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The State of the Nation's Ecosystems: A Piece of the Sustainability Puzzle

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Late in 1995, the White House's Office of Science and Technology Policy (OSTP) recognized the need for a new kind of report on the state of the nation's environment (Executive Office of the President 1997). The intent was to create something with broad political credibility—something that would not be viewed as the voice of one particular sector, interest group, or political camp. Rather, the goal was to provide decision makers and the public with periodic, non-partisan reports, focusing on aspects of ecosystem condition that are valued by society as a whole, and describing them in ways that are as objective and free from policy bias as possible. Scientific credibility was also viewed as crucial to such an undertaking: while such reports would need to be understandable to a general audience, its more scientifically-versed readers should find it substantively correct and well-documented. Developing such reports clearly would require close interaction with the myriad monitoring programs that currently provide extremely valuable data on environmental conditions across the country. Indeed, the process of developing such a report would provide an excellent opportunity for pointing out gaps in the overall coverage of these extremely important programs. Finally, just as it took years to establish the suite of economic indicators as an American institution during the first half of last century, it will take several iterations and perhaps many years to develop and refine to maturity a succinct, yet powerful suite of indicators of ecosystem condition and use. Ultimately, the goal is to move environmental debates beyond arguments over whose data are better, to more productive conversations about what changes are needed given the current state of affairs, and how we, as a society, might attain these goals.

Developing *The State of the Nation's Ecosystems* report series has been a major program at The H. John Heinz III Center for Science, Economics and the Environment since 1997. This paper attempts to describe how the Heinz Center process and the indicators themselves can help to inform debates on sustainability and, in particular, sustainable water use. While indicators of ecosystem condition and use are just one part of complex puzzle needed to evaluate sustainable uses of natural resources, they are, we believe, integral pieces of the puzzle.

A Useful Process: The Heinz Center Approach

One will notice little, if any, use of the term "sustainability" in *The State of the Nation's Ecosystems*. This was a very conscious decision—the many parties involved in our discussions did not agree on the meaning or implications of the term, and defining the term was not necessary for our core task of identifying what aspects of ecosystems should be tracked through time. In fact, this rather subtle point speaks volumes about the Heinz Center's process.

Started in honor of the late Senator John Heinz from Pennsylvania, the Heinz Center strives to foster the same type of multi-sector collaborations on tough environmental problems that Senator Heinz championed during his career in Congress. From a process standpoint, undoubtedly the most important aspect is that all committees involved in the project, both past and present, have been carefully chosen so that four key sets of values and perspectives will be clearly reflected in the outcome—those of the business community, the environmental community, government managers and regulators, and academics. Ultimately, our goal is to have the work of our committees represent the views of society, broadly speaking, rather than the voice of any one interest group. This works as essential insurance that *The State of the Nation's Ecosystems* will not end up being relegated to a pile of reports that have a particular political spin, or that are labeled as "just another report from intransigent environmentalists" or as "yet another report from hired guns trying to re-direct the debate away from the practices of their funders."

The obvious concern about such a committee structure is that the "least common denominator" principle will be in force. Perhaps more than many, this project offered an opportunity to describe a full range of "what people care about"—whether they are from the environmental community, industry, government, or academia. While no one in the process got everything they wanted on the final list of indicators, we did make sure that the final list reflected the most important aspects of ecosystem condition, from the perspective of these various groups. Thus, the process has produced a suite of indicators that are true to an assortment of values and are, we believe, much more likely to be used broadly than if any single sector had dominated the process. (The Heinz Center's process for this project has been described at length elsewhere (Heinz Center 2002; O'Malley et al. 2003)).

A key decision was to limit the report's scope to descriptions of ecosystem state or condition, leaving to others the important tasks of assigning causes to observed conditions and determining what if any policy responses are needed. It is not that difficult to imagine reaching agreement in a mixed committee on acceptable indicators and data sources to describe how much water is removed from an aquifer each year, or how the groundwater level has changed from 10 years ago. However, reaching agreement on the actual role of the various factors contributing to changes in groundwater level (e.g., evapotranspiration from shallow aquifers; pumping for domestic, industrial, and agricultural uses; recharge from rainwater; etc.) would be much more difficult given both the uncertainties involved and the assortment of values represented at the table. It would be equally difficult—if not more so—to imagine reaching agreement on what actions should be taken by public or private entities to create condition X or Y in the future—not to mention agreeing on the characteristics of condition X or Y.

The paper in this issue by Baron and Poff (2004) is an excellent demonstration of the challenges faced as society contemplates indicators of sustainable water use. Not only will it be necessary to confront the thorny issue of competing water uses by different sectors (e.g., industrial, agricultural, domestic), but it will be necessary to reach agreement on how much water a river ecosystem "needs" in order to maintain—or to be restored to—a certain level of ecosystem function. In the view of many, *The State of the Nation's Ecosystems* should have addressed sustainability instead of stopping short, by reporting only ecosystem state. However, we strongly believe that the creation of an objective source of information on the actual condition of the resource we care about—a data source that is at least a few steps removed from the politically charged policy debates that accompany water allocation decisions—will be a real and lasting contribution both to these policy debates and to the larger debate on sustainability.

Commonality Achieved Across Disparate Ecosystem Types: The Framework

To date, one of the major accomplishments of *The State of the Nation's Ecosystems* project is the development of a framework for reporting on ecosystem condition and use across disparate ecosystem types (i.e., coasts and oceans, farmlands, forests, fresh waters, grasslands & shrublands, and urban & suburban areas). Developed in part as a pragmatic step to lessen the chaos caused by six independent ecosystem working groups trying to separately develop schemes for describing "their" system, the framework became much more than simply a planning tool. That is, this framework (Table 1) bundles together indicators describing key ecosystem features—system dimensions, chemical and physical properties, plants and animals, and human uses—into a short list of 10 parameters that, in general, provide a strategic view of ecosystem condition and use. In reality, each system's unique features meant that these 10 parameters translated into about 15 indicators per ecosystem.

Table 1. Framework for reporting on ecosystem state across disparate ecosystem types.

Ecosystem Characteristic	What Do The Indicators Measure—and Why Are They Important?
System Dimensions	
Extent	How much area does an ecosystem or land cover type occupy? *The area of an ecosystem is its most basic characteristic—increases or decreases mean gains or losses of all the goods and services associated with that system.*
Fragmentation and Landscape Pattern	What are the shapes and sizes of patches of an ecosystem type, and how are they intermingled with one another? *These characteristics can greatly influence the goods and services an area provides, such as wildlife habitat, filtering sediments from runoff, and providing solitude.*
Chemical and Physical Conditions	
Nutrients, Carbon, Oxygen	How much nitrogen, phosphorus, oxygen and carbon are found in different systems? *Nitrogen and phosphorus are key plant nutrients, but in excess can cause water quality problems. Carbon storage in ecosystems is a key consideration in global warming discussions, and oxygen in rivers, lakes, and coastal waters is needed for fish and other animals to survive.*
Chemical Contaminants	How many synthetic compounds and heavy metals are found in ecosystems, and how often do these compounds exceed regulatory or advisory thresholds? (For urban / suburban areas, we also include air pollution from ozone in this category.) *Chemical contaminants can harm people and damage ecosystems through their effects on plants and animals.*
Physical Conditions	What is the condition of key aspects of the physical makeup of an ecosystem, such as the temperature of the water or the amount of salt in the soil? *Plants and animals are adapted to certain physical conditions and can be harmed by changes in these conditions.*
Biological Components	
Plants and Animals	What is the status of native and non-native plant and animal species? *People care deeply about wildlife, and the condition of plants and animals can reflect broader ecosystem conditions. Non -native species can disrupt ecosystems and cause economic damage.*
Biological Communities	What is the condition of the plant and animal communities that make up an ecosystem? *Interacting biological communities form the "biological neighborhood" within which individual species exist.*
Ecological Productivity	What are the trends in plant growth on land and in the water? *Changes in the amount of plant growth may signal important changes in overall ecosystem condition.*
Human Use	
Food, Fiber, and Water	How is the amount and quality of key ecosystem products changing over time? *Ecosystems produce goods that meet a variety of important human needs and that are important to the national economy.*
Other Services, Including Recreation	How often do people take part in outdoor recreation activities, and what other services, such as soil building and flood protection, are provided by natural ecosystems? *Though less tangible, these other services are also important both to people and to the ecosystems themselves.*

The Indicators of Freshwater Ecosystem Status

Fifteen indicators were included in the Freshwater Chapter of *The State of the Nation's Ecosystems*. In addition, another 16 indicators related to fresh waters in particular ecosystems (such as forests) are found in the chapters on those ecosystems as well as the chapter on the core national indicators. Together, these present a description of the condition and use of freshwater ecosystems in the United States. Many of these indicators had partial or complete data available (filled-in circles in Table 2). About one-quarter of the indicators lacked data adequate for national reporting; these indicators plus those for which partial gaps exist make up a substantial fraction of the total. The following short synopses outline the main indicator groups as presented in Table 1. For more detail, please refer to *The State of the Nation's Ecosystems* (Heinz Center 2002), which is also available on-line at www.heinzctr.org/ecosystems.

Table 2. Indicators of the condition and use of freshwater ecosystems. Note that the key at bottom explains icons used in left column to describe data availability.

System Dimensions		
◐	Extent of Freshwater Ecosystems	What is the area of lakes and wetlands, and the length of streams, rivers, and their stream bank (riparian) areas?
◐	Altered Freshwater Ecosystems	How much of the nation's lakes, wetlands, streams, and riparian areas has been significantly altered?
(?)	Stream Bank Vegetation *(along Urban/Suburban streams)*	What fraction of urban/suburban stream banks are vegetated?
Chemical and Physical Conditions		
◐	Nutrients (Nitrogen & Phosphorus) in Streams, Rivers, Lakes, Reservoirs, and Groundwater (*multiple indicators*)	How much nitrogen and phosphorus are there in fresh waters? In addition, how do amounts compare across ecosystem types (e.g., farmlands versus urban & suburban areas)?
◐	Chemical Contamination *(multiple indicators)*	How many contaminants are found in fresh waters, and how often do the amounts of these contaminants exceed accepted guidelines for the protection of humans and aquatic life?
●	Changing Stream Flows *(two indicators)*	How many streams have had major changes in the size or timing of their lowest or highest flows since the 1930s and 1940s? How many streams have zero flow for at least one day on grasslands & shrublands, and are these zero-flow periods getting longer or shorter?
⊖	Water Clarity	How clear are lakes in the United States?
Biological Components		
◐	At-Risk Native Species	How many freshwater species are at different levels of risk of extinction?
◐	Non-Native Species	How many non-native species are found in watersheds throughout the United States?
◐	Animal Deaths and Deformities	How many die-offs of waterfowl, fish, mammals, and amphibians occur? How common are amphibian deformities?
⊖	Status of Freshwater Animal Communities	What is the condition of communities of fish and bottom-dwelling animals in the nation's streams?
◐	At-Risk Freshwater Plant Communities	How many wetland and stream bank plant communities are rare and thus potentially at risk?
(?)	Stream Habitat Quality	What is the quality of the habitat in the nation's streams?
Human Uses		
●	Water Withdrawals	How much fresh water do people withdraw, and what do they use it for?
⊖	Groundwater Levels	Are groundwater levels changing? Are they increasing or decreasing and at what rate?
●	Waterborne Human Disease Outbreaks	How often do people get sick from drinking or swimming in contaminated water?
⊖	Freshwater Recreational Activities	How much recreation takes place in the nation's fresh waters?

●	All necessary data Available	◐	Partial data available	⊖	Data not adequate for national reporting	(?)	Indicator development needed

System Dimensions—Tracking changes over time in the size of the many types of freshwater ecosystems is the most basic way of describing the condition of the nation's fresh waters and is accomplished by tallying the area of lakes and wetlands and the length of streams, rivers, and different riparian habitats along stream banks. The second indicator will track the alteration of these same elements of the freshwater system (by leveeing, channelizing, excavating, impounding, and the like). A third indicator, in the Urban/Suburban chapter, focuses on whether or not stream banks in these developed areas are vegetated.

Chemical and Physical Conditions—Three indicators in the Freshwater Chapter describe the chemical and physical condition of fresh waters, and these are complemented by more than ten additional indicators found in other ecosystem chapters. Most of these indicators focus on water quality: the concentration of nitrogen and phosphorus (vital plant nutrients that can lead to problems if present in excess), the clarity of lakes and reservoirs, and chemical contamination. (Contaminant indicators present both the frequency of detection of these compounds and how often these detections exceed generally accepted guidelines for protecting aquatic life or human health.) As detailed in the paper by Baron and Poff (2004) in this issue, water quantity and timing of high and low flows are of considerable importance. One indicator reports on key flow characteristics of streams and rivers, and a second focuses on periods of zero flow in grassland/shrubland streams and whether or not these periods are becoming longer or shorter.

Biological Components—The biological condition of freshwater ecosystems is described by eight indicators. One indicator tracks native freshwater plant and animal species that are at varying levels of risk of extinction, and a parallel indicator tracks the fraction of wetland and riparian communities that are at risk of elimination. A third indicator tracks non-native species, reporting now on non-native fish established in major watersheds but eventually including amphibians, mollusks, and plants. A fourth indicator will measure how closely fish and bottom-dwelling animal communities resemble those in relatively undisturbed lakes and streams in each region; there is also an analogous indicator just for urban/suburban streams. Because abnormal environmental conditions sometimes lead to unusual animal mortality events, a sixth indicator tallies unusual mortality events among birds, fish, mammals, and amphibians (so far, data are available only for waterfowl). The final indicator will focus on measures of stream habitat quality; a companion indicator is included in the farmlands chapter.

Human Use—Four indicators describe the human uses of fresh waters, two related to water withdrawals, one to waterborne disease, and one to recreation. The first indicator tracks withdrawals by use (e.g., for irrigation, electricity generation, or municipal use) and by source (surface or groundwater). The second tracks whether groundwater levels in large regional aquifers are changing. (Note that a companion indicator in the Grasslands & Shrublands chapter covers only shallow aquifers and is considered a "Chemical and Physical Conditions" indicator because of the importance of shallow aquifers on stream flows and plant growth in this biome.) A third indicator tracks a human-focused measure of water quality—the frequency of waterborne disease outbreaks attributed to both drinking of and swimming in contaminated water. The fourth will report such recreational activities as swimming and fishing.

What We Cannot Tell About The State of Freshwater Systems

The short—and unfortunate—story is that there is a surprising amount that we cannot tell about the condition and use of freshwater systems. One gains a sense of this by tallying the number of data-availability icons in Table 2 that are not filled-in circles (i.e., do not have all the data needed for reporting at a national scale). Indeed, for one-third of the indicators (5 of 15) in the freshwater chapter, adequate data do not exist at a national level or the indicator had not yet been defined. Adequate data were available to permit reporting at a national level for only 3 of the indicators in the freshwater chapter. As mentioned earlier, there were a number of indicators in other chapters of the report that deal with freshwater issues. For 6 out of these 16 indicators, adequate data did not exist at a national level or the indicator had not yet been defined. In contrast, for half of the indicators—most of which were indicators of nutrients in water—adequate data were available to permit reporting at a national level. This story for freshwater data gaps is similar to that found overall in *The State of the Nation's Ecosystems*: only one-third of the indicators in the overall report had all of the necessary data.

As part of its efforts to turn *The State of the Nation's Ecosystems* from a one-time report to a continuing series, the Heinz Center is using a multi-pronged approach to make sense of these numerous data gaps. One goal is to establish rough cost estimates of what would be needed to fill each gap. These estimates are meant to be useful planning tools and not specific programmatic proposals from the various government agencies. A second goal is to gain some insight into the priority placed on filling the various data gaps by various sectors of society—hopefully absent serious consideration of the cost involved. This point is an important one because we expect that there will be some very costly data gaps that many people will believe are of high priority, whereas some inexpensive data gaps may simply not rise to the top of anyone's list for short-term investment. We have received nearly 300 responses to a survey that elicits feedback on such priorities, and it appears that it will be possible to partition the various data gaps into broad categories (e.g., low, medium, and high). A third goal is to be able to articulate something about the feasibility of filling each data gap, which is the degree to which an operational program exists that could collect the data—the extreme is that there is no obvious implementation mechanism that would enable collection of indicator data. A final goal is to step back from the obvious data gaps revealed by *The State of the Nation's Ecosystems* and explore whether there are changes in funding or program focus that would make it likely that data that were available for the 2002 *State of the Nation's Ecosystems* report might *not* be available 5 or 10 years from now. This goal presents a major challenge: policy decisions at many different levels factor into this viability, and only some of these decisions can be anticipated at any given time. We are extremely pleased that the U.S. General Accounting Office (GAO) is undertaking such a study, focusing on a broad range of monitoring programs, including all those relied upon by the 2002 *State of the Nation's Ecosystems* report. In this area, it is the Center's hope that there will also be periodic reporting on the state of the nation's monitoring and reporting system. Such reports would identify progress (hopefully) in filling data gaps, and review the status of the overall monitoring, analysis, and reporting systems that are needed to report on the state of the nation's ecosystems.

It is rather astounding how large the gaps in the nation's ability to report on the condition and use of U.S. ecosystems are at a national scale. This is especially surprising given that the federal government spends over one-half billion dollars each year on environmental monitoring and related research, and imposes additional expenditures on the private sector for monitoring effluents and emissions (Executive Office of the President 1997). Further, state and local governments and environmental organizations devote major resources to environmental monitoring, and there is private sector investment besides that which is mandated by the federal, state, and local governments. The Heinz Center process has brought together some of the best minds, representing a wide cross-section of society, and their conclusion is that these gaps are serious enough to greatly hinder the ability of decision makers to see the "big picture"—something that is crucial if we as a nation are to manage effectively. It is also worthy to consider the situation faced by less-well-off countries, if this is the state of environmental monitoring in the United States. This situation presents a caution as well as a challenge: as countries develop their environmental monitoring programs, it is important to have an overall framework, not simply to develop separate monitoring programs for separate resource categories, and it is important to step back periodically to make sure these programs are meeting the needs of a broad spectrum of society.

Providing the nation with a "big picture" perspective on ecosystem condition and use in the United States will be anything but simple. Any new investment faces a substantial hurdle in these times of tight budgets, and cutting one program to pay for expanding another often requires incredibly difficult and painful tradeoffs. It is very important to stress that the suite of indicators found in the *State of the Nation's Ecosystems* report does not represent the full list of indicators valuable to the nation (Heinz Center 2002). That is, policy makers should be strongly dissuaded from concluding that a program is of little use to society just because its data did not appear in *The State of the Nation's Ecosystems*. The indicators in our report provide one view of ecosystem conditions, and other views—at other geographic scales, at other levels of detail, etc.—are also quite important.

We Need to Be Able to Walk Before Running: Improving The Pieces of the Puzzle

The challenge facing the movement toward sustainability is the "reconciliation of society's development goals with the planet's environmental limits over the long term" (Clark and Dickson 2003). It is fair to ask how *The State of the Nation's Ecosystems* project fits into this sustainability movement. This project might be viewed as a baby step when one considers the vast complexity inherent in measuring and predicting sustainable resource use. However, we believe it is a carefully chosen and well-executed baby step.

One might consider the holy grail of "sustainability science"—a term coined by the National Research Council (NRC 1999)—to be a suite of conceptual models, which would lead to mathematical models, that would accurately capture the vast interactions between the environment (nature) and human society. Such models would be sensitive to perturbations, such as increased draws on groundwater for irrigation purposes or the spread of an invasive weed species that is adept at drawing down shallow aquifers and, therefore, out-competing native species. Sustainability scientists would use a vast array of current conditions and assumptions based on future resource uses and societal needs to predict future conditions, be they the groundwater level in a particular aquifer or the health of a nation's export economy. Of course, along the road to this state of nirvana, groups will continue to carve out a portion of these nature-society interactions having particular interest, and they will endeavor to create indicators of varying degrees of complexity to characterize these interactions. The end result will be indicators that can measure, in a holistic manner, aspects about a resource as well as be used as tools to guide policy decisions that might produce more sustainable resource use in the future.

The purpose of *The State of the Nation's Ecosystems* is explicitly *not* to connect the dots in these conceptual models, at least not when it is clear that multiple connections—and conclusions—are possible (sometimes depending on who is connecting the dots). That is, an expert from the forest industry would undoubtedly define the interaction between logging operations and stream sediment very differently than would an activist interested in maintaining their version of stream health. Clearly this is a simplistic example, however, it does raise the question as to the type of forum we should expect to generate the models of sustainable resource use—the models that will ultimately drive the design of measures of sustainability. We are of the opinion that such models could and, perhaps, should be developed in a multi-sector forum, such as fostered by the Heinz Center. However, we believe also that *The State of the Nation's Ecosystems* process should be isolated from future efforts to develop such explicit sustainability assessments. Each indicator of "state," be it of ecosystem state or economic state (e.g., unemployment rate), that is endorsed equally by all sectors of society, will ultimately contribute to the much more challenging task of creating universally-accepted assessments of sustainable resource use. In other words, debates about how to resolve differing scientific opinions on cause and effect (i.e., developing models and assessing sustainability) should be separated from the more straightforward debates of deciding how to define the state of an ecosystem component or resource and which data best describe this state.

Efforts such as *The State of the Nation's Ecosystems* will continue to provide glimpses, or snapshots, of a particular set of current conditions that tell us something about the current state of the system. In the case of freshwater ecosystems, the snapshot found in *The State of the Nation's Ecosystems* provides a launching pad for discussions about how to sustain a critical resource for terrestrial and freshwater species, including humans. As more such snapshots develop, let the debate be about how—if at all—the indicator values should change with time, now that we as a society can agree on the current state of affairs.

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