DEVELOPING KEY WATER QUALITY INDICATORS FOR SUSTAINABLE WATER RESOURCES MANAGEMENT

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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 to a framework for understanding the sustainability of these changes long term for ecosystems, communities and businesses. Therefore, the objective of this paper is to provide an overview of the key water quality candidate indicators for sustainable water resources management and preliminary evaluation of their performance metrics.

This paper presents the inter-agency collaboration efforts by Sustainable Water Resources Roundtable (SWRR) (http://water.usgs.gov/wicp/acwi/swrr/), which has begun the endeavor of developing sustainable water resources indicators. Key issues include: (1) what are the important questions to ask to determine the degree to which the nation is on a sustainable course in its use and management of water resources? (2) 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 for voluminous data on 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. The work of the Roundtable is just beginning. 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 and Sustainable Water Resources Roundtable

INTRODUCTION

Sustainable Water Resources Development has been working at the international level over the past decade. The Water Section Reports at United Nations World Summit on Environment and Development (1992 and 2002) are a key foundation element. As a working text, the definition used by the Brundtland Commission (1987) is used in this paper:"*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". Agenda 21 of the 1992 Earth Summit called for the development of new ways to measure and assess progress toward sustainable development. In response, significant efforts to assess performance have been made by corporations, non-government organizations, academics, communities, nations and international organizations. 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 nation's water resources are at risk. 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. In dealing with this array of water resources problems, two things have become evident. First, that some means of tracking what is happening is needed if we are to know whether policies and other actions are leading in a desirable direction. Second, that water quality is a central topic among all the interacting elements; it is certainly a subject of great interest and activity in government and the private sector, and clearly one of the most important components of water sustainability for the nation. 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 to a framework for understanding the sustainability of these changes long term for ecosystems, communities and businesses. Therefore, the objective of this paper is to provide an overview of the key indicators for sustainable water resources management with the emphasis on water quality indicators.

METHODOLOGY

In order to find out what studies already exist about sustainability, a review was conducted for "Sustainable Water Resources Indicators" nationwide (Table 1). This paper presents the inter-agency collaboration efforts by Sustainable Water Resources Roundtable (SWRR) (http://water.usgs.gov/wicp/acwi/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.

Moffatt, Hanley & Wilson (2001) provides some guiding principles of criteria for good indicator of measuring and modeling sustainable development. In general, it is possible to begin to address the key problem of how to create measures of tracking, by looking carefully at the key questions relating to sustainable water resources development. In this study, the following three important issues were investigated: (1) Key Issues - What are the key questions to ask to determine the degree to which the nation is on a sustainable course in its use and management of water quality? How can a set of indicators be developed that is large enough to be comprehensive, but small enough to be readily understandable and practical? (2) Analytical and Statistical Tools - How can the large collections of water quality data somehow be summarized in statistical form, and further analyzed to produce water quality indicators that are accepted as legitimate tracking measures? (3) Data Gaps - Data gaps may well exist, if the available statistics are compared to conceptual models of what is really needed to understand water quality as it relates to human and ecosystem requirements.

As a good initial attempt, several measures from readily available data sources are illustrated as good candidate water quality indicators. A detailed discussion on some technical problems with water resources indicators and current challenges are also provided. An introduction to criteria and indictor framework for water resources sustainability is presented.

RESULTS AND DISCUSSION

Criteria for Indicator Selection

This review is built upon seven existing studies that include criteria and indicators for sustainability of water resources. The seven available studies for sustainable water resources indicators are listed in Table 1.

Table 1: List of Available Studies for Sustainable Water Resources Indicators

Source	Water-related indicators
Roundtable on Sustainable Forestry (http://www.sustainableforests.net/)	area, flow, biological diversity, and quality
Sustainable Rangeland Roundtable (http://sustainablerangelands.cnr.colostate.edu/)	area, flow, erosion, biota, quality, channels, groundwater change, wetlands, and riparian extent and condition
Sustainable Minerals Roundtable (http://www.unr.edu/mines/smr)	quality compliance, problem sites re: withdrawal and groundwater, use, consumption, discharge, recycling, reinjection, and evaporation
Sustainable Development in the U.S. (Interagency Working Group on SDI; http://www.sdi.gov)	quality and supply vs. withdrawal
State of the Nation's Ecosystems [Heinz Center (Washington, D.C.); http://www.heinzctr.org/ecosystems/index.htm]	area, length, chemical & physical conditions, biota, withdrawal, groundwater level, disease, and recreation
EPA's draft *State of the Environment Report* (http://www.epa.gov/indicators/)	area, length, use standards, withdrawal, ecosystems, riparian land cover, atmospheric deposition, runoff, sedimentation, toxic releases, nutrients, wetlands, coastal waters, eutrophication, drinking water quality, recreation, and seafood consumption
USGS' *Concepts for National Assessment of Water Availability and Use* (Circular 1223; http://pubs.water.usgs.gov/circ1223/)	surface and groundwater availability (flow, storage), withdrawal, consumption, losses, and water cycle (inflow, outflow, storage)

The seven studies examined for this analysis show a great variety of water indicators, although there are a few that appear repeatedly. The purposes of each study are different, and that certainly tends to tailor the indicator to the purpose. For example, the Sustainable Minerals Roundtable is very concerned with the problems associated with extractive mineral sites, and for that reason there tends to be a concentration on water quality and compliance measures at individual sites. In some of the studies water is just a part of the focus, which tends to preclude going into detail if a limited number of total indicators is an objective. Clearly, it will be much harder to grasp an overall picture if one must deal with a very large number of indicators.

Some types of indicators tend to recur. For example, some measure of water quantity, measured in flow, area, water use, or availability. The terminology may differ. Also, one will find measures of water quality in chemical and/or biological terms. Interestingly, it is much harder to find indicators of extreme hydrologic conditions, such as floods and droughts. There may be an assumption of "business as usual" underlying many of these studies.

Future selection of indicators for the Water Roundtable may thus depend on how one defines water resources sustainability. If sustainability implies some form of long-term balance among environmental, economic, and cultural elements, then water indicators must be connected not only with other parts of the environment, but also with the economy and the culture as well. Substantial research problems exist in developing just how this might be done. It is likely that working on these problems will be part of the future program of the Water Roundtable, and perhaps finally lead to water indicators of sustainability that can be used by a wide variety of organizations throughout the nation.

In brief, the following measures summarized from the professional literature could be used to see what kind of criteria is proposed for selecting good indicators.
- The data from which it is calculated should be readily available
- The indicator should be easy to understand;
- The indicator must be measurable;
- The indicator should measure something believed to be important in its own right;
- There should only be a short lag time between the state of affairs referred to and the indicator becoming available;
- The indicator should be based on information that can be used to compare different geographical areas;
- International comparability is desirable.

Some Technical Problems

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.

Prioritization: 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.

Professional Literature: Clearly, one of the cardinal sins of the researcher is to assume that no one has worked on the subject before. Thus, we should recognize at the outset that water indicators have been developed by a wide variety of organizations, perhaps not overtly linked with the notion of sustainability. How can indicators that others have developed be somehow used and improved? What are the relationships among such water indicators? Among the many that have been noted on the web site, the indicators developed by the U.S. Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS), and the Heinz Center are just some that should be considered. Many scientists have worked on these and other studies. This issue is the start of a process whereby we hope to tap the professional literature to foster the development of water sustainability indicators.

Avoiding Extreme Conditions: Extreme conditions of any type appear to be impossible in a world with both human and non-human elements. It seems unrealistic to expect that only untouched wilderness could exist everywhere; equally, we cannot see how humans could continue to exist if the natural resources needed by civilization were entirely exhausted. Unless humans can maintain themselves in some stable life support system, there will be no interest in providing for natural elements, and hence no resources to be tapped. The existence of external diseconomies shows that many natural resources have been underpriced historically, because they seemed to be inexhaustible. Western philosophies often impute low priority to non-human elements. The systems problem is to find the balance between preservation and utilization. Often the idea of carrying capacity is close to this concept.

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.

Static vs. Dynamic Systems: It was once assumed that our human/natural systems could be thought of as reaching a state of equilibrium. Models have been built around ideas like comparative statics that depict how elements exist in balance. This implies that some kind of steady state would be the norm. More recently, it appears that human systems embody a set of conditions that may seek equilibrium in a dynamic sense, but never reach it. This may be the case because the forces that impact the system are changing faster than the system can adjust, thus making it impossible to reach equilibrium.

Buffering: It is important to realize that the buffering capacity of a system has limits. This determines the amount of “wiggle room” that we have, in which we can carry out policies that provide benefits without real damage to other parts of the system. The system is not so tightly determined that no changes can be made, nor is it so flexible that infinite action will make no difference. The balance lies somewhere between. Possibly a good example of this situation is national debt, which can continue for perhaps very long periods but which ultimately lead to serious system degradation.

Deterministic vs. Stochastic Systems: Earlier ideas depicted our relationships in deterministic terms. As in the case of algebraic equations, a change in x must have an effect on y. But now it appears that our systems are more stochastic. A change in x thus will change y, but only with some probability. Multiple causes lead to multiple effects, with probabilities mediating each link in the system. Needless to say, such systems are much harder to model. The nature of the system makes it very hard to intervene in a way that is highly likely to produce only positive results. It is almost certain that the so-called law of unintended consequences is rooted in this system property, even assuming that all parts of the system are well known, which is not usually the case.

A corollary of this stochastic property involves the nature of sustainability. When we deal with such systems, all the variables exist in a probabilistic context. Each one can be represented by some mean value, but in truth has its own probability distribution function. This means that the very nature of system sustainability is probabilistic, and can only be stated in terms, for example, of minimum and maximum values. Needless to say, we are far from being able to do this now in any reasonable way.

Wild Cards and Tipping Points: Large scale patterns seem to show that long term trends may continue for long periods without much change, even though the results may be harmful to the system that represents civilization. The structure becomes increasingly unstable. If a wild card event occurs with some probability, this can cause rapid unexpected change in the system, in the same way that a input step function might. This kind of tipping point is hard to anticipate or prepare for. It might well be forecast, but prevailing forces tend to discount it as an unlikely event compared to daily occurrences. An example of this behavior might be the recurrent tendency to build in flood plains, in which the demonstrated benefits of the location are thought to outweigh the small chance that a flood will occur.

Here it may be useful to connect these ideas with the concept of duration discussed above. The time frame of an individual is greatly different than that of the system (i.e., civilization) within which he exists. Rational decisions on an individual basis may, especially in the aggregate, lead to the gradual degradation of the system as a whole. Depending on the factors noted in the preceding paragraph, various outcomes can occur. Gradual and irreversible negative changes in the whole system may occur; such changes may in fact be reversible, but only at a cost considered exorbitant by those then living. Alternatively, the negative changes that originally happened gradually may be stopped or reversed, but only by measures that must be carried out in a short time. This would be like sending a step function through the system, which is usually a destabilizing action. All these effects lead to outcomes for the whole system, which can well make it unsustainable. History offers some interesting examples that look very much like exactly this process. In parts of the Middle East, we can detect from satellite the remains of irrigation canals that were constructed by successive civilizations, which occupied the same region. There are repeated cycles of canal building, followed by increasing soil salination, followed later by the collapse of the central government. We cannot push this example too far, since there are clearly many other things besides water that can contribute to this kind of change. But it certainly would appear that a progressive inability to maintain an agricultural food supply, in an arid region, would not promote the stability of the government then in existence.

Conceptual Framework

In dealing with this array of water resources problems, two things have become evident. First, that some means of tracking what is happening is needed if we are to know whether policies and other actions are leading in a desirable direction. Second, that water quality is a central topic among all the interacting elements; it is certainly a subject of great interest and activity in government and the private sector, and clearly one of the most important components of water sustainability for the nation.

A Conceptual Model Working Group composed of Water Roundtable participants has been cooperating to develop a rational approach for coping with how one can address the water sustainability problem. Taking into account the knowledge gained during the Status Review, the group continues to grapple with the problem of how to develop an operational set of water sustainability indicators. Details of the model may be found in Heintz (2004), Kranz et al. (2004) and Smith (2004). Figure 1 serves to illustrate some of the basic concepts contained in the model.

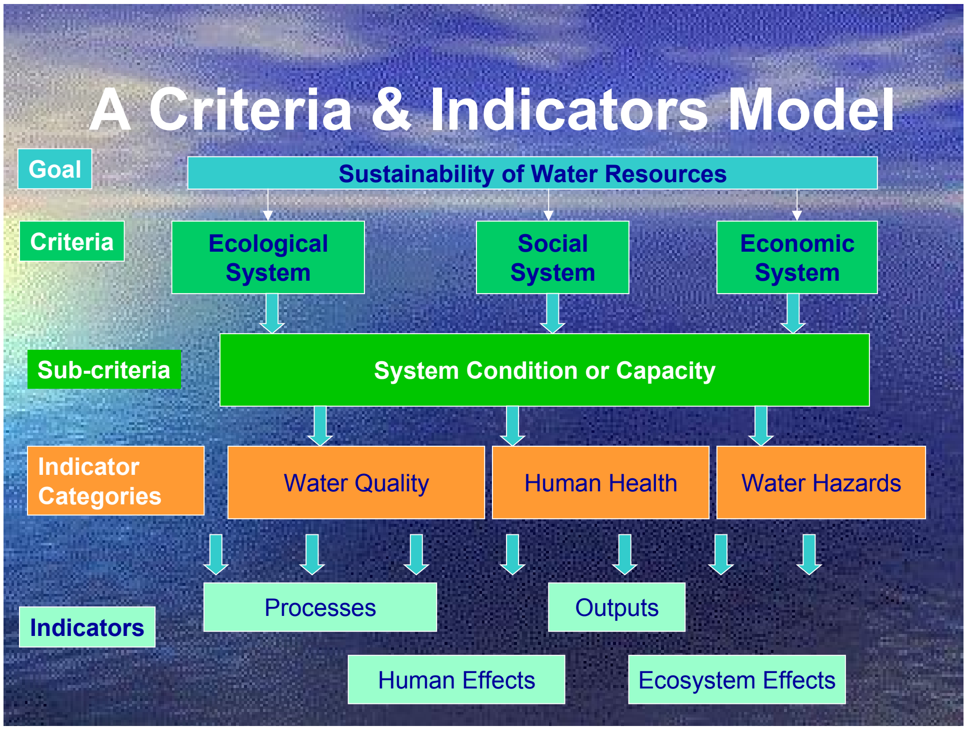

Figure 1: A Criteria and Indicators Model for Sustainable Water Resources Framework (Heintz, 2004; Kranz et al., 2004; and Smith, 2004)

This approach weaves together the ecological, social, and economic systems, and in a number of different categories is aimed toward developing indicators that support the idea of sustainability. In its present form, the model may be populated with specific indicators according to the following outline in Table 2.

Note, for example, that water quality occurs in more than one place in the outline. Furthermore, concepts like biological conditions and water-based recreation, which are often thought of in close association with water quality, exist elsewhere in the outline. This means that there has been a careful effort to sort out the best locations for a whole variety of concepts, and to organize them in what is hoped to be an improved framework.

However, it’s difficult to comprehend indicators without some specific numerical examples. For that reason we include here some examples of readily available statistics, without necessarily claiming that they are yet appropriate as indicators. Following our focus on water quality, these are examples of water quality statistics. We can see in the paragraph on each that there are pros and cons in selecting any of these statistics to be called water quality indicators:

Table 2: Suggested Water Criteria and Indicators

Criterion I. *Ecological System*
A. Sub-Criterion: *Capacity to make water of appropriate quality and quantity available to support ecosystems*. • **Indicator Category 1:** *Water-quality indicators.* • **Indicator Category 2:** *Water-quantity indicators.* • **Indicator Category 3:** *Human-infrastructure indicators.* **B. Sub-Criterion**: *Integrity of ecosystems.* • **Indicator Category 1:** *Water-quality indicators.* • **Indicator Category 2:** *Water-quantity indicators.* • **Indicator Category 3:** *Water-use indicators.* • **Indicator Category 4:** *Biological indicators.* • **Indicator Category 5:** *Landscape indicators.*
Criterion II. ***Social System***
A. Sub-Criterion: *Social well-being resulting from the use of water resources.* • **Indicator Category 1:** *Human-health indicators.* • **Indicator Category 2:** *Water-use indicators.* • **Indicator Category 3:** *Recreational indicators.* • **Indicator Category 4:** *Human-infrastructure indicators.* **B. Sub-Criterion**: *Social well-being resulting from the use of water-related ecological resources.* • **Indicator Category 1:** *Native-American cultural indicators.* • **Indicator Category 2:** *Recreational indicators.* **C. Sub-Criterion**: *Legal, institutional, community, and technical capacities for the management of water and related land resources for sustainability.* • **Indicator Category 1:** *Legal indicators.* • **Indicator Category 2:** *Institutional indicators.* • **Indicator Category 3:** *Human-infrastructure indicators.*
Criterion III. ***Economic System***
A. Sub-Criterion: *Capacity to make water of appropriate quality and quantity available for human uses*. • **Indicator Category 1:** *Water-use indicators.* • **Indicator Category 2:** *Human-infrastructure indicators.* • **Indicator Category 3:** *Water-conservation indicators.* **B. Sub-Criterion**: *Economic well-being resulting from use of water and related land resources.* • **Indicator Category 1:** *Economic-value indicators.* • **Indicator Category 2:** *Recreational indicators.* • **Indicator Category 3:** *Water-hazard indicators.* **C. Sub-Criterion***: Economic well-being resulting from the use of water-related ecological resources*. • **No subcategories**

Existing Statistics and Data Gaps

The Sustainable Water Resources Roundtable (SWRR) faces many challenges, among them problems concerning how to populate indicators that may be developed. This paper is a work in progress that attempts to address three related aspects of these problems.

First, what existing statistics may be available that could be used to develop indicators. The statistics shown in the following tables and figures are certainly not exhaustive, and are generally from secondary sources. For example, USGS data has been used in statistics reported by more than one of these sources. However, the sources were selected because data from a number of different origins are readily available in a single place, and also because the data have been organized into formats that are generally recognized as descriptive statistics. That is, statistical information is presented as a time series or by some geographical area, in a way that lends itself to national synthesis.

The categories in the Table 2 are those currently being used by SWRR. Attempts have been made to find statistics and organize them under each of these categories, sometimes with duplication from different sources. There are a number of categories for which no existing statistics have so far been found. If in the future some sources for these statistics are located, they can be added to the tables. The web links for each source are noted in the References.

The second problem concerns data gaps, and follows directly from the absence of some statistical information. In this case the work of the Heinz Center is very important, and has been used as a case study. This project has been conducted over a period of years, and has made use of many experts to assist in the conclusions as now reported. Here we examine the results for fresh water resources, and see what the availability of statistics is for developing indicators. It can be seen that there are many data gaps still to be addressed for the categories used by the Heinz Center project. Evidently, the lack of statistics for many SWRR categories is not solely due to the author's inability to find them in the literature.

The third problem is to determine what effort would be required to close the data gaps and to develop acceptable indicators from statistics. For this the case study chosen is the USGS report to Congress on national assessment of water availability and use (USGS, 2002). Again there were many experts involved in the report, so that we at least know that credible scientific expertise was involved. It is noteworthy that the categories studied by the USGS were, in part, some of the ones for which statistics are already available. The conclusion is that there is much more to developing indicators than just available statistics. Clearly the data must be available, but beyond that the USGS report says that the effort to develop acceptable indicators is measured in years.

<u>Candidate Water Quality Indicators</u>

Table 3 tabulates sources of specific water resources statistics, using the nomenclature of the source. The sources so far used are the Statistical Abstract of the United States (Stat. Abs.), the Council on Environmental Quality (CEQ), the EPA Index of Watershed Indicators, and the Heinz Center. Each table is noted according to its source, and all are given in the References by web link. A number of the SWRR categories are still blank, because so far no statistics have been found for them.

Table 3: A List of Candidate Water Quality Indicator using Existing Water Resources Statistics

Candidate Water Quality Indicator	Data Source
No. 369. U.S. Water Quality Conditions by Type of Waterbody: 2000	Stat. Abs.
No. 370. Oil Spills in U.S. Water—Number and Volume: 1997 to 2000	Stat. Abs.
No. 378. Toxic Chemical Releases and Transfers by Media: 1988 to 2001	Stat. Abs.
No. 379. Toxic Chemical Releases by Industry: 2001	Stat. Abs.
No. 380. Toxic Chemical Releases by State: 1988 to 2001	Stat. Abs.
No. 389. National Ambient Water Quality in Rivers and Streams Violation Rate: 1980 to 1995.	Stat. Abs.
Table 6.4 Designated-use Support in Surface Waters of the United States, 1996	CEQ
Table 6.6 Ambient Water Quality in U.S. Rivers and Streams: Violation Rates, 1975-1997	CEQ
Table 6.8 Oil Polluting Incidents Reported In and Around U.S. Waters, 1970-1998	CEQ
Percent of Assessed Rivers, Lakes, and Estuaries Meeting All Designated Uses (1994, 1996, & 1998) - Latest State Information Reported	EPA
Contaminated Sediments (1980 - 1993)	EPA
Ambient Water Quality Data - Four Toxic Pollutants (1990-1998)	EPA
Ambient Water Quality Data - Four Conventional Pollutants (1990-1998)	EPA
Toxic Loads Over Permitted Limits (1999)	EPA
Conventional Loads Over Permitted Limits (1999)	EPA
Estuarine Pollution Susceptibility Index (1989 - 1991)	EPA
Atmospheric Deposition Estimates for Total Nitrogen (1996)	EPA

It is worth of noting that the example statistics in Table 3 are not necessarily all different. For example, one may find some of the same water quality statistics published by the Statistical Abstract and by CEQ.

Figure 2 to 7 illustrates sample statistics (including time series) for candidate indicators. In particular, Figure 2 shows the ambient water quality assessment by a few selected key pollutants and Figure 3 illustrates of water quality assessment by waterbody type. However, as pointed out by EPA's Draft Report on the Environment (USEPA, 2003), at this time, there is not sufficient information to provide a national answer to the question "*What is the condition of waters and watersheds in the U.S.*" with confidence and scientific credibility.

A great deal is currently known, however, about the condition of regional, state, and local waters due to the tremendous monitoring efforts of state and local authorities and watershed groups and citizens. Yet a number of factors limit what the data from Section 305(b) National Water Quality Inventory can say about condition at the national level. Most states, territories, and tribes collect data and information on only a portion of their waterbodies. Also, their programs, sampling techniques, and standards differ. Many have targeted their monitoring programs to known problem areas. Although the use of targeted sampling informs local decision-making, it does not present a comprehensive understanding of the condition of water resources at a very large scale. Furthermore, the standards of each state accommodate both the state's policies and the important physical and ecological differences that can exist between waters.

In summary, given existing data and differing monitoring approaches, a comprehensive nationwide assessment of watershed condition has not been achieved. More comprehensive and consistent monitoring is needed, particularly when the changing face of the landscape is considered. Building dams and channels, withdrawing water for irrigation, and expanding development are changing the shape and flow of streams, but there are insufficient data on the effects of those activities on aquatic habitats (USEPA, 2003).

Regarding to water quantity and availability, the USGS study on water withdrawals and uses in the U.S. provides a good supplementary measure relating to water quality issues (Figure 4). Water availability, especially in Western Region, has become one of the key limiting factors for water quality improvement, such as those highlighted in "*Water 2025 Initiative*". The number of wastewater treatment facilities is a good measure of water infrastructure (Figure 5).

The oil spills in the U.S. water (Figure 6) might serve as candidate indicator from perspective of the negative impact of accidents on water quality. It may be difficult to find good ecological indicator that can directly link to water quality. Figure 7 lists the number of endangered species in 2001 to address water quality indicator from ecological system perspective.

Ambient Water Quality (Figure 2): This trend line shows only three water constituents for which data are available. There may be tens or hundreds of constituents that are important for some reason. The problem is which ones to pick and why. Too few will not adequately describe the problem, and too many are unmanageable.

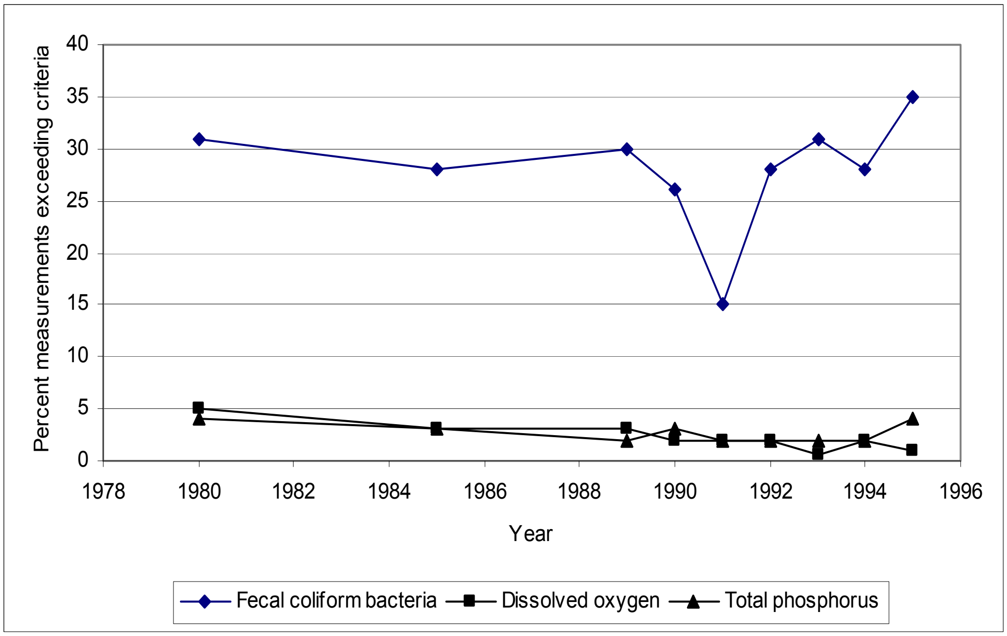

Figure 2: Sample Statistics for Candidate Indicator - Ambient Stream Water Quality

Water Quality by Waterbody Type (Figure 3): Another way to look at water quality is by problem area. For example, this graph might imply that in 1998 the Great Lakes shoreline has problems, but that the ocean shoreline is in relatively better condition.

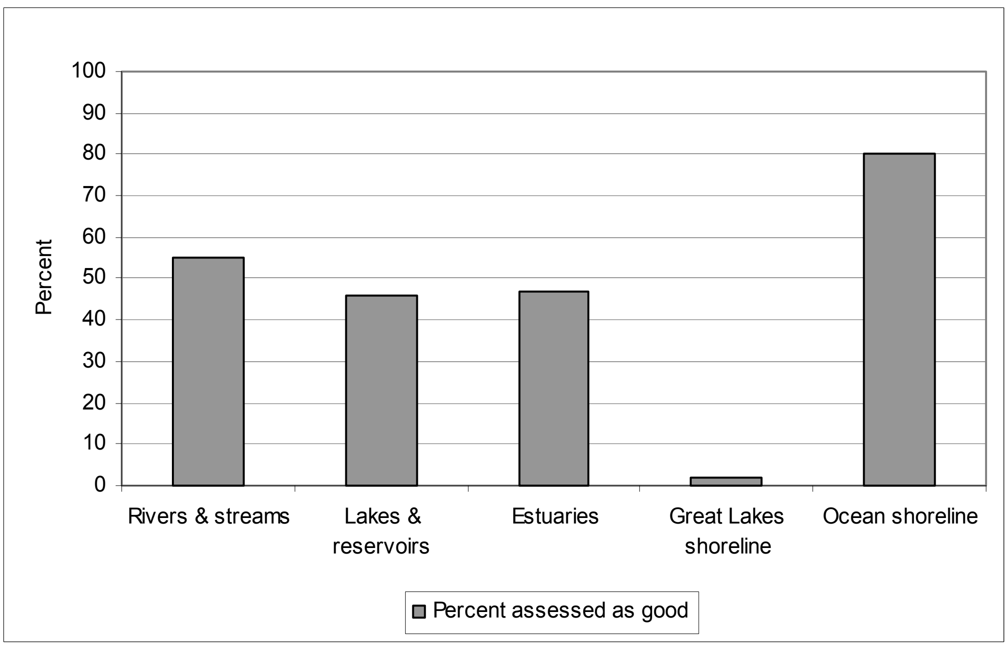

Figure 3: Sample Statistics for Candidate Indicator - Percent of Assessed Waterbody as Good Water Quality

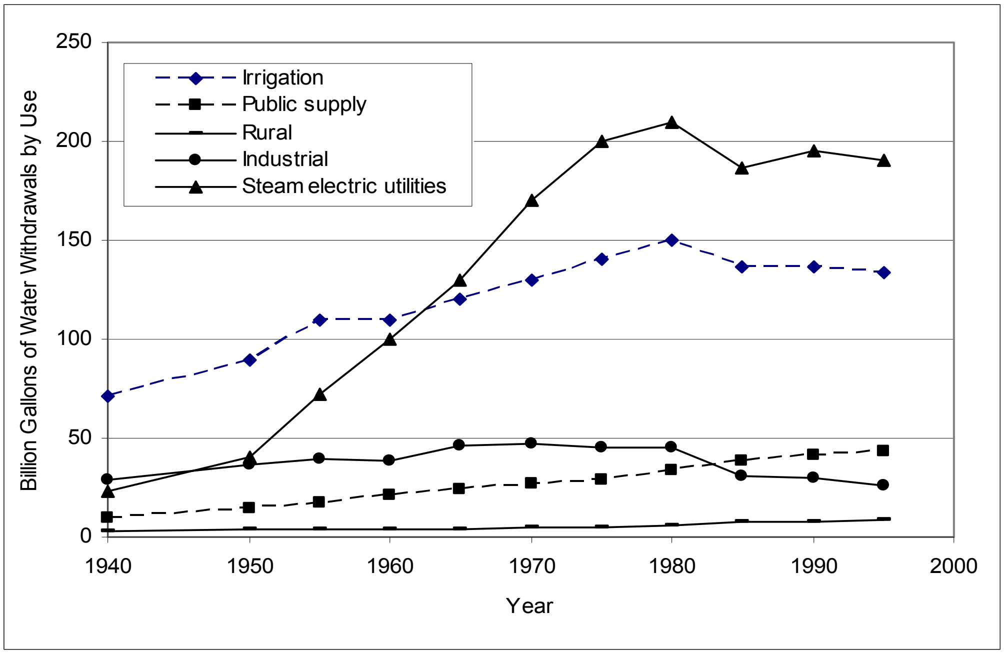

Figure 4: Sample Statistics for Candidate Indicator - Water Withdrawals by Use

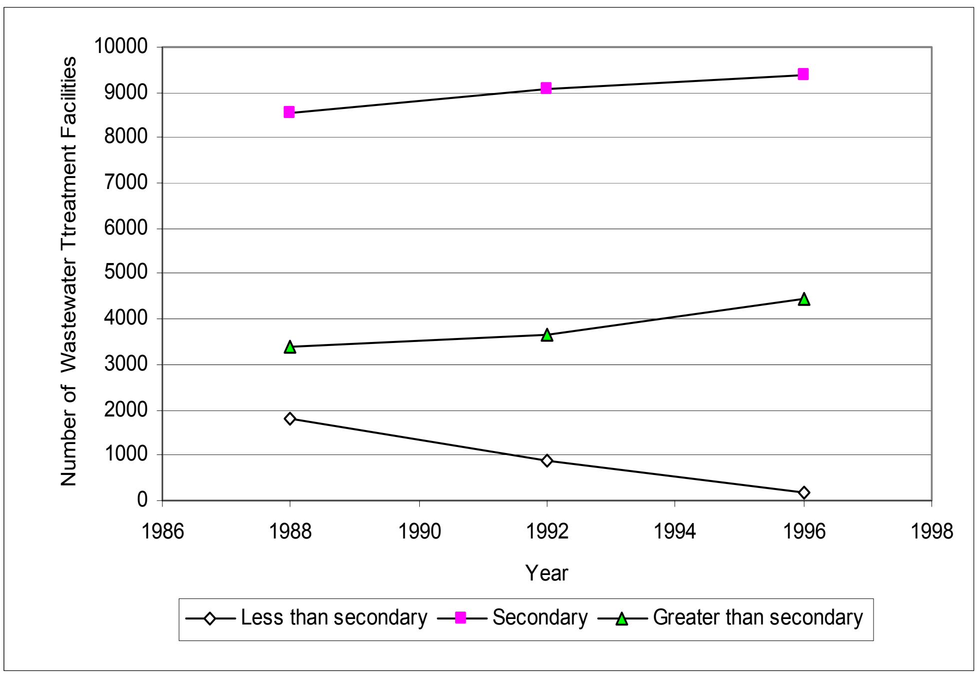

Figure 5: Sample Statistics for Candidate Indicator - Number of Wastewater Treatment Facilities

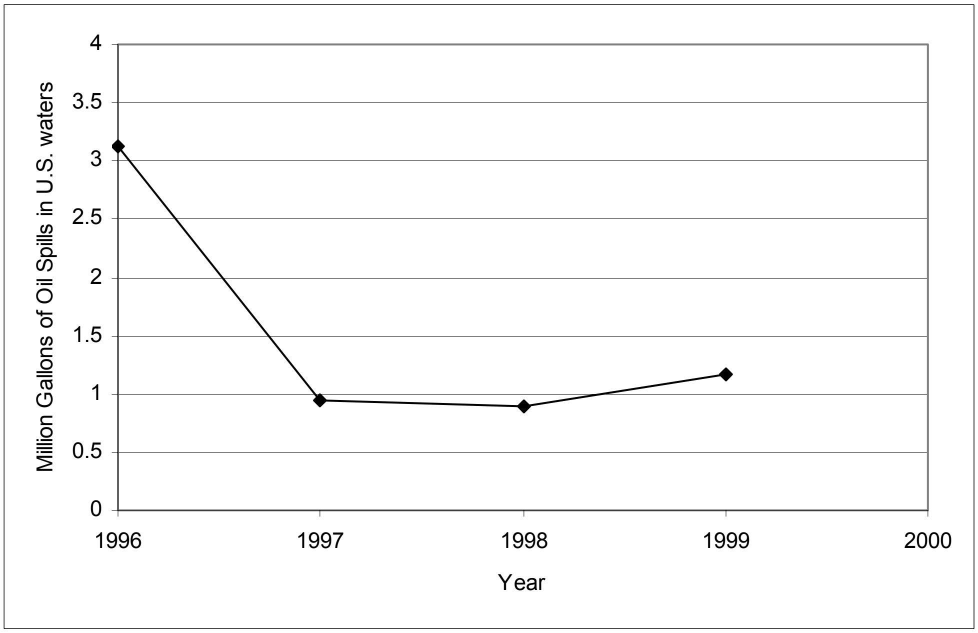

Figure 6: Sample Statistics for Candidate Indicator - Oil Spills in U.S. Waters

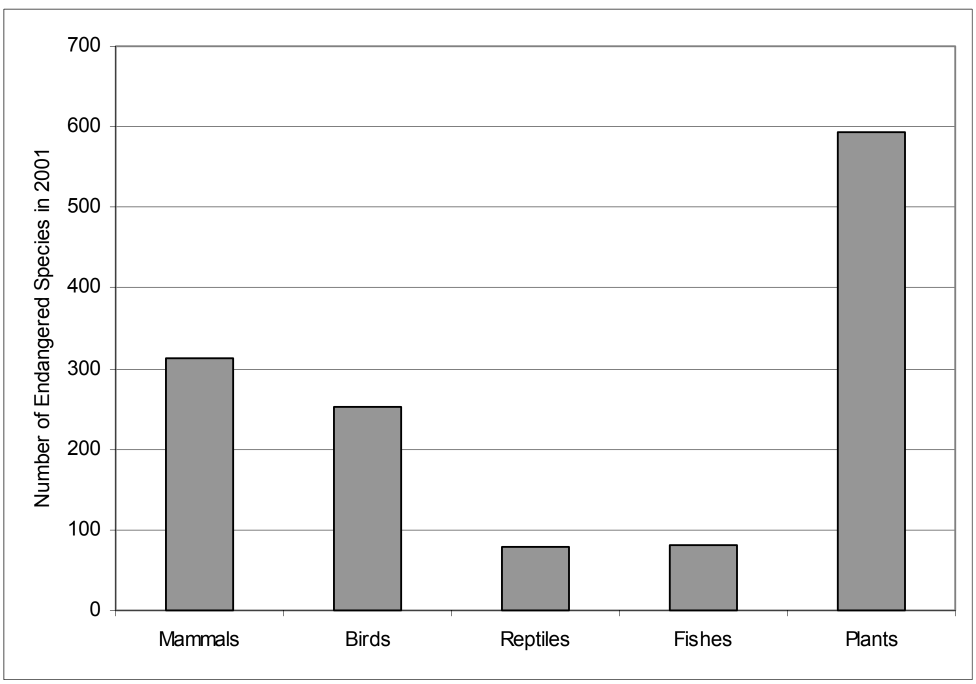

Figure 7: Sample Statistics for Candidate Indicator - Number of Endangered Species

The Path Forward

Work will continue on development of the conceptual model and the associated outline that leads all the way to lists of potential water indicators. As in the case of other studies, we are coming to a fork in the road that will allocate efforts depending on the nature of available statistics. The model contains many worthy ideas for water indicators, but only some of them are supported by current data collection and statistics programs. When the list of possible indicators is flagged according to whether or not there are existing data collection programs to provide the needed data, two different kinds of initiatives are immediately suggested. For those indicators for which data collection programs currently exist, we can proceed to consider potential water indicators, and where best to obtain the statistics that will support them.

Apart from the large number of on-line data programs, there are some existing collections of available statistics that may provide ready sources of water indicator data. For reference, the web site of the Water Roundtable continues to add links to its Conditions and Trends page to help locate data sources, most of which are maintained by some Federal agency. The *Statistical Abstract of the United States*, used earlier in this article, has about twelve data series about water in its 2003 Section 6, Geography and Environment. The Council on Environmental Quality has in the past published water statistical tables in its annual report *Environmental Quality*. These statistics are still available on-line, although the report has ceased publication. One of the most ambitious of the statistical programs is the EPA Index of Watershed Indicators. The national map of "*Index of Watershed Indicators*" developed by EPA in 1999 is shown in Figure 8.

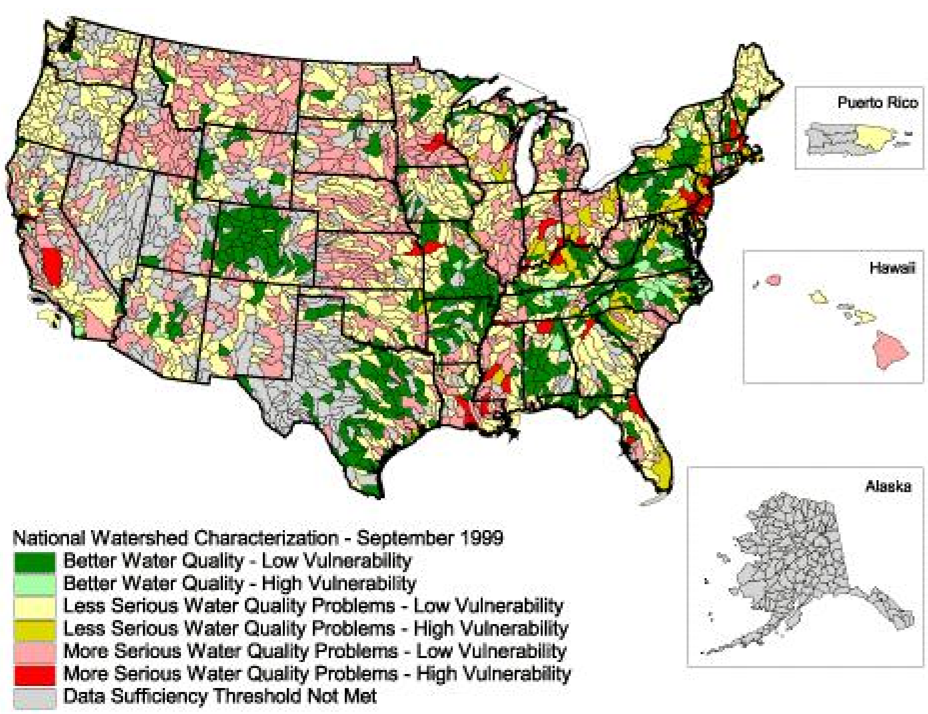

Figure 8: EPA Index of Watershed Indicators

The EPA map is based on statistics from about 22 data series. The map shows a good way to display geographical variation, and also illustrates the second problem posed by the other fork in the road. The fact that there are some areas with insufficient data means that this problem will continue and in fact increase as we attempt to construct better water indicators. If we determine that some of the water indicators are indeed essential to assessing national water sustainability, this implies a serious attempt to close the data gaps and find support for new data collection programs. Given the problems of maintaining even the current data collection programs that the agencies face, this would be a major endeavor. This may be some of the most important work to be done in the water resources field. In the absence of reliable indicators of present conditions, it is hard to see how to tell what effects any proposed policies might have.

A Mosaic of Institutions: Faced with this daunting set of problems, it is perhaps no wonder that some generally accepted set of water sustainability indicators has not yet appeared. The job now seems to be to organize the effort, recognizing that there is ample work to go around. In this spirit this paper contains thoughts about various aspects of water indicators. But this is just the beginning. Table 4 illustrates the first attempt to develop a set of tasks that should be pursued, and what organizations should address these tasks. Some choices are noted in the cells of the matrix, but the reader is invited to think carefully about all aspects of the matrix. There are quite likely many ways in which it can be improved, and we are looking for just those ideas.

Table 4: Suggested Groups for Each Task Needed to Establish Sustainable Water Indicators

	Federal, state, and local governments	Business community	Professional associations	Public interest groups	Academia	Congress and state legislatures
Data collection	X					X
Archiving	X					
Develop statistics	X					
Decide on indicators	X	X	X	X	X	
Report and outreach	X		X		X	
Develop policy	X					X

While considering this set of ideas, it is well to remember that in our experience no single organization that works on an issue like this can maintain its focus for more than perhaps five years. Organizations also evolve and change over time, there are reorganizations and budget problems, and partners which may influence the organization change or disappear. Clearly our organizations, which are the primary tools for our efforts, also must be assumed to be subject to change. For this reason we suggest the notion of a diversified portfolio of organizations, with several in each category working at once. This perhaps offers a way in which the iron hand of time may be diverted from simultaneously degrading all parts of the effort. There is of course no guarantee, but at least the luck of the draw is better.

The work of the Roundtable is just beginning. It will strive to utilize the significant undertakings of many organizations that have parallel goals, and hope to add value to their efforts through a process of synthesis to the larger world of sustainable water resources. The long-term goals of SWRR include the development of principles, criteria and indicators of sustainable water resources 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.

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 work of the Roundtable is just beginning. It will strive to utilize the significant undertakings of many organizations that have parallel goals, and hope to add value to their efforts through a process of synthesis and relating water quality to the larger world of sustainable 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. Collaboration is under way in development of a 2005 Report on “the Sustainability of Water Resources and Uses in the United States”. 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.

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

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

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: 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, US 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/