HOW DO WE KNOW IT'S SUSTAINABLE?

Measuring water sustainability effectively is challenging

Ethan T. Smith and Harry X. Zhang

U.S. water resources are at risk. The nation needs a framework for tracking and understanding changes to the health of its waterbodies that takes into account environmental, economical, and cultural interrelationships. Unfortunately, most organizations are designed to focus solely on physical, chemical, engineering, and other traditional water concerns. Although our institutions have served us well in the past, a new approach is needed to ensure water sustainability.

Sustainability Questions

In 1987, the Brundtland Commission (the World Commission on Environment and Development) presented a special report to the United Nations, *Our Common Future*, in which it defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." To begin examining water sustainability, we need to answer the following questions:

- How sustainable is current U.S. use and management of water resources? What sustainability issues must be addressed?
- How should sustainability be measured and monitored? Which indicators would be most useful, and for what purposes?
- What information is needed to develop water sustainability indicators? How can this be done?
- What sources of data or statistics should be considered for water sustainability indicators?
- If we need new data for these indicators, which organizations should collect it and why? What data collection gaps should be filled?

Sustainable solutions to water resource problems can be found if people thoroughly understand the issues and how each aspect of society contributes to them.

Some Technical Problems

When considering these questions, some technical problems immediately arise.

Number. Because water is ubiquitous, we can easily make a long list of possible indicators, all of which seem necessary. But how many do we really need? Choose too many, and the sustainability problem becomes impossible to comprehend. Choose too few, and our picture of water resources will be too sketchy to be useful. We need to find an appropriate balance.

Scale. In systems analysis, the sum of a set of optimal results may not provide an optimal result for the whole. Likewise, indicators that ensure sustainability at a national scale may not be effective at regional or local scales. To avoid the "tragedy of the commons," we need to find indicators that are appropriate at various scales. So far, some water indicators seem scalable (much like employment numbers can indicate local, regional, and national economic health), while others seem to be closely tied to local public policy issues or physical conditions (humid East vs. arid West) and may not have meaning at a national scale.

Duration. Sustainability clearly has to do with time, but

What Is the Sustainable Water Resources Roundtable?

The Sustainable Water Resources Roundtable (SWRR; Reston, Va.; water.usgs.gov/wicp/acwi/swrr/) is part of the Advisory Committee on Water Information, which was established under OMB Memorandum 92-01 [Dec. 10, 1991, Office of Management and Budget] to enable water-information users and professionals to advise the federal government on the effectiveness of its water-information programs.

SWRR was created to

- serve as a national forum for sharing information and promoting responsibility and research on sustaining U.S. water and related land resources;
- identify and describe criteria, indicators, and methods that characterize the sustainability of U.S. water resources;
- share information about data availability and quality, data gaps, and how best to acquire desired information;
- share perspectives about trends affecting U.S. water and related land resources that have policy or other coordination implications; and
- consult regularly with other sustainable development groups about common considerations and programs.

SWRR is governed by a Steering Committee with representatives from several federal agencies, states, and non-governmental organizations. The Water Environment Federation (Alexandria, Va.) serves on the Steering Committee and provides an administrative "home" for SWRR.

how long must a system function effectively in order to be considered sustainable? Whole civilizations rise and fall in a matter of centuries or millennia, depending on how long their governments and other institutions can effectively manage water and other resources. Is this an appropriate time-scale, or should we measure sustainability in years or decades?

Keep in mind that decisions that make sense in the short term (a typical human's lifetime) may be problematic in the long term (a typical civilization's lifetime). Consider, for example, satellite images of the Middle East showing the remains of irrigation canals constructed by successive civilizations in the region. The area's history notes repeated cycles of canal building, followed by increasing soil salination, followed by the collapse of the central government. Although this example is simplistic, it certainly seems that a progressive inability to maintain a food supply in an arid region does not promote political stability.

Prioritization. Must we consider all water indicators simultaneously, or can we prioritize them? If so, on what basis do we prioritize them? In prioritizing indicators, we will be indirectly prioritizing the issues associated with them, and so far our nation has not developed an effective method for doing so.

Indeed, public policy issues sometimes seem to have lives of their own — birthed by a book (like *Silent Spring*) or a charismatic politician, growing in importance to a crowning achievement, and then declining, to be replaced by another issue. Interestingly, like phoenixes, some

Table 1. Promising Indicators Used by Others

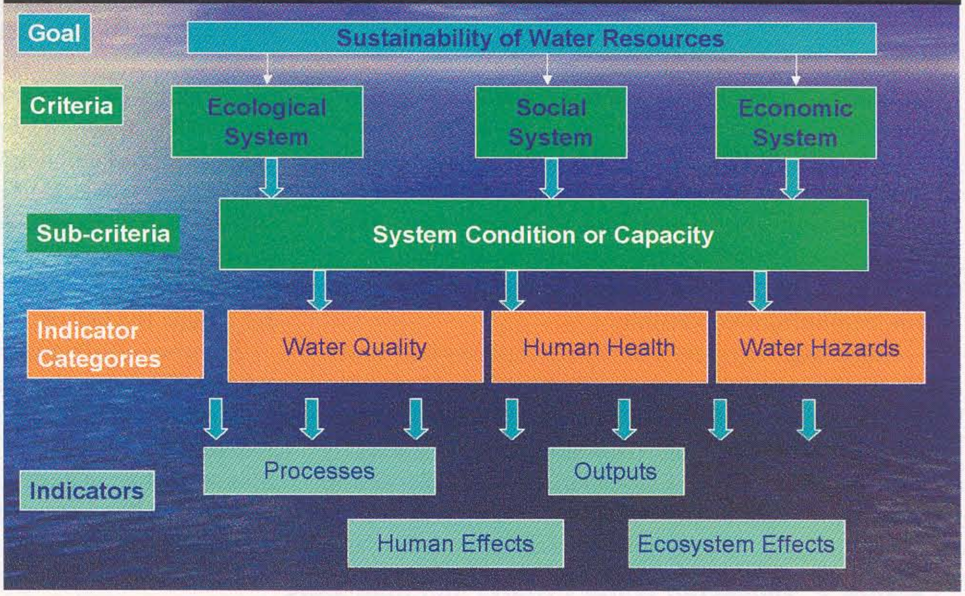
Source	Water-related indicators
Roundtable on Sustainable Forestry (http://www.sustainableforests.net/)	area, flow, biological diversity, and quality
Sustainable Rangeland Roundtable (http://sustainablerangelands.cnr.colostate.edu/)	area, flow, erosion, biota, quality, channels, groundwater change, wetlands, 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)

issues mysteriously rise again in some evolutionary fashion. If we were to prioritize indicators based on current public policy issues, indicators for nonpoint source pollution, endocrine disruptors, and pharmaceuticals might take precedence over those for point source pollution and dissolved oxygen.

Prioritizing based on current issues can make data collection problematic. Maintaining adequate data collection programs (which are expensive) will be difficult as water quality professionals attempt to determine which issues will gain or lose importance and which related statistics will be needed.

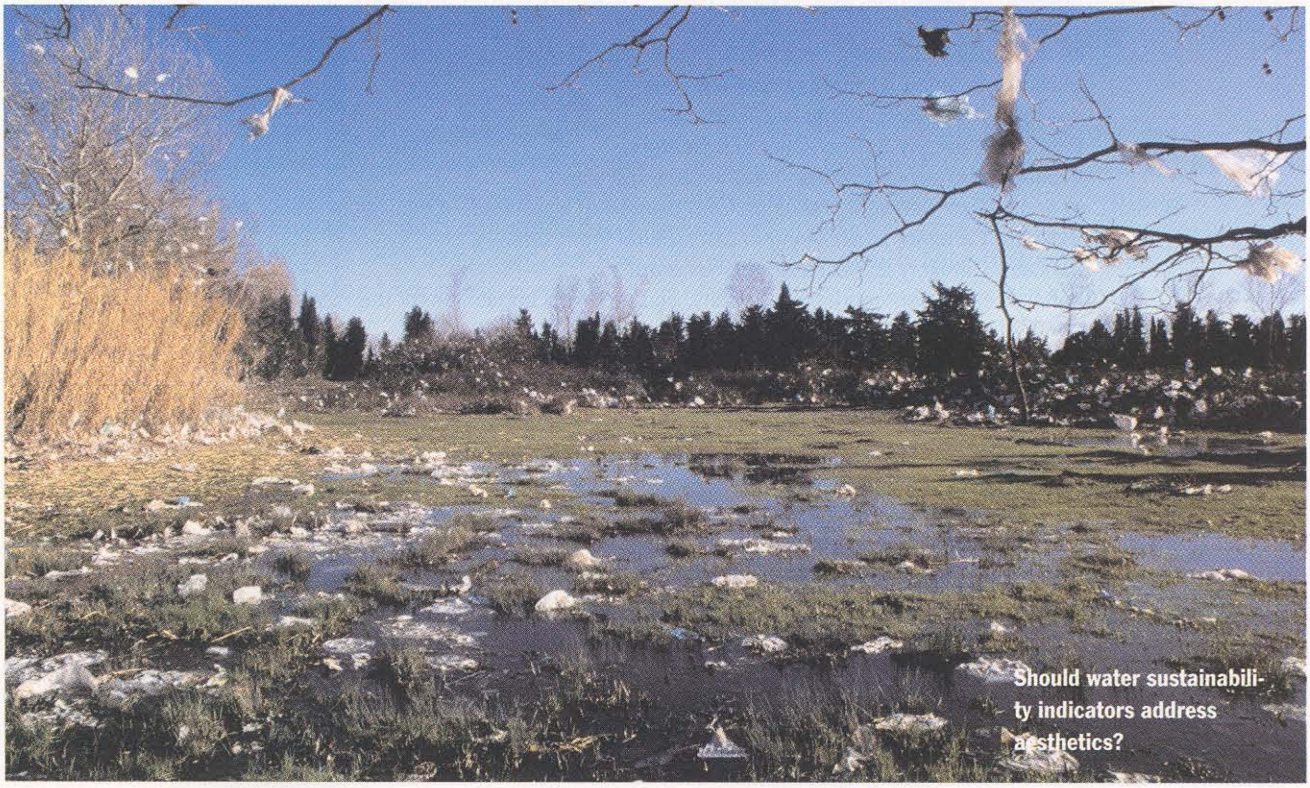
Professional literature. One of the cardinal sins of researchers is assuming that they are the first to study a subject. We recognize that many organizations, including the U.S. Environmental Protection Agency, the U.S. Geological Survey, and the Heinz Center (Washington, D.C.), have developed water indicators that may or may not be overtly linked with sustainability. What are the relationships among these indicators? How can we use and improve them?

Figure 1. A Criteria and Indicators Model



Extreme conditions. Extreme conditions seem to be impossible in a world with both human and non-human elements. It seems unrealistic to expect untouched wilderness everywhere, but humans cannot thrive if natural resources are exhausted. Humans, therefore, need to maintain a stable life-support system that balances preservation and use of natural resources.

Rate of change. When studying a system, we need to determine how quickly it can change. Systems typically are sensitive to change, and too much change too quickly often



Should water sustainability indicators address aesthetics?

makes them undesirably unstable. Sustainability implies gradual, progressive change that allows the system time to adjust.

Static versus dynamic systems. Scientists once assumed that systems could reach a state of equilibrium (implying that steady-state is the norm) and built models around ideas like comparative statics, which depict how elements exist in balance. Now, it seems that systems may dynamically seek equilibrium but never reach it — possibly because the forces affecting a system change faster than the system can adjust, making true equilibrium impossible.

Buffering. A system's buffering capacity has limits, which determine the amount of "wiggle room" we have to benefit parts of the system without damaging other parts. No system is so tight that any change is inherently damaging or so flexible that infinite actions will make no difference. The balance lies somewhere between. Consider, for example, the national debt, which may be able to continue for a long time but ultimately leads to serious system degradation.

Deterministic versus stochastic systems. Earlier ideas depicted our relationships in deterministic terms, so a change in X *must* affect Y. But now it seems that systems are more stochastic, so a change in X *may* affect Y. Multiple causes lead to multiple effects, with probabilities mediating each link in the system. These systems are harder to model — even if all parts of the system are well known — and difficult to change solely for the better (think: the law of unintended consequences).

So, when dealing with stochastic systems, the very nature of system sustainability is probabilistic, and can only be stated in terms, for example, of minimum and maximum values. At present, we are far from being able to do this in any reasonable way.

Wild cards and tipping points. Large-scale patterns

Figure 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

Table 2. Suggested Groups for Each Task Needed to Establish Sustainable Water Indicators 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
Evaluate performance	X	X	X	X	X	
Determine improvements	X	X			X	X

seem to show that long-term trends persist (think: inertia), even though the results may harm civilization and make the system increasingly unstable. "Wild card" or "tipping point" events, on the other hand, create rapid, unexpected change. Such events are hard to anticipate, even if forecast, because prevailing forces tend to discount them as unlikely. Consider, for example, people's recurrent tendency to build in flood plains because the location's demonstrated benefits are thought to outweigh the small chance of flooding.

SWRR Work to Date

According to *Measuring and Modelling Sustainable Development* by Ian Moffatt, Nick Hanley, and Mike D. Wilson, good indicators should be measurable, easy to understand, and monitor something believed to be important in its own right. They also should be rapidly available, based on readily available data, and comparable among various geographical areas, including those in other countries.

With this information in mind, the Sustainable Water Resources Rountable (SWRR; see sidebar, p. 38) began by reviewing seven existing studies of criteria and indicators to draft a list of potentially useful water quality indicators (see Table 1, p. 38, and water.usgs.gov/wicp/acwi/swrr/ on the Web). Roundtable members found that a wide variety of water indicators were being used, and few recurred or dealt with extreme hydrologic conditions, such as floods and droughts.

They also found that the choice of indicators depends on how one defines water resources sustainability. If sustainability implies some form of long-term balance among the environment, economics, and culture, then good water indicators must relate to all three and be usable by a wide variety of organizations.

SWRR then established a Conceptual Model Working Group to formulate a rational approach for developing a functional set of water sustainability indicators. So far, the working group has created a draft model that weaves together ecological, social, and economic systems, and is trying to organize potential sustainability indicators, such as water quality, biological conditions, and water-based recreation, into several logical categories (see Figure 1, p. 39; Figure 2, p. 40; and Issue 127, Feb. 2004, of *Water Resources Update*, published by the Universities' Council on Water Resources).

At press time, the model contained many worthy ideas for water indicators, but only some were supported by current data collection and statistics programs. So now the group will be challenged to determine where best to obtain the statistics that will support each indicator (see water.usgs.gov/wicp/acwi/swrr/ on the Web for details). The group must also identify the water indicators that currently lack related data collection programs to determine which are essential.

Data collection currently is the "weak link" in developing an effective water sustainability program. Given the problems agencies already have maintaining current data collection programs, adding new ones would be a major endeavor. This may be some of the most important work to be done in the water resources field, because without reliable indicators of existing conditions, it is hard to determine what effects proposed policies might have.

Help Wanted

Sustainable solutions to water resource problems can be found if people thoroughly understand the issues and how each aspect of society contributes to them. However, considering the daunting challenges involved, it is perhaps unsurprising that a generally accepted set of water sustainability indicators does not yet exist.

The job now seems to be to organize the effort, recognizing that there is ample work to go around (see Table 2, above). In our experience, no organization can focus on an issue like this for more than about 5 years, because of normal changes in organizational focus, staff, and resources. So, to keep the process from faltering, SWRR ideally would like the help of several organizations. The group also welcomes suggestions in improving both the process and results. For more information, contact the authors at wateroundtable@netscape.net.

***Ethan T. Smith** is coordinator of the Sustainable Water Resources Roundtable (c/o U.S. Geological Survey; Reston, Va.), and **Harry X. Zhang** is a senior engineer in the Fairfax, Va., office of Parsons Corp. (Pasadena, Calif.).*