OUR JOURNEY TOWARDS SUSTAINABLE WATER RESOURCES MANAGEMENT: PRELIMINARY REPORT BY SUSTAINABLE WATER RESOURCES ROUNDTABLE

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ABSTRACT

Sustainable Water Resources Roundtable (SWRR) has been a subgroup of the Advisory Committee on Water Information (ACWI) since 2001 and operates under authority of OMB M-92-01. 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. SWRR participants are committed to interdisciplinary, inter-jurisdictional, and cross-ownership collaboration that identifies and supports national, state, and field-level activities to sustain water resources.

Two earlier papers in this series described work leading up to the completion of this Preliminary Report. The present paper is a summary of the Preliminary Report that contains all the background about development of the conceptual framework, how sustainability indicators might be selected, and how the Nation's water resources can be described in terms of seventeen such indicators. The paper begins by describing the conceptual foundations that have been developed to aid in understanding sustainability. SWRR recognizes the importance of the 1987 Brundtland Commission definition, which relies on maintaining equity between generations to help define terms. Beyond this, however, SWRR embraces systems analytic concepts to sharpen the definition. Systems analysis divides each of these systems into progressively more disaggregate subsystems, which can then be tracked by indicators that will also show the interrelationships among the systems. Furthermore, SWRR grappled with the problem of how to choose indicators, and the report contains the criteria that were developed. In general, indicators should consider the condition and capacity of ecological, social, and economic systems; must focus on long-terms consequences; must include both substantial geographic and temporal scales; must be measurable and scientifically based; and, must not be so abstruse that the informed lay reader is unable to comprehend them. The long-term goals of SWRR include the development of principles, criteria and indicators to support decision-making and identification of opportunities for collaboration on research needs. 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

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.

In an effort to address this set of problems, the Sustainable Water Resources Roundtable (SWRR) was created. 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.

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.

METHODOLOGY

Two earlier papers in this series described work leading up to the completion of this Preliminary Report (Smith and Zhang, 2004a; 2005). The present paper is a summary of the Preliminary Report that contains all the background about development of the conceptual framework, how sustainability indicators might be selected, and how the Nation's water resources can be described in terms of seventeen such indicators. The paper begins by describing the conceptual foundations that have been developed to aid in understanding sustainability. SWRR recognizes the importance of the 1987 Brundtland Commission definition, which relies on maintaining equity between generations to help define terms. Beyond this, however, SWRR embraces systems analytic concepts to sharpen the definition. For example, the natural, social, and economic systems can be regarded as producing flows of services or goods that meet various needs over time. Systems analysis divides each of these systems into progressively more disaggregate subsystems, which can then be tracked by indicators that will also show the interrelationships among the systems. SWRR also includes in its framework the idea that scientific information in itself is not usually sufficient to meet the needs of policymakers. At the top of the information pyramid are relatively simple stories that are told in various media, which is the form often, required by policymakers. Content of "stories" might include, for instance, a specific target of 10 percent increase in water for irrigation; or, convincing policymakers that water for irrigation should be increased; or, merely convincing policymakers that water for irrigation is a legitimate issue.

Furthermore, SWRR grappled with the problem of how to choose indicators, and the report contains the criteria that were developed. In general, indicators should consider the condition and capacity of ecological, social, and economic systems; must focus on long-terms consequences; must include both substantial geographic and temporal scales; must be measurable and scientifically based; and, must not be so abstruse that the informed lay reader is unable to comprehend them.

RESULTS AND DISCUSSION

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.

Selecting the Right Indicators

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.

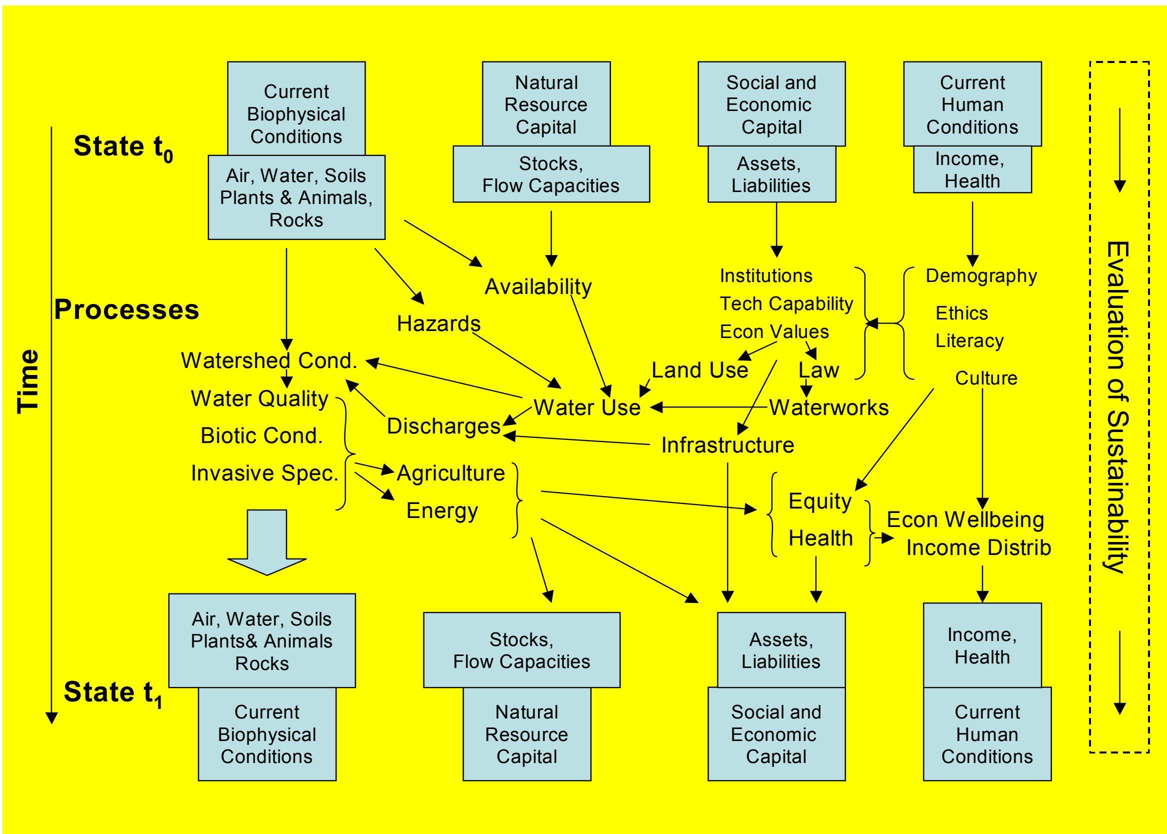

Figure 1: Water resources in the physical-economic-cultural system

The figure shows far more concepts than can be captured as indicators. Some are quantitative, but others qualitative and not readily measured. We are therefore faced with choosing some limited number of indicators; too many will overwhelm the policy making process, and may paralyze decision making. Too few will fail to describe issues in sufficiently comprehensive manner. There is no single set of criteria for what makes a good indicator. In the report on which this paper is based, there is an extensive process set out for selecting indicators. However, perhaps a simple checklist will make it possible to at least begin this difficult selection process. Table 1 is based on the GAO Report

"Environmental Indicators: Better Coordination Is Needed to Develop Environmental Indicator Sets That Inform Decisions" (GAO, 2004).

Table 1: Ten Criteria Used to Select Indicators Most Frequently Cited by GAO Survey Respondents (GAO, 2004)

Measurable	Data quality
Relevant	Importance
Appropriate geographic scale	Appropriate temporal scale
Understandable	Data comparability
Data available	Trend data available

The List of Indicators in the 2005 Preliminary Report

In September 2005, SWRR published a report with chapters on the role of indicators, conceptual foundations for the work of the roundtable, and criteria and indicators on the sustainability of water resources. The report also covers the research needs for sustainable water resources management that were discussed at SWRR meetings and covered in depth at a workshop held at the University of Michigan in April 2005. A final chapter discusses conclusions, recommendations and future work, as well as how federal and state governments, the private sector and non-profit organizations can help to achieve the sustainability of water resources. The appendices present a discussion of the water budget approach to management, a full list of candidate indicators and the SWRR terms of reference (bylaws). The report can be found at: http://acwi.gov/swrr/Rpt_Pubs/prelim_rpt/index.html

Because of space limitations, it is impossible to present the description of each indicator that is in the 2005 report. A selected few have been covered in the articles that comprise the remainder of this paper. But to show that much effort has gone into attempting a comprehensive approach, the following is a complete outline of the indicators in the report, all of which can be seen in the on-line report at the web site noted above.

A. **System capacities, quality and allocation**: Capacities are the amounts (e.g., flow rates) and quality of water available in nature and the related ability to allocate water among various human uses through social and economic processes.

    1. Gross water availability. An estimate of the total amount of renewable water supply in the natural system

    2. Total withdrawals for human uses. A measure of the total water withdrawn for use by people

    3. Water in the environment. A measure of the water remaining in the environment after withdrawals and consumption

4. Water quality. A representation of the quality of water in the environment

5. Total capacity to store, deliver, and treat the water supply over unit of time (i.e., infrastructure capacity). By basin, watershed or aquifer, estimations of:

- Public supply, private supply
- Irrigation
- Industrial/commercial
- Thermo-electric
- Capacity for treatment of return flows in municipal waste streams

6. Social and organizational capacity. Measures of the capacity of society and its organizations to manage water sustainably, including:

- Number of organizations dedicated to water and water-related education
- Number of states active in statewide comprehensive water planning
- Numbers of states with regulations providing equal protection and access by all sectors to water resources
- Numbers of states with emergency rules in place that address human preparedness, resistance and resilience to/from/with water problems and disasters

B. **Consequences of the way we allocate water capacity**: Allocations result in the flow of water to various human uses and water remaining in the environment.

7. Environmental conditions. Indices of the biological, chemical and physical conditions of the environment, including:

- Index of biological integrity
- Extent of eutrophication (chlorophyll *a*, organic carbon)
- Contaminant body burdens in biota (or contaminant burdens in excess of health advisory triggers)
- Water quality impacts (need composite index or method) (plankton biodiversity index by water body type, since plankton = base of food chain)
- Extent of altered wetlands (acres or % wetlands converted)
- Extent of altered river flow (e.g. due to impoundment or levee constraints)

8. Resources and conditions. Characterization of the amounts and quality of resources supported by water, including:

- Total availability of waters of suitable quality to maintain recreational uses
- Toxics body burdens and population changes in fish and birds

9. The quality and quantity of water for human uses. Measuring the quality and quantity of water used in different sectors, including:

- Quantity of water used for public supply: per capita use of water (would need total population)
- Quantity of water used for irrigation: per acre use of water for irrigation (by major crop type)

- Quantity of water used for industrial & commercial purposes: usage per day per employee (or per ton of finished product; or per unit produced)
- Quantity of water used for thermo-electric power generation: per unit of power generated, or consumptive use per unit of power generated
- Populations served by community water systems (drinking water measure) that meet all health-based standards
- Hydro-electric output per unit flow

10. Resources withdrawals and use. Uses of resources that depend upon water in the ecosystem, including:
    - Uses of harvested resources (e.g. consumption of fish, oysters, crabs, cranberries or other resources); numbers of sport fishing, water fowl hunting licenses sold annually
    - Uses of non-harvested water dependent resources (e.g. water-based recreation days); boat, water craft sales/licenses sold; marine fuel sales, non-sport birding surveys)

C. **Effects on people of the conditions and uses of water resources**: Flows of water in the environment affect water dependent resources and the environmental conditions for humans.

11. Human conditions. Measures of the value people receive from the uses of water and the costs they incur, including:
    - Value of goods and services related to uses of water withdrawn (e.g. public supply, etc.)
    - Value of use of non-harvested water dependent resources (e.g. recreation days)
    - Value of uses of harvested resources (e.g. fish value or cranberry value)
    - Human health conditions related to water resource use/exposure

D. **Important factors affecting water resources**: People use land, water and water dependent resources in ways that affect the conditions of ecosystems and human life.

12. Land use. Measures of the important elements of land use that affect water quality and quantity, including:
- A GIS-based presentation of land cover elements, including information on impervious surfaces, stream crossings, point and non-point sources, etc.

13. Residual flows. An accounting of the flow of water and wastes back into the water system, including:
    - Loading from point sources (chemical and biological pollutants)
    - Loading from non-point sources (chemical and biological pollutants)

14. Social and economic processes. Measures of the systems people and organizations develop to influence water resources and sustainability, including:
- Water pricing (e.g., full-cost basis for pricing)

15. Ecosystem (environmental) processes. Measures of ecosystem system processes that govern water resources and sustainability, including:

- Net Ecosystem Productivity – carbon flux over time per unit area

E. **Composite sustainability assessment**: These indicators combine or otherwise integrate some of the above indicators. Although more thought needs to be given here, we suggest two indicators. Each should be GIS based and designed for presentation at watershed, regional, state or national levels.

16. Water use sustainability. In each watershed, show the ratio of water withdrawn to renewable supply.

17. Water quality sustainability. In each watershed, indicators of the suitability of water quality for the uses desired, including ecosystem uses.

Comparing Key Indicators to 2005 Report Indicators

The previous paper in this series was "Formulating Key Indicators for Sustainable Water Resources Development Part II: Scale Issues and Geographic Patterns" (Smith and Zhang, 2005), which was published at WEFTEC'05. In that paper we presented a proposed list of key indicators, intended to move toward a list of limited size but with comprehensive coverage. That list is repeated in Table 2. During the remainder of this paper we shall attempt to describe the 5 indicators that appear in **both** our key list and the 2005 report; possibly these are the most important to watch. These indicators are shown in Table 2 in **blue.** Note that this only means there is similarity between the two sets; they are not necessarily identical.

But the 2005 report contains many more indicators. For completeness, we have included in this paper 5 other indicators that do not appear on the key list, but are in the report. These seem important to us, so we include them in abbreviated length.

Finally, there are still indicators on the key list which do not appear at all in the 2005 report. These are shown in Table 2 in ***red and italic.*** These seem to be indicators that need further investigation.

Table 2: 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**

(1) Water Quality in the Environment

This indicator is related to our key national ambient water quality indicator, but is not the same. There are many statistical measures that compete for indicator status, including new USGS work on emerging contaminants. Therefore, this indicator is best regarded as a work in progress, subject to much updating.

This indicator provides a representation of the quality of water in the environment. Because of the myriad chemical constituents that can potentially impair water quality, it is clear that this indicator would need to address a large number of constituent types. Therefore, the indicator likely would be a composite indicator that could take one of a number of forms. For example, the indicator might consist of a single value, or index, that synthesizes all of the data into an overall measure of the quality of the water environment, such as "the percentage of streams within a basin that meet all water-quality standards." Alternatively, the indicator might consist of several water-quality measures shown together in a single summary graphic such as a star diagram or two- or three-dimensional bar charts in Lane et al. (1999) or shown separately in a series of maps, graphs, or tables.

One of the most important measures of the water quality conditions of a stream or lake is the concentration of nitrogen. Nitrogen is a critical nutrient for plants and animals and a key indicator of ecosystem function. Excess nitrogen concentrations may indicate a decline in the ability of watersheds to assimilate point and non-point and atmospheric sources of nitrogen pollutants. The resulting nitrogen may have harmful effects as it moves downstream to coastal ecosystems. An indicator of nitrogen in the water environment has been prepared for the Heinz Center and EPA indicator initiatives using stream flow and water quality data collected by the USGS. The indicator tracks trends in the discharges of nitrate from the four largest rivers in the United States: the Mississippi, Columbia, St. Lawrence, and Susquehanna. While not inclusive of the entire nation, these four rivers account for approximately 55 percent of all fresh water flow entering the ocean from the lower 48 States.

The amount of nitrate carried by two of the four rivers covered in this indicator increased for several decades peaking in the early 1980s or 1990s (see Figure 2). The Mississippi River had the most striking increase in nitrate discharge but has declined in recent years. The Mississippi, which drains more than 40 percent of the area of the lower 48 states, carries roughly 15 times more nitrate than any other U.S. river. The nitrate load in the Columbia River increased to almost twice its historical loads during the later half of the 1990s, but returned to levels similar to those seen in the 1980s during 2000, the last year of record. Nitrate loads in the Susquehanna and St. Lawrence Rivers do not appear to have shown upward or downward trends during their periods of record.

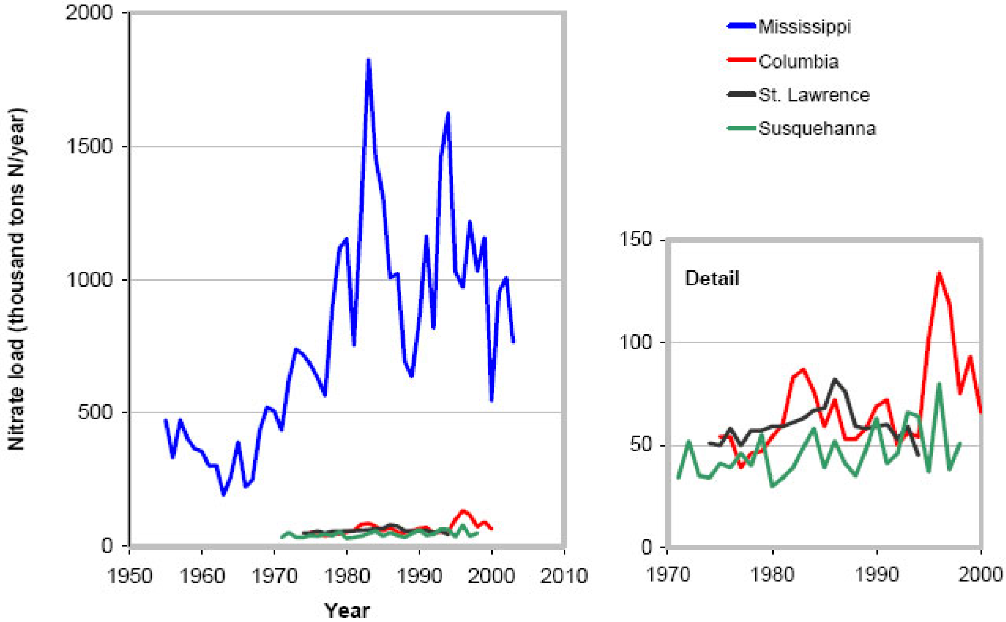

Figure 2: Nitrate Load Carried by Major Rivers (USEPA, 2003)

(2) Environmental Conditions

This indicator only covers part of the nation, but is related to several of our key indicators: water quality, sediment, and wetland resources. The idea of developing an index is close to our indicator concept, so this may be a good method to pursue.

This indicator addresses consequences of water allocations on the physical, biological, and chemical conditions of the environment. Although several efforts have been made to summarize water quality conditions in the U.S., no commonly accepted summaries exist. The widely different standards and methods used by the many agencies that take measurements are partly responsible for this deficiency.

The U.S. Environmental Protection Agency's (USEPA) Draft Report on the Environment (ROE) (2003) has two indicators for the condition of surface waters and watersheds in the U.S. The first index, *altered fresh water ecosystems,* reports the percentage of each of the major fresh water ecosystems that are altered. The definition of "altered" varies for each water type. The data were incomplete, varied in consistency from state to state, and were not aggregated. The conceptual approach has merit, despite problems in development and implementation of the index. The second index in the ROE, *lake trophic state index*, classifies lakes into eutrophic, mesotrophic, or oligotrophic states. No national data were available and the one report was based on phosphorus concentrations in northeast lakes. The limitations to this index include: the lack of national data; failure to account for non-lentic water bodies; and the fact that biota respond to variables other than phosphorus.

A rating system developed for the second National Coastal Condition Report (NCCR II) has several positive features (USEPA 2001, 2004). The NCCR II is the result of collaboration among the USEPA, National Oceanic and Atmospheric Administration (NOAA), U.S. Fish and Wildlife Service (USFWS), and U.S. Geological Survey (USGS). The NCRR II is concerned with the condition of coastal regions of the United States, and characterizes coastal water bodies based on measures related to aquatic and human uses. The ecological condition of individual sites is scored and assigned to one of three categories: 'good,' 'fair,' or 'poor.' Each region is then assigned a rating based on the overall condition of individual sites (Figure 3). For the NCRR II, coastal condition was characterized using data from USEPA's National Coastal Assessment (NCA), NOAA's Status and Trends Program, and USFWS's National Wetlands Inventory. Table 3 shows the indices used to measure aquatic and human uses.

Table 3: Indices Used for the National Coastal Condition Report II map

Aquatic Use Indices	**Index components**
1. Water Quality Index	dissolved oxygen, chlorophyll a, nitrogen, phosphorus, water clarity
2. Sediment Quality Index	sediment toxicity, sediment contaminants, sediment TOC
3. Benthic Index	benthic community diversity, pollution-tolerant species, pollution-sensitive species
4. Coastal Habitat Index	long-term decadal wetland loss rate (1780-1990); present decadal wetland loss rate (1990-2000)
Human Use Indices	
5. Fish Tissue Contaminants Index	composite concentrations in relation to EPA Guidance range
All indices calculated based on 1997-2000 data.	

The NCRR II rated the overall quality of national coastal waters as 'fair.' Specifically, 21 percent of the estuarine area of the country is unimpaired and 44 percent is threatened for human and/or aquatic life uses. The remaining 35 percent are considered impaired, with 15 percent of the coastal waters impaired for both human and aquatic life use, 13 percent for aquatic life use only, and 7 percent for human use only.

To reflect the natural geographic differences in aquatic ecosystem characteristics, the NCRR II identified indices specific to six major regions in the U.S. The scale of each indicator was unique to the site within each region. The whole region was then ranked based on the percentage of sites that were categorized good, fair, or poor. A system of this type is important for characterization at regional and national scales; however, an obvious drawback of NCRR II is its limited geographic focus on coastal waters. The NCRR II report relies heavily on data collected through EPA's National Coastal Assessment from 1999 - 2000 and the coastal portion of the 1997-1998 Mid-Atlantic integrated Assessment (USEPA/EMAP and NCA).

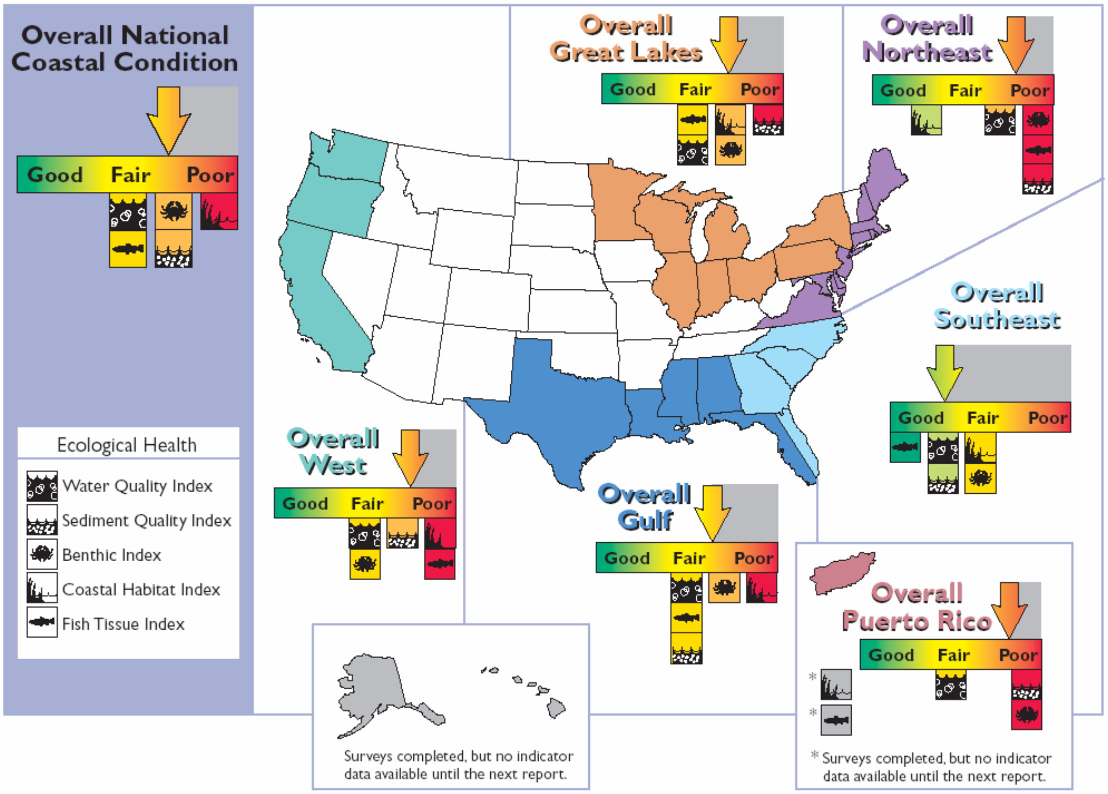

Figure 3: Overall national and regional coastal condition between 1997 and 2000 (USEPA, 2004)

The NCRR II is a product of the component data. Debate is inevitable regarding the relative importance, as well as the presence or absence, of certain data. Although the data elements included in these indices are broad, there are no elements that explicitly deal with impacts of ground water withdrawal or threatened/endangered species. There is no perfect index and different data elements may be needed at finer geographic scales.

In summary, it is difficult to find a single set of water indicators useful at all scales and for all regions. A challenge of future work in developing indicators to assess environmental condition will be to find commonalities that can work at the national level, while retaining sufficient detail to be helpful to regions and specific sites.

(3) Gross Water Availability

This indicator is closely related to our key water supply indicator, although as can be seen there are different ways to calculate the water budget.

This indicator reports the total amount of renewable water supply in the natural system. Different approaches have been used to quantify gross water availability, but all approaches require measurements (or estimates) of one or more of the water-budget components of the hydrologic cycle within a watershed, as illustrated for example in figure A.1 of Appendix A of the online 2005 report of the Sustainable Water Resources Roundtable at http://acwi.gov/swrr/, under Reports and Publications.

One of the simplest approaches is to quantify the mean annual surface and sub-surface (shallow aquifer) runoff, accumulated as river discharge (Vorosmarty et al, 2000). Another approach defined the *renewable supply* in a region as the amount of available precipitation, which is shown in Figure 4 (Roy et al, 2005). Available precipitation is defined as the difference between precipitation and potential evapotranspiration totaled for all months in a year when precipitation exceeds potential evapotranspiration.

The U.S. Geological Survey (USGS) defined the renewable supply of water within a watershed as the sum of precipitation and imports, minus natural evapotranspiration and exports (USGS, 1984). This method may be seen online at http://water.usgs.gov/watuse/misc/consuse-renewable.html They also showed that renewable supply could, alternatively, be determined as the sum of surface-water outflow and consumptive use minus the long-term depletion of ground-water storage in a watershed. The USGS noted that although renewable supply represents the flow that is theoretically available for use in a watershed on a permanent basis, it is actually a "simplified" upper limit to the amount of water consumption that could occur in a region on a sustained basis. It is simplified in the sense that the variables involved - precipitation, imports, natural evapotranspiration, and exports - are subject to change due to natural causes and human intervention. Moreover, where there are legal and institutional requirements to maintain minimum flows in streams to enable uses such as navigation, hydroelectric power generation, fish propagation and habitat, the actual amount of available water is reduced to an amount that might be defined as *net water availability*.

Nationwide, the renewable supply of water (precipitation less evapotranspiration) is much larger than the rate of consumptive use (Alley, 2002). From a national perspective, therefore, water resources appear ample. Locally, however, the situation varies widely. Much of the western U.S., except some coastal areas, has far lower water availability than the eastern U.S. In the eastern states, water availability is lower in regions with higher potential evapotranspiration, such as south Florida (Roy et al, 2005). Overall, these results are consistent with those of the USGS using 1980 data and updated by Alley (2002) using 1995 data. Alley (2002) notes, however, that these maps can suggest a relative abundance of water in regions that actually face challenging water-availability issues. He cites as an example the South Atlantic-Gulf region, an area with so-called "water wars" (at least, within the judicial system) among competing users for allocations of water from sources that cross boundaries.

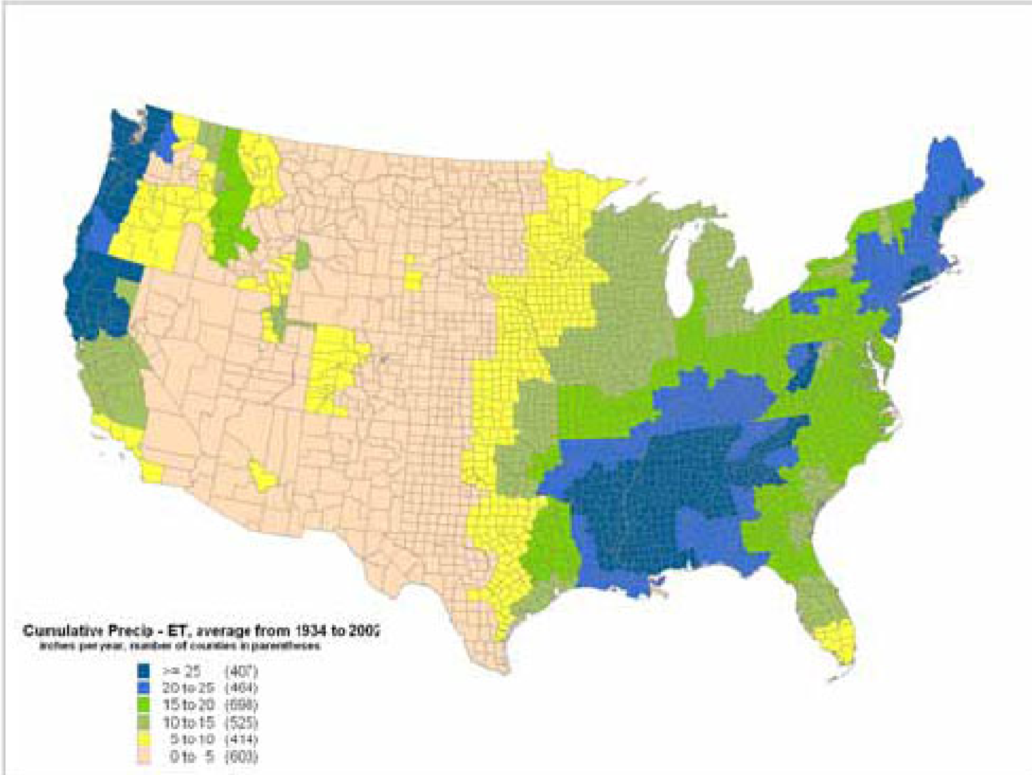

Figure 4: Available Precipitation (difference between monthly precipitation and potential evapotranspiration) across the United States based on 1934-2002 average data at the climate division level (Roy et al., 2005)

(4) Water Use Sustainability

This indicator is closely related to our key water withdrawals indicator. As presented here, it is perhaps one of the best measures of long term water sustainability.

Water use sustainability requires meeting the needs of humans and nature over the long term at a variety of scales, from local to national to global. This indicator reports the total amount of fresh water withdrawn for human uses as a percent of available precipitation shown as gross water availability or total precipitation minus potential evapotranspiration. As a gross measure of long term sustainability, people can only withdraw as much fresh water overall as is eventually renewed by net precipitation and is not required to support ecosystems.

This measure does not account for flows of water from one area to another. In many populated areas and dry agricultural counties, more water is withdrawn than falls as precipitation. That water is either drawn from other areas conveyed by ground water, surface water or built infrastructure, or alternatively, is mined from local ground water.

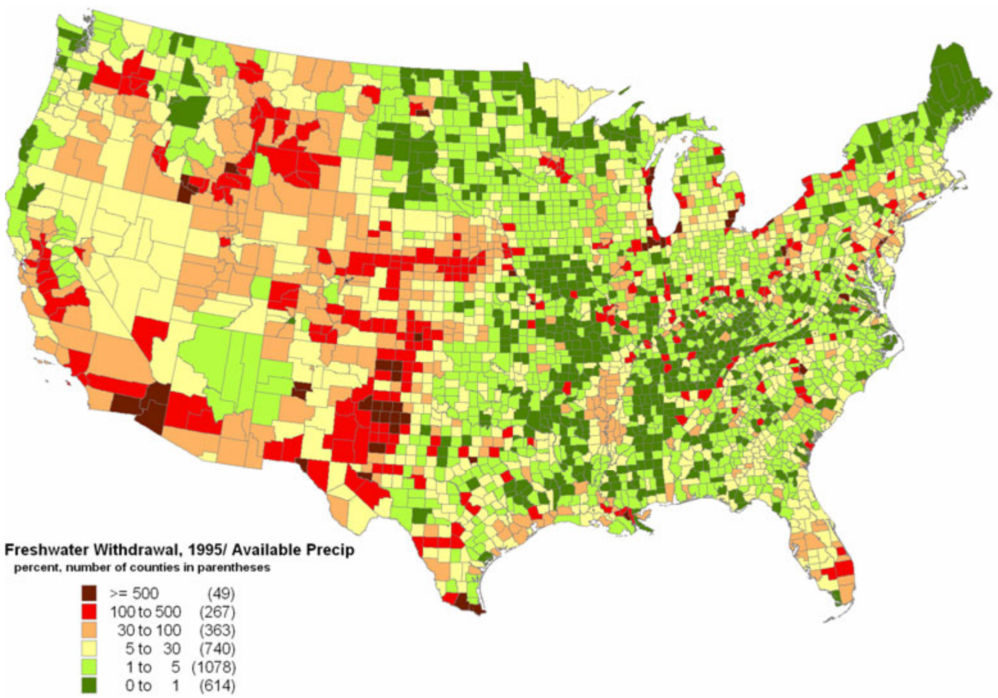

Figure 5: Total Freshwater Withdrawal in 1995 (as a percent of available precipitation) (Roy et al., 2005)

An indicator of water use sustainability should ideally be map based at a fine enough resolution to be useful at the different scales needed for water supply planning. But in none of the example indicators shown have we reached the ideal. That will require a mapable quantification of the extent of renewable water supplies across the nation, the variable and fluctuating needs of ecosystems, and the needs of people for water today and for the long term future.

Water use sustainability is a key indicator because it helps us understand when and where water needed for human and ecosystem uses may exceed available supplies. In many regions of the US and the world, water is used at rates that cannot be maintained. Being aware of where these trends exist will support development of the information, programs and policies required to avoid critical water shortages in the near and long term.

The United States has renewable supplies of water larger than the rate of use, but it is not evenly distributed. Many areas use more water than can be considered sustainable. Nationally, water resources appear ample but this is an indicator for which the nationwide average is not meaningful. Locally, the situation varies widely. In all the red and dark maroon areas on Figure 5, water use exceeds the total available precipitation. This excess is made up by drawing water from other areas or drawing down water supplies. This may not be ecologically, economically or politically viable for the long term.

(5) Land use

This indicator shows the kind of land use effect that we contemplate in our key index of agricultural runoff potential. The subject is very complex, so again we should regard this indicator as only part of the story. However, the spirit of what we intend is contained here.

This indicator addresses the important elements of land use – developed land and cropland – that affect water quality and quantity. The developed land measure includes small-urban, large-urban, and built-up areas, as well as highways, roads, railroads, and associated right-of-ways in rural areas. The cropland measure shows the watersheds that have the highest potential for sediment, pesticide, and nutrient runoff, as well as pesticide and nitrogen leaching to groundwater. The data for both measures is presented on a watershed basis using the U.S. Geological Survey's 8-digit hydrologic cataloging unit.

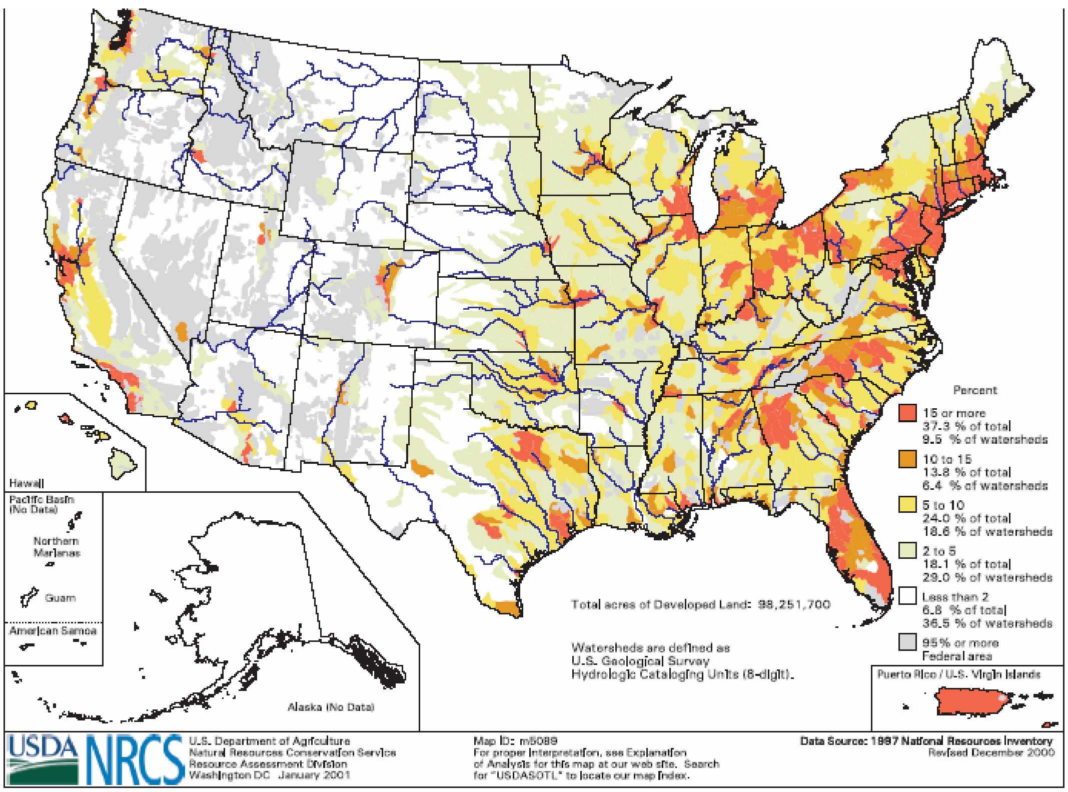

Figure 6: Percent of Hydrologic Unit in Developed Land (USDA, 1997)

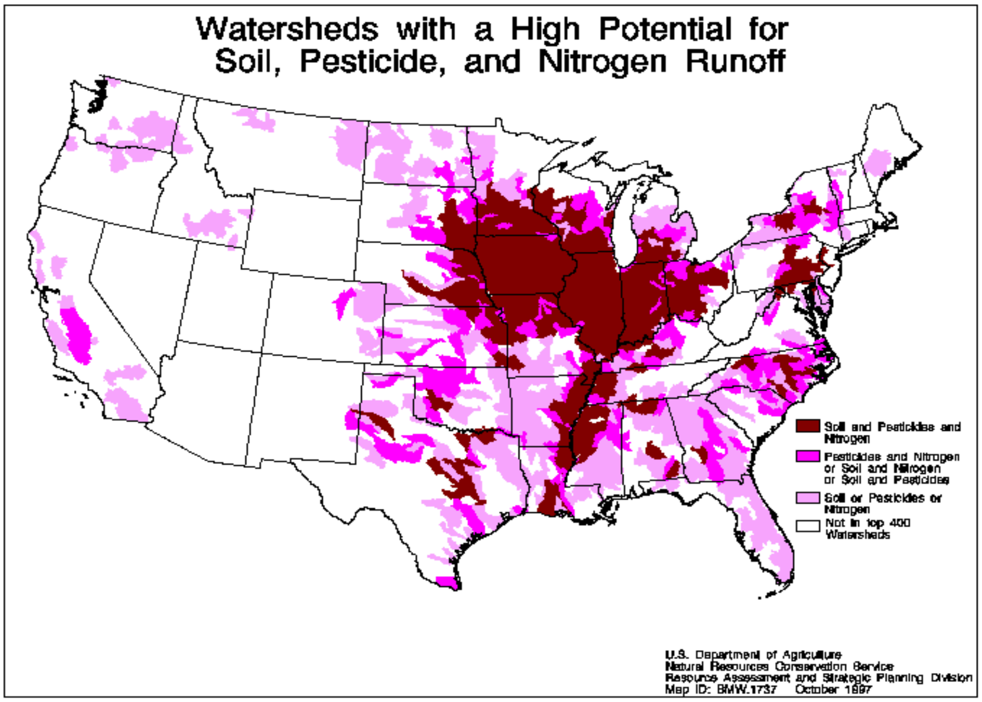

Figure 7: Watersheds with a High Potential for Soil, Pesticide, and Nitrogen Runoff (USDA, 1997)

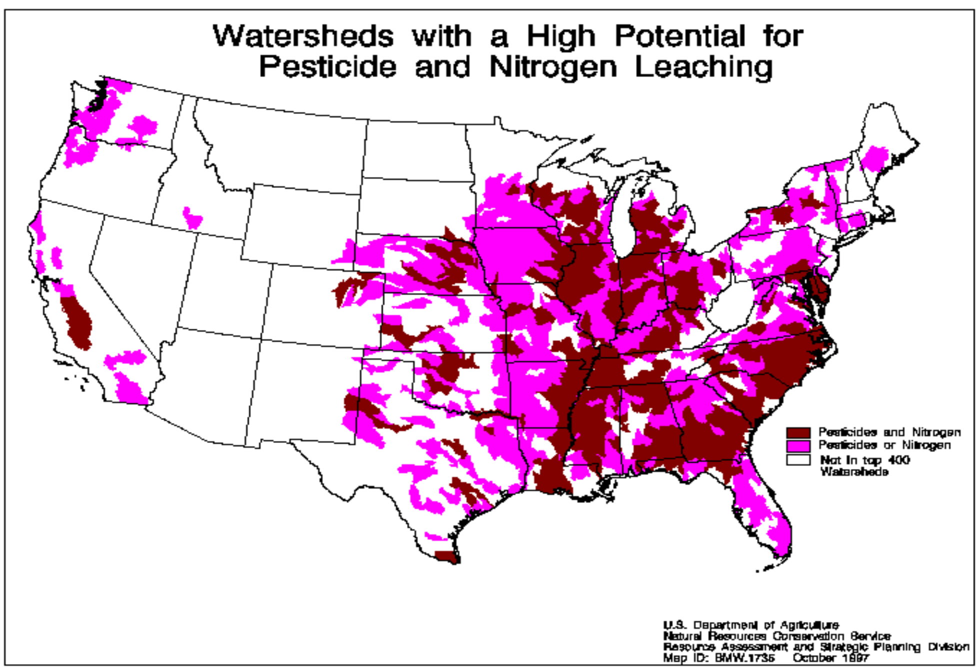

Figure 8: Watersheds with a High Potential for Pesticide and Nitrogen Leaching (USDA, 1997)

The way people, business, and government use land profoundly affects water resources. It affects the timing and magnitude of surface water flows, the recharge of ground water, the demand for water and the resultant discharge of wastewater. Further, the chemicals put on the land end up in the water thus affecting water quality. Land use also directly and indirectly affects wildlife habitat and other valued, water dependent ecosystem features.

As shown in Figure 6, in 1997, over 98 million acres of land in the 48 contiguous states are considered developed. Nearly 10 percent of the nation's watersheds have at least 15 percent of their land in a developed state. The extent of development is greatest in the Northeast, the Southeast Piedmont, Florida, the Industrial Midwest, including the Great Lakes states, and parts of the West Coast. While the measure is useful with implications for a broad range of water-related concerns – from timing of flows to water quality, quantity, use and habitat destruction – it does not directly measure these factors.

As shown in Figures 7 and 8, from one-third to one-half of the watersheds in the 48 contiguous states show high potential for pollutant runoff and infiltration from cropland. This assessment is based on a determination of the top 400 watersheds for each factor. The greatest concerns were evident in the Midwest and Southeast.

(6) Resources and Conditions

This indicator characterizes the amount and quality of resources that are directly or indirectly dependent on water quality and/or quantity. It includes measures that can indicate whether resources in the environment associated with water are impacted by changes in the biogeochemical integrity of aquatic ecosystems. Such measures include fish contamination and the percentage of impaired water bodies.

The indicator is designed to be a measure of the condition of the resource in the natural environment rather than when consumed by people. Fish consumption advisories, while based on safety of the fish for human consumption are also a measure of the condition of a watershed itself because they are issued when the concentration of toxic substances in fish and shellfish in a water body exceed safe levels (Flint, 1992). Contamination of edible organisms indicates serious pollution problems in a water body, typically because persistent toxic chemicals have contaminated the sediments and food chain or pathogens have contaminated the water column (see Figure 9).

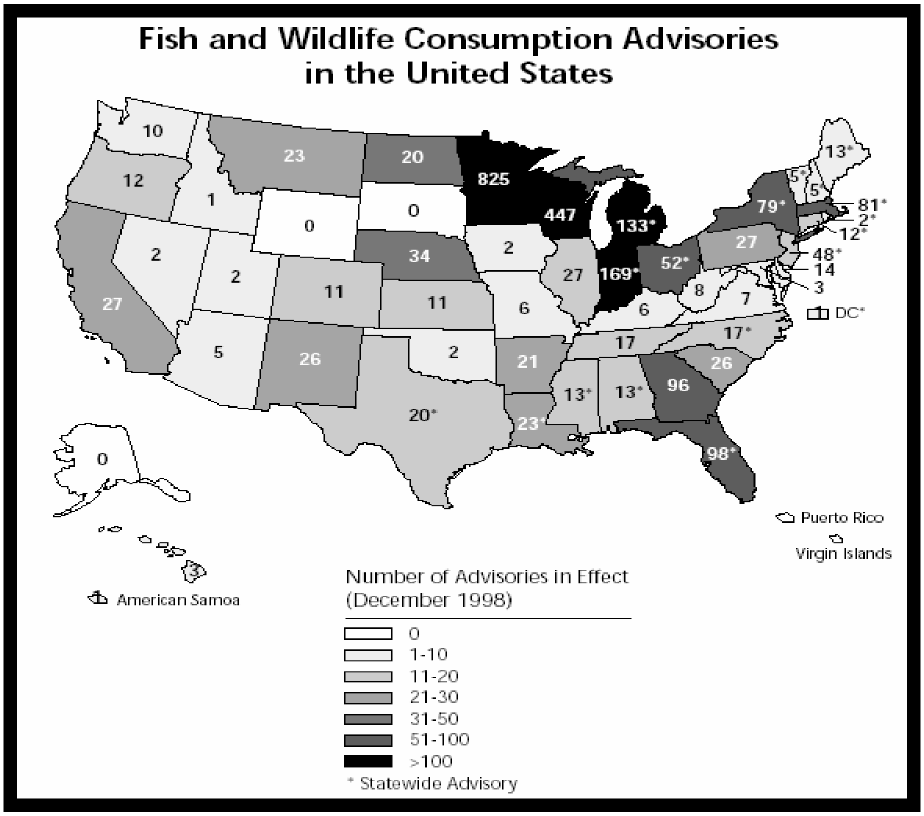

Figure 9: Contamination of Fish and Wildlife (percentage of water bodies measured that are impaired) (USEPA, 1998)

The consumption advisory map for 1998 illustrated in Figure 9 shows that only 2 of the 48 contiguous states did not report the need for issuing consumption advisories. For the other 46 states, the Great Lake's states had the highest number of fish consumption advisories, followed by the states in the extreme southeast of the U.S. The Sustainable Water Resources Roundtable only found data for 1998 so no trends can be reported for consumption advisories across the U.S. Although no continuous records on an annual basis were discovered for the reporting of consumption advisories, the importance of this measure as a potential health risk indicator to humans from the use of water related resources suggests the need to keep continuous and consistent annual reporting records on this measure.

(7) Indicating Water Related Human Conditions: Infrastructure and Drinking Water

This indicator measures the value people receive from the uses of water and the cost they incur from not having these resources. One of the critical measures of value is the access of people to potable water and sanitation. A measure of that is the availability of plumbing and sanitation for the population. This tells us the population living with access to the basic resources of potable water and sanitation. There is a well established link between potable water and public health (see Figure 10).

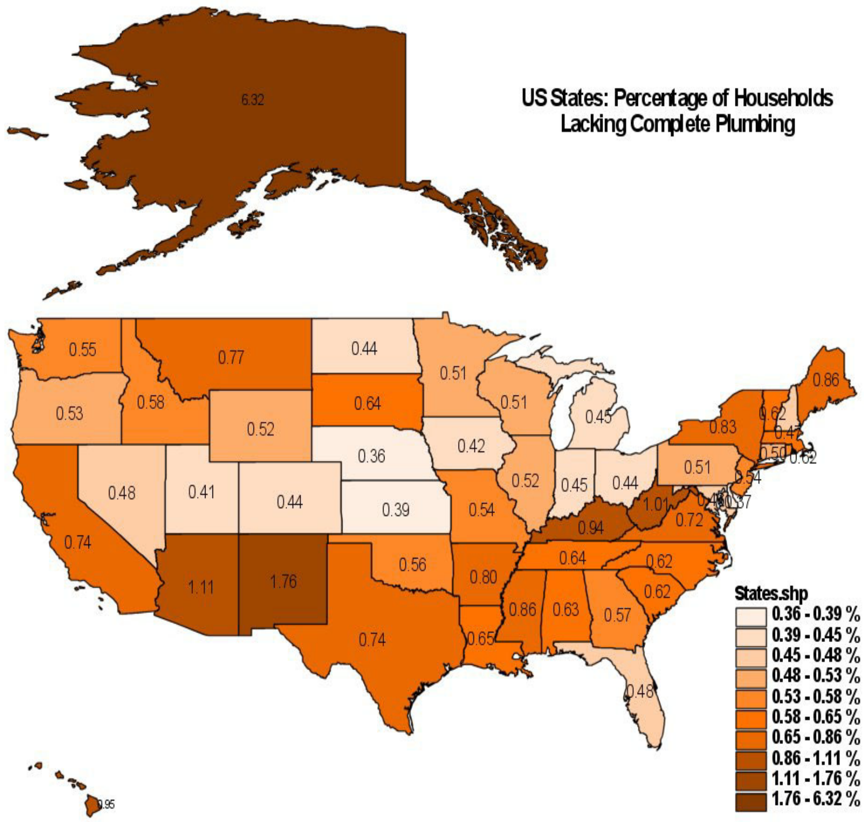

Figure 10: Percent of the Population Lacking Complete Plumbing by State (RCAP, 2004)

The percent of the population living without access to potable water and sanitation is an accepted international indicator of quality of life. Indeed, the United Nations Children's Fund (UNICEF) has correlated the percentage of the population with potable water and sanitation with deaths per 1,000 for children under five years old in 20 nations (UNICEF, 2006). Their research shows that the greater the access to potable water and sanitation the lower the incidence of early child mortality. Even if people have access to piped water, the question still remains whether the water that is coming out of the tap is potable. This can be measured by the trend in outbreaks in of waterborne disease. This information is collected periodically by the Center for Disease Control (CDC).

In the United States, the U.S. Census long form survey has the number of people who say they have water and sanitation in the home since 1950. The percentage of the population lacking either plumbing has diminished steadily from 27 percent in 1950 to .64 percent of the population in 2000. As is clear from the map above, however, the distribution of those lacking plumbing services is not even across the United States. Alaska, Arizona and New Mexico carry disproportionate percentage of those lacking plumbing services.

Viewed by ethnicity, Native Americans and Hispanic-Latino/as are disproportionately likely to be living without water and sanitation (RCAP, 2004).

(8) The Quantity and Quality of Water for Human Uses

The first part of this indicator reports how the water that is withdrawn within (or imported to) a watershed is actually used by the different water use sectors within the watershed. The USGS has collected national data at five-year intervals on amounts of water used in homes, businesses, industries, and agriculture. The data are collected at the county level, but are totaled and reported for each state. SWRR recommends that water uses be reported periodically for at least the following four water use categories: public supply, irrigation, industrial and commercial purposes, and thermo-electric power generation. These data might also be used to derive related indicators, such as per capita use of water, per acre use of water (by major crop type), water usage per day per employee (or per ton of finished product or per unit produced), and per unit of power generated (or consumptive use of water per unit of power generated).

Trends in the allocation of water withdrawals to the major water use categories for the 50-year period 1950-2000 are shown in Figure 11. The largest uses of water have consistently been for irrigation and thermo-electric power generation, although the amounts of water used for these purposes have stabilized since 1985. With respect to water use for thermo-electric power generation, since the 1970s, power plants increasingly were built with (or converted to) closed-loop cooling systems or air-cooled systems, instead of using once-through cooling systems. The use of re-circulated water for cooling in a closed-loop system reduces the water requirement of a power plant, resulting in reduced water withdrawals. Estimated withdrawals for public supply have increased continually since 1950, as has the population served by public suppliers. The percentage of population served by public suppliers increased from 62 percent for 1950 to 85 percent for 2000.

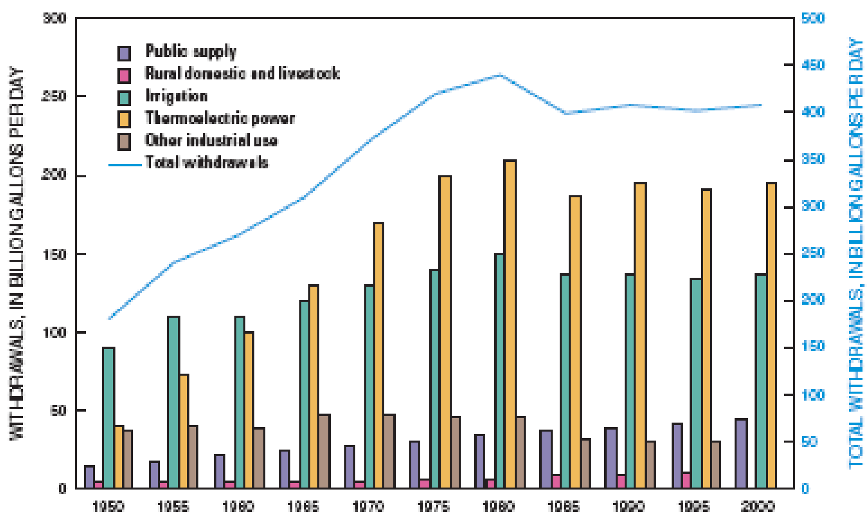

Figure 11: Trends in total water withdrawals by water-use category, 1950-2000 (USGS, 2004)

(9) Residual Flows

This indicator reports the flow of water and wastes back into the water environment after human use and, possibly, treatment. These flows can originate from either point or non-point sources. Residual flows are important because they may contain chemical and biological constituents detrimental to the environment, or have physical properties (such as temperature) that impair the environment.

An important source of data on wastewater discharges to the water environment is provided by the National Pollutant Discharge Elimination System (NPDES), which is administered by the U.S. EPA. NPDES is a national system for permitting of wastewater discharges that was created under the Federal Water Pollution Control Act (FWPCA) Amendments of 1972 (further amended in 1977 as part of the Clean Water Act). Under NPDES, all facilities that discharge pollutants from any point source into waters of the United States are required to obtain a permit. Pollutants are defined broadly by the NPDES regulations and litigation and include any types of industrial, municipal, and agricultural waste discharge into water. Municipal sources are publicly owned treatment works that receive primarily domestic sewage from residential and commercial customers. While provisions of the NPDES Program do address certain types of agricultural activities (such as concentrated animal feeding operations), the majority of agricultural facilities are define as non-point sources and are exempt from NPDES regulation. As of 2001, more than 50 categories of industry (including several hundred thousand businesses) and the nation's network of more than 16,000 municipal sewage treatment systems comply with standards implemented in NPDES permits.

As shown in Figure 12, the USGS reported total releases of some 41,000 million gallons per day of treated wastewater from about 16,400 publicly-owned treatment facilities nationwide during 1995. The return of treated water generally is to surface waters, although over two percent of the treated wastewater that was released was reclaimed for beneficial uses such as irrigation of golf courses and public parks. Illinois and Ohio, which have large public supply withdrawals, reported the largest releases of treated wastewater; Florida, California, and Arizona reported large uses of reclaimed wastewater.

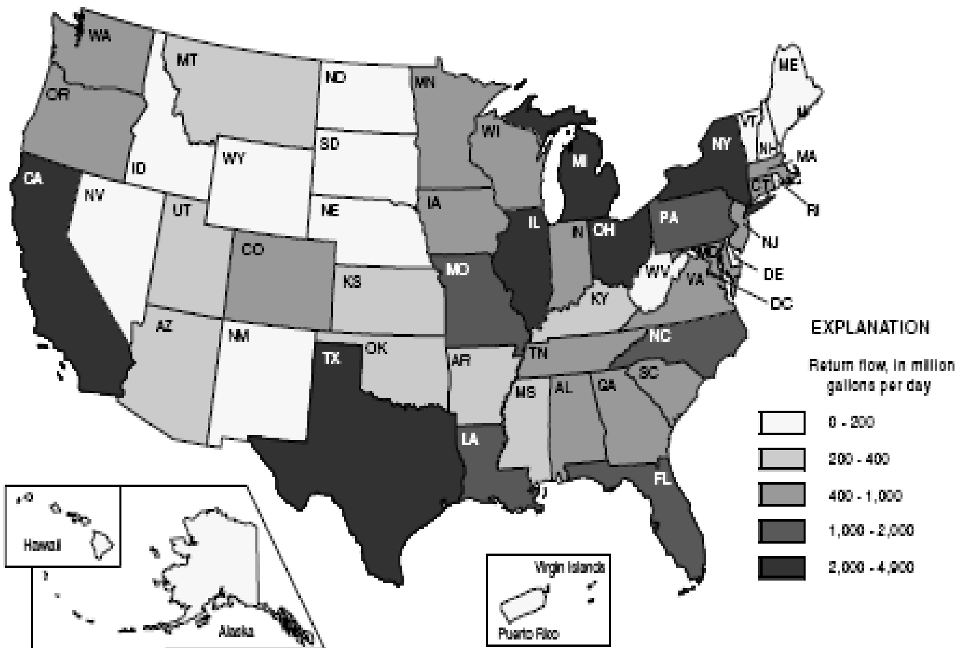

Figure 12: Wastewater treatment return flow by State, 1995 (Solley et al., 1998)

(10) Health of Ecosystem Processes

This indicator measures ecosystem processes that govern water resources and sustainability.

The integration of biological productivity in an aquatic ecosystem through a measure like fish production, can demonstrate the health of that ecosystem's different interrelated processes. If there are no fish to catch in a particular body of water, one could assume that this system is much less productive (less healthy) than a body of water that allowed fisherman to catch 10 lbs of fish per man-hour of fishing. The measurement of fish productivity in ecosystems from the measurement of fish catch is a good indicator of aquatic ecosystem health because:

- Fish populations and individuals generally remain in the same area during summer seasons.
- Communities are persistent and recover rapidly from natural disturbances.
- Comparable results can be expected from an unperturbed site at various times.
- Fish have large ranges and are less affected by natural microhabitat differences than smaller organisms. This makes fish extremely useful for assessing regional and macro-habitat differences.
- Most fish species have long life spans (2-10+ years) and can reflect both, long-term and current water resource quality.

- Fish continually inhabit the receiving water and integrate the chemical, physical, and biological histories of the waters.

Fish represent a broad spectrum of community tolerances from very sensitive to highly tolerant and respond to chemical, physical, and biological degradation in characteristic response patterns.

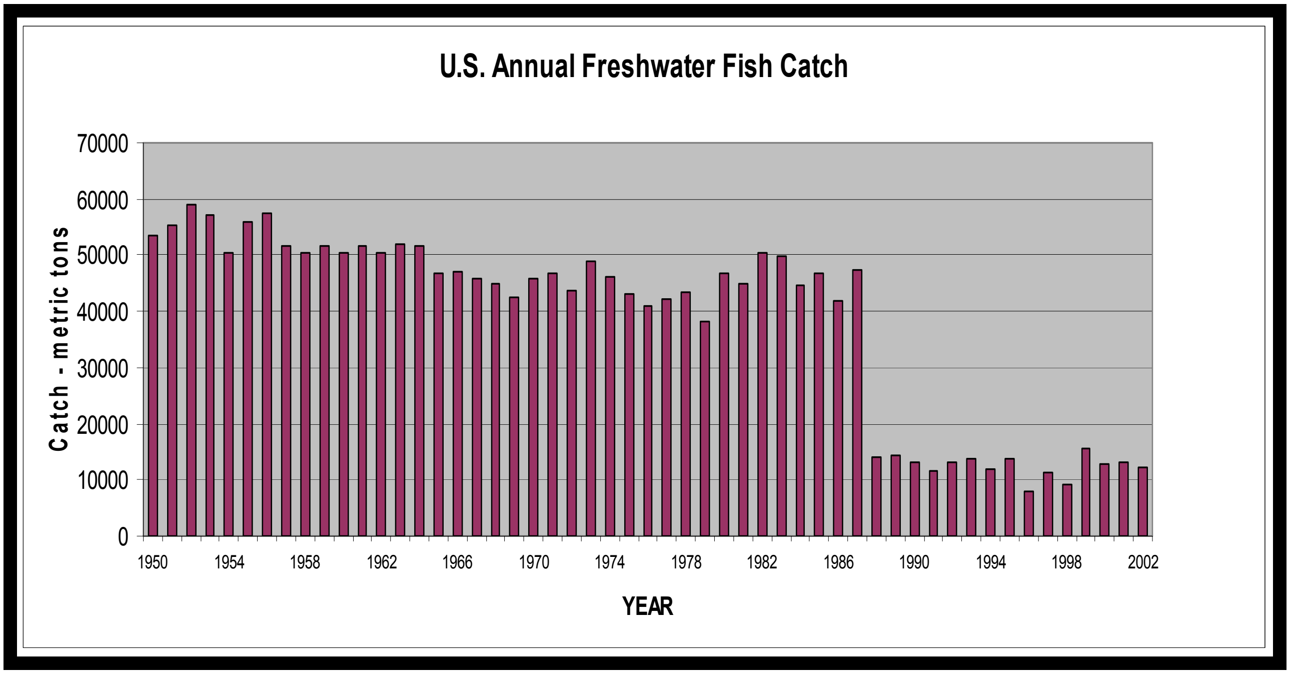

Figure 13: U.S. Annual Freshwater Fish Catch (WRI, 2004)

As shown in the U.S. annual fresh water fish catch graph illustrated above, 53 years of annual fish catch data show a major decline in catch after 1987. This decline is so sharp and large that one might conclude the data before and after 1987 might have been collected or reported in different ways. Since the data was all collected by the same organization (FAO of the UN) it could reasonable be presumed that there were no major shifts in collection or reporting method. If so, then the steep decline for fish catch after 1987 might suggest an indication of less fish production in fresh water ecosystems in the U.S. related to declining health of these ecosystems. But alternative interpretations of the data can also be made, especially because the decline in annual fish catch also somewhat mirrors the decline in fishing participation by humans as illustrated in the Resources and Conditions indicator.

CONCLUSIONS

Sustainable Water Resources Roundtable participants are committed to interdisciplinary, inter-jurisdictional, and cross-ownership collaboration that identifies and supports national, state, and field-level activities to sustain water resources. The long-term goals of SWRR include the development of principles, criteria and indicators to support decision-making and identification of opportunities for collaboration on research needs.

Several ongoing initiatives by SWRR include:

- Continue to refine investigations into water indicators, especially which indicators can best support the efforts of other organizations doing related work, such as the Heinz Center or the other Roundtables
- Recruit representatives from additional water interests, such as environmental groups, the business community, and Western water management agencies
- Continue work to establish and maintain relationships with the scientific community, to help build on the best ideas and practices in the water discipline. Encourage research into the nature of sustainability as it relates to water resources
- Plan to host a National Forum on Sustainable Water Resources to focus attention on the subject. Develop a cross-section of sponsors to ensure adequate support

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

ACKNOWLEDGEMENTS

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