for a comprehensive suite of chemical constituents and physical properties would further aid in determining the relation between land use and ground-water quality.

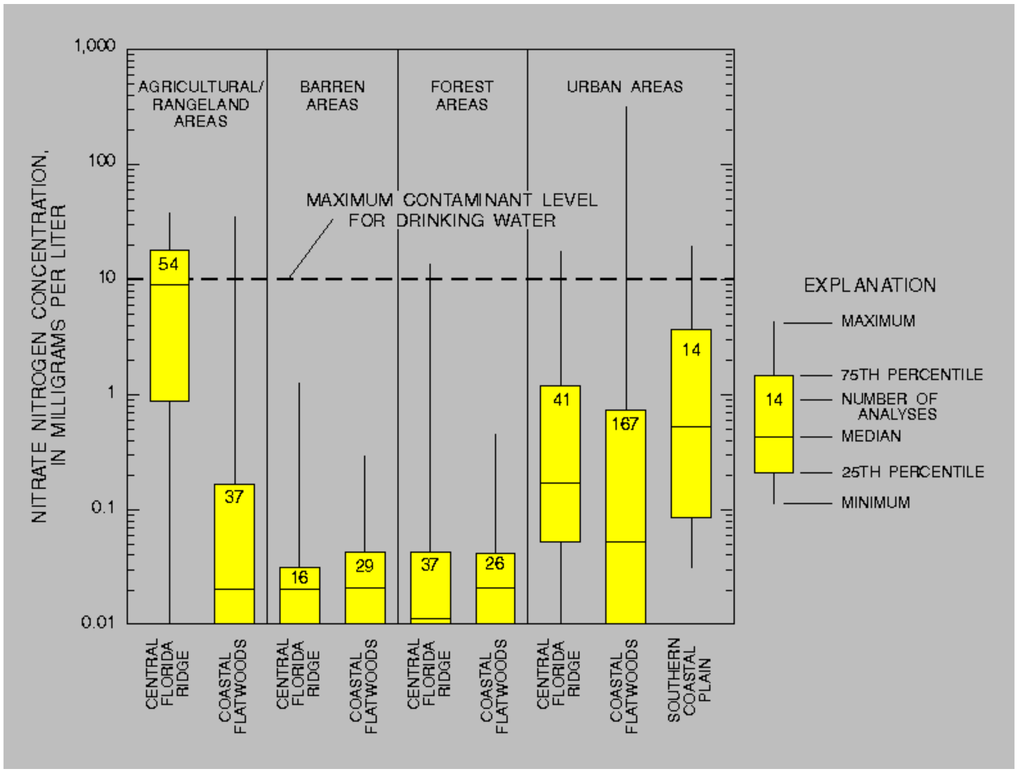

Figure 3. Nitrate Concentrations in the Georgia-Florida Surficial Aquifer (Berndt, 1990)

Local Water Quality Indicators. As noted above, the example chosen to illustrate local indicators is the Tampa Bay area. For this area, cooperative work among several organizations has collected data on a number of parameters, such as water chemistry including temperature, dissolved oxygen, sediments, pH, and salinity. The Tampa Bay Estuary Program (TBEP) 1999 Atlas was produced for the TBEP by the Florida Fish and Wildlife Conservation Commission. The Atlas features maps of the bay showing various layers of information, including seagrass recovery, habitat restoration sites, bathymetry, drainage basins, bird nesting colonies and manatee deaths (USGS, 1999).

Figure 4 illustrates this local level effort. Unlike other figures in this paper, this map shows just the areal components of a nitrogen management plan. The map does not itself depict indicators per se, but does show how local public policy has been developed to cope with the issue of how to protect local waters from nitrogen contamination. Taken together, figures 2, 3, and 4 show statistics and governmental response to address a water quality problem.

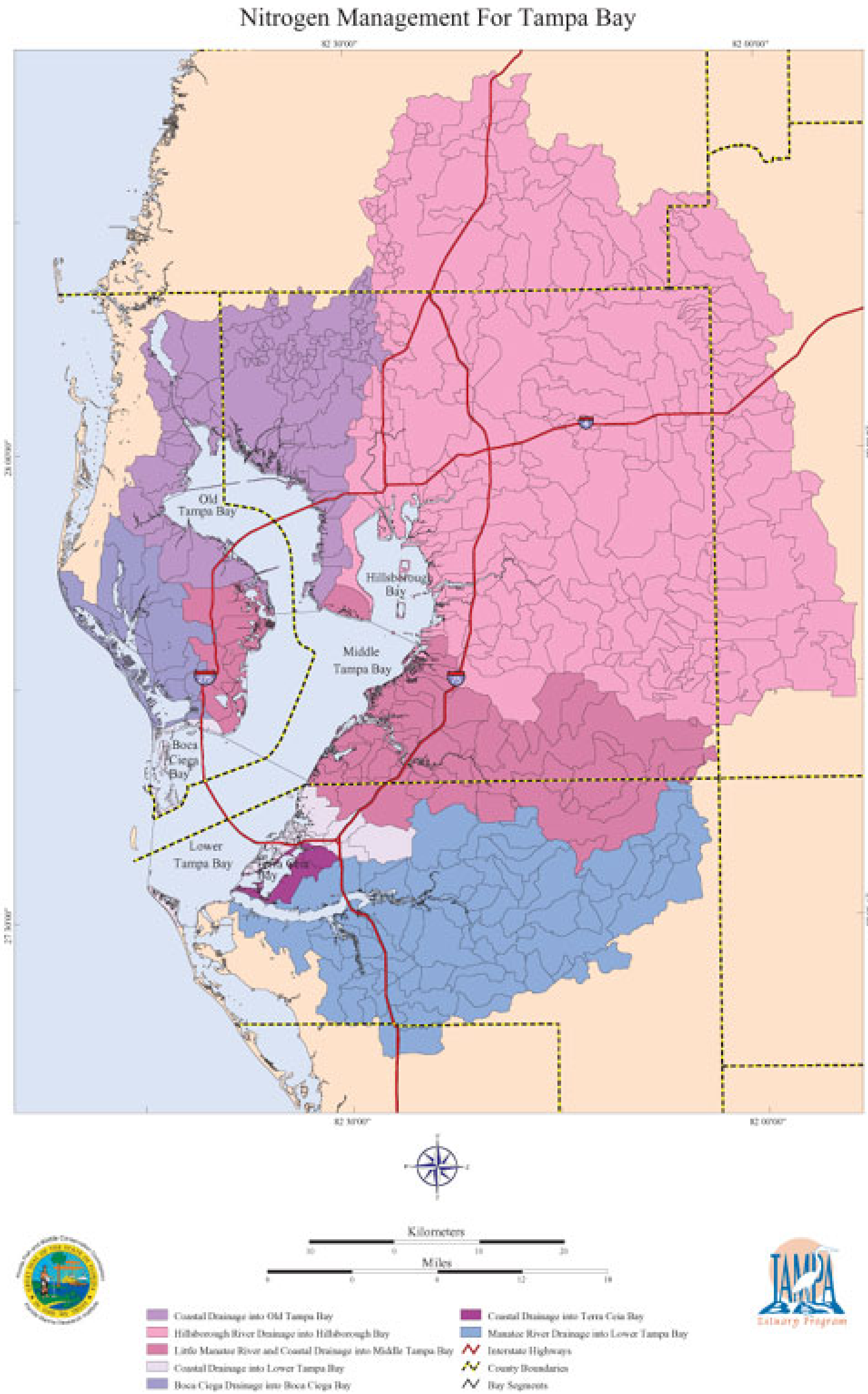

Figure 4. Nitrogen Management For Tampa Bay, http://dl.nwrc.gov/tampa/prod_search_tampa.aspx

Water Availability and Use Indicators

Water availability and use are different but related topics, and for this reason we elect to treat them together in this paper. Here we are looking at water availability as a measure of the amount of water that is available for use, whereas water use (which is often measured in terms of withdrawal) refers to the use made of the water for public supply, agriculture, industry, or for other purposes. As noted above, we will continue with the example of starting at the national geographic scale, then move to the regional Florida scale, and finally end at the Tampa area local scale.

National Indicators of Availability and Use. There are two indicators used in the SWRR 2005 Preliminary Report that make good examples in this case. The figures in the report are 4.1.1 (for water availability) and 4.16.1 (for water use). (See Sustainable Water Resources Roundtable, 2005). These illustrations are shown here as figures 5 and 6, respectively. Both of these figures were developed for the Electric Power Research Institute from USGS data, and were published in the Journal of the American Water Resources Association (Roy et al, 2005).

Nationwide, water availability is much larger than the rate of consumptive use. From a national perspective, therefore, water resources appear ample. A clear division is visible in both figures between the humid East and the arid West, along the line of the 100th meridian. Some anomalies can be seen in the pattern where there may be high evapotranspiration. However, we must recall that long-term averages often mask significant short-term variability, especially if a drought coincides with a time of peak demand from seasonal uses. For this reason, the idea of “water wars” may not be limited to western regions where long-term availability is low.

Figure 6, showing water use by county, already gives us some idea of geographical pattern. High rates of water use cannot be maintained over long durations, if precipitation is insufficient. The nation has taken major steps to supplement precipitation by irrigation via surface constructions and pumping ground water. There are limits to such actions: sites suitable for dams are largely exhausted, and in many cases aquifers cannot be replenished rapidly by natural processes. Indicators showing these effects promote the development of the information, programs and policies required to avoid critical water shortages in the short and long term.

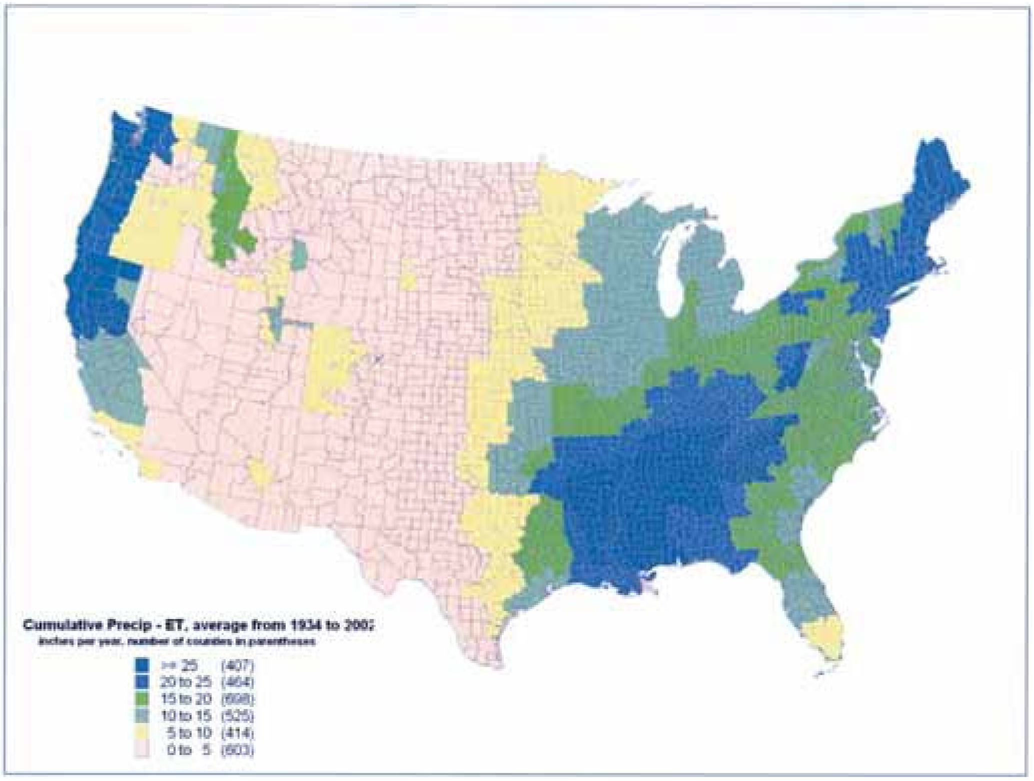

Figure 5. Water Availability as Cumulative Precipitation Minus Evapotranspiration, (Sustainable Water Resources Roundtable, 2005)

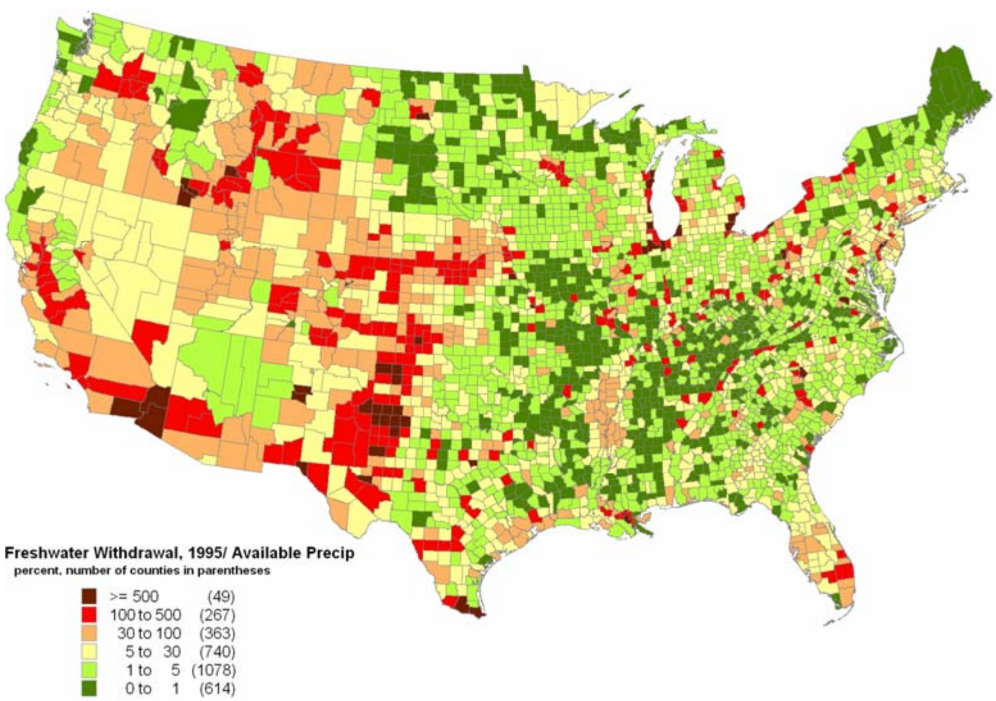

Figure 6. 1995 Water Use as Freshwater Withdrawal Divided By Available Precipitation.
(Sustainable Water Resources Roundtable, 2005)

Regional Indicators of Availability and Use Proceeding to the regional geographic scale, it is possible to examine the next level of availability and use. The renewable water supply is the sum of precipitation and imports of water, minus the water not available for use through natural evapotranspiration and exports. Renewable water supply is a simplified upper limit to the amount of water consumption that could occur in a region on a sustained basis. Requirements to maintain minimum flows in streams leaving the region for navigation, hydropower, fish, and other instream uses limit the amount of the renewable supply available for use. Also, total development of a surface-water supply is never possible because of increasing evaporative losses as more reservoirs are used. Nevertheless, the renewable supply compared to consumptive use is an index of the degree to which the resource has already been developed (USGS, 1995).

Figure 7 shows the pattern of consumptive use divided by renewable water supply, by water resources region. The ratio for the South Atlantic-Gulf region, which includes Florida, shows a generally favorable result; but, note must be taken of the more localized problem areas that have been mentioned, and which might occur under adverse conditions in the counties seen in figure 6. For example, note the characteristics of South Florida in these terms.

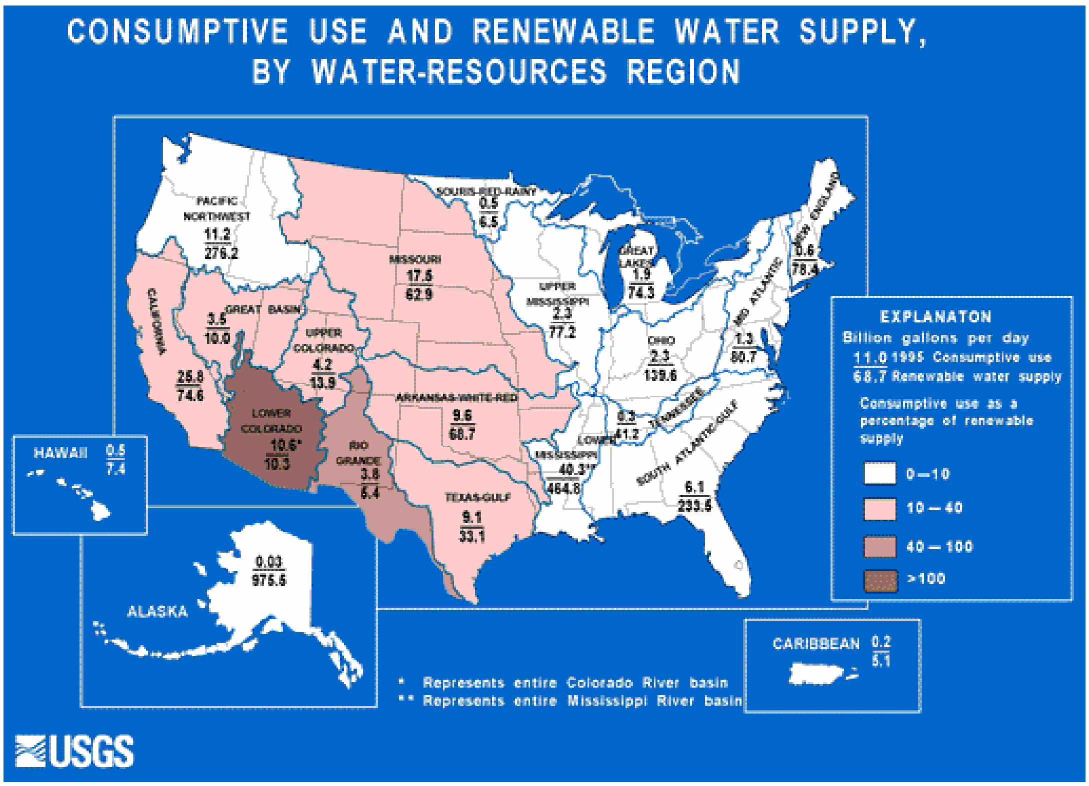

Figure 7. Consumptive Use Divided By Renewable Water Supply.
(USGS, 1995)

Figure 8 is the most complete depiction of water use, and this shows the relationship of Florida to the rest of the nation in several ways. These spatial indicators are from the 2000 USGS Water Use Program, and were used in the SWRR 2005 Preliminary Report as figure 4.2.1 (Sustainable Water Resources Roundtable, 2005).

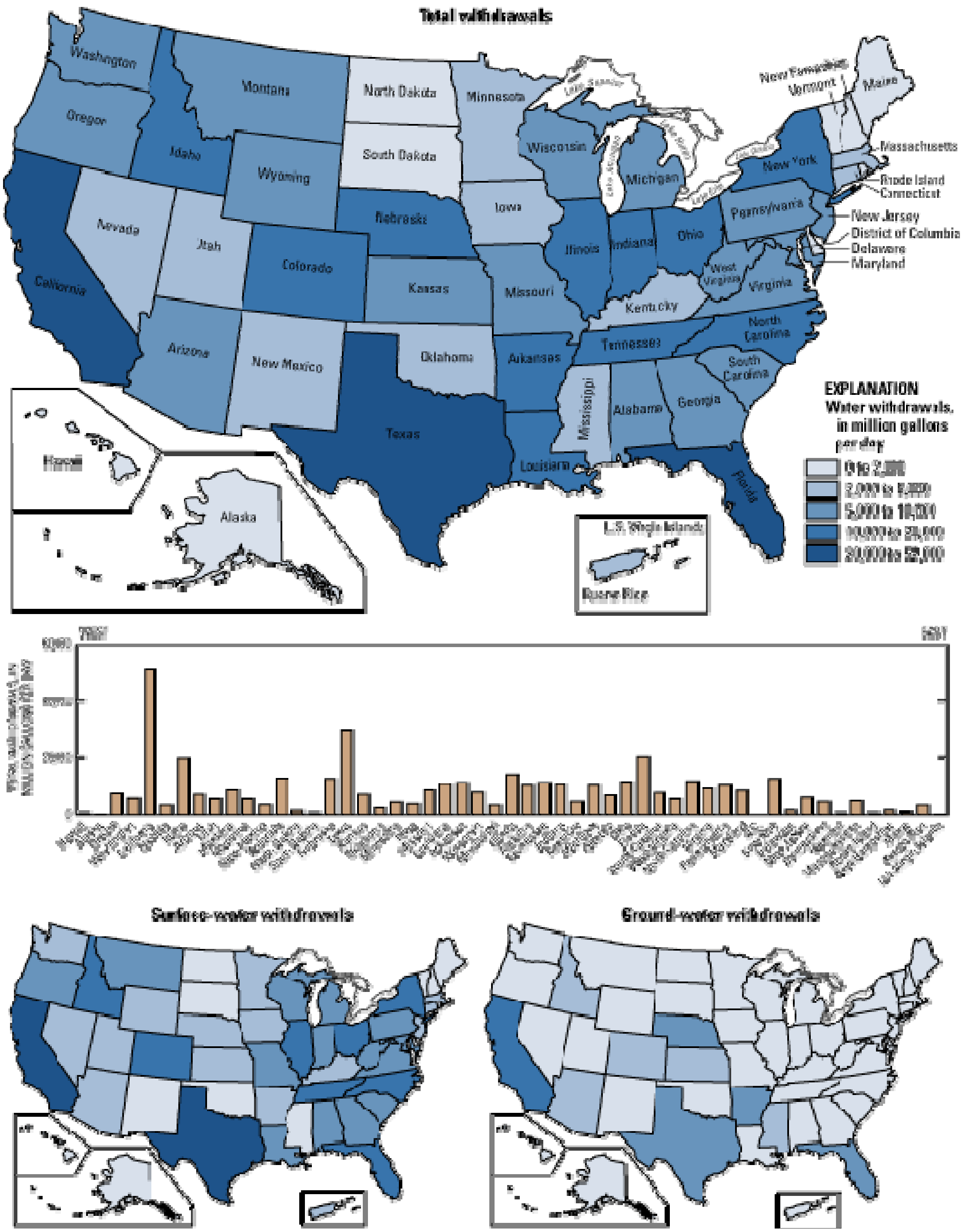

Figure 8. USGS 2000 Choropleth Indicators of Water Withdrawals.
(Sustainable Water Resources Roundtable, 2005)

Local Indicators of Availability and Use Following the analysis process for this paper, we complete the examination of water availability and use by looking at the Tampa Bay area. Figures 9 and 10 complete the picture. In figure 9 we see the major drainage basins in the Tampa Bay Watershed. The important point of this figure is the location of the USGS gaging stations that are indicated for each drainage basin by the dots in the figure. The USGS information systems contain very large and significant data holdings at the gaging station level, and allow the user to track trends in water availability in great detail. Figure 10 shows the statistical distribution at the county level of year 2000 total water withdrawals, which then allows the analysis of possible local problems and the development of policies to address those problems (USGS 1999B, 1999C).

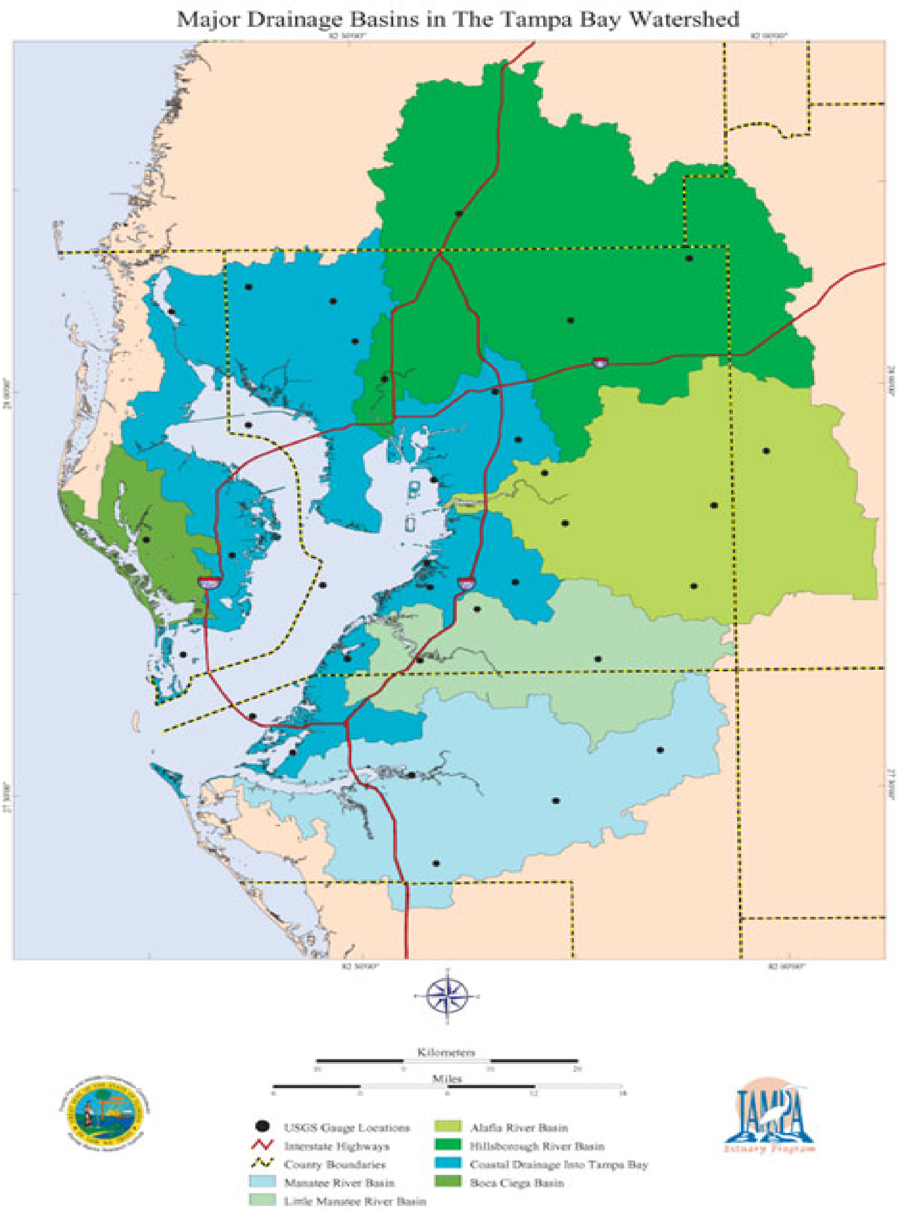

Figure 9. Major Drainage Basins in the Tampa Bay Watershed, (USGS, 1999B)

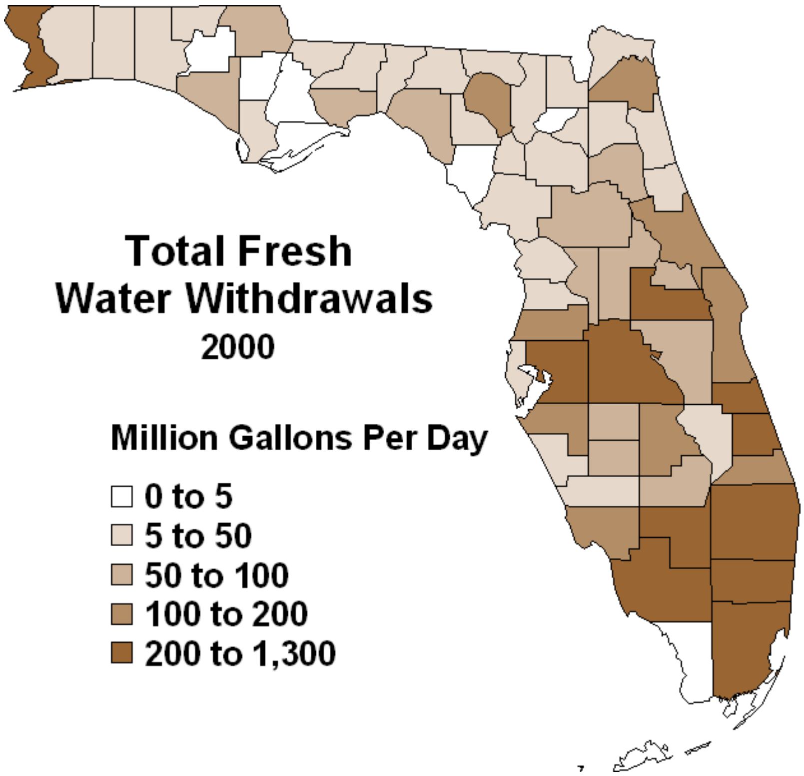

Figure 10. Florida Total Fresh Water Withdrawals,
(USGS, 1999C)

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. 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. 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.

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.

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