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Conceptual Foundations for the Sustainable Water Resources Roundtable

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This paper summarizes a set of concepts that were selected for discussion by the Sustainable Water Resources Roundtable as a basis for its ongoing efforts to identify criteria and indicators that would be useful in the assessment of the sustainability of water resources in the U.S. The Sustainable Water Resources Roundtable is a multi-stakeholder process to develop consensus indicators to guide water resources use and management in the U.S. Similar efforts are also under way in the areas of forests[1], rangelands[2], and minerals[3]. Although we have developed the framework discussed below without explicit linkages to these other roundtables, we recognize the usefulness, when possible, of consistency in outputs across roundtables and have considered this in our work.

At the outset, we acknowledge the complexity in developing a conceptual approach in this context. Each person comes to the table with a set of concepts through which they understand how the world works. Our own concepts are so familiar to us that we experience them concretely. Yet to others who do not share them, they often seem abstract. Thus, in our effort, as a diverse set of people discussing fundamental concepts, we worked through confusion and disagreement, pushing forward with the discussion in the expectation that differences would gradually be replaced by shared understanding. The conceptual framework presented in this paper is a result of these discussions and should be regarded as a basis for ongoing discourse. We describe key components of an indicator system for these frameworks, and link these to other tools for assessing water resources sustainability.

Sustainability and the Conceptual Framework

The most widely known definition of sustainability is that put forth by the Brundtland Commission in 1987: "meeting current needs without compromising the opportunities of future generations to meet their needs" (World Commission 1987). In lieu of attempting to come up with an alternate definition of sustainability that the diverse group of stakeholders involved in the Sustainable Water Resources Roundtable (hereafter "the Roundtable") could agree upon, we have proposed the following set of principles regarding sustainability in water resources to be used in our discussions.

> The sustainable development of water resources is a multi-dimensional way of thinking about the interdependencies among natural, social, and economic systems in the use of water. In this view, our efforts to achieve economic vitality should occur in the context of the enhancement and preservation of ecological integrity, social well-being, and security. The sustainable development of water resources:
>
> - Involves policies, plans, and activities that improve equality of access to water;
> - Recognizes that there are limits and boundaries of water use beyond which ecosystem behavior might change in unanticipated ways;

- Requires consideration of interactions occurring across different geographical ranges - global, national, regional, and local; and
- Challenges us to look to the future and to fully assess and understand the implications of the decisions made today on the lives and livelihoods of future generations, as well as the natural ecosystems upon which they will rely.

Definitions

In order to minimize both redundancy and confusion, we have adopted terminology wherever possible that is consistent with that used by the Interagency Working Group on Sustainable Development (www.sdi.gov) and the USEPA's environmental indicators initiative (www.epa.gov/indicators/abouteii.htm). Explanations of concepts and definitions of key terms used in this paper are provided below.

Systems Concepts: We use systems concepts to represent our understanding of "how the world works." In the case of water resources, we are interested in those parts and processes in our world by which water moves from place to place, interacts with other components of the biosphere, and is used by humans.

Information Concepts: These are used to organize, communicate, and apply information. They are concepts about how the small patterns of energy and matter that we call information relate to human actions and to non-human phenomena. These concepts can help us understand the roles and uses of information, how they vary from one institutional context to another, and what characteristics make information effective for decision making within different contexts. In water resources management, information is used in a wide variety of political, economic, and social institutions. Because information and its communication are fundamental to life and such a part of our daily lives, we often assume that we all know what characteristics make information effective. Even so, in discussions about the design of a criteria and indicator set, it is helpful to be explicit about the information concepts that represent that understanding.

In our conceptual framework we include both systems concepts and information concepts. They help to link the above sustainability principles to the identification of criteria and indicators.

Criteria: Standards or points of reference that help in choosing indicators.
Indicators: Measurements that track processes and conditions over time.
Goals: Ultimate desired outcomes.

Systems Concepts

A Venn diagram[4] depicts the overall relationships among three major systems (natural, social, and economic) encompassed by the concept of sustainability (Figure 1). The Biosphere includes all living things on Earth and the non-living systems with which they interact and on which they depend. The Social System includes all the human elements of the Biosphere. "Natural Systems" are thus the non-human elements of the Biosphere, often referred to as the environment. The quotes show our recognition that humans are in reality a part of nature, not apart from it, despite our use of the term natural in this context to mean non-human. The Economic System is embedded within the Social System. Because of the focus on interactions, a view of the concept of sustainability as a property of the Biosphere that emerges from interactions among the natural, social, and economic subsystems of the Biosphere is attractive to experts and managers in many fields.

Capital Maintenance Concepts

One way to apply the systems concept of sustainability in identifying criteria and indicators is to recognize that sustainability can be achieved by maintaining the capacity of capital in all forms to meet various human and non-human needs within the biosphere (See Heintz in this issue). Economists

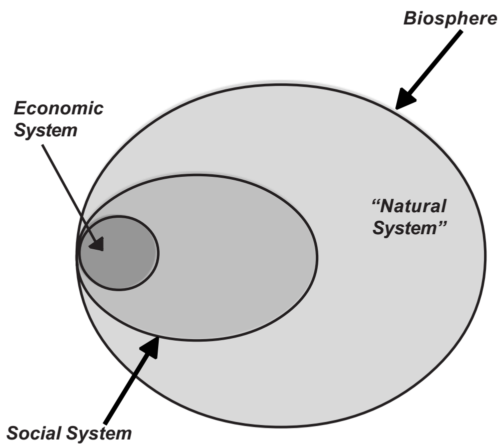

Figure 1. General systems perspective

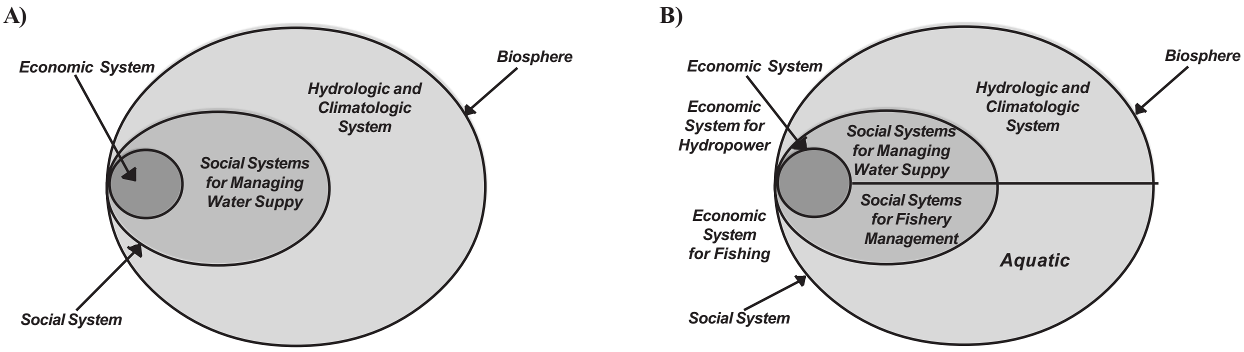

Figure 2. Examples of system perspectives that illustrate the relationships between system processes and natural/human capital. A) Community water supply example. B) Hydropower and fishery example.

regard capital as the capacity to produce a flow of value over an extended time—value being produced by satisfying human needs. Although capital is a term most often identified with economics, it is also used for other types of analysis. All three systems—natural, social and economic—produce flows of services, experiences, or goods that meet various needs over time. It is in this sense that all three systems contain capital.

In general, the capacity to meet needs over a period of time results from the characteristics of "subsystems," "components," "structures," and "processes of interaction" within the biosphere. In general, systems analysts divide systems into subsystems, and subsystems into components. An understanding of how the world works is expressed by specifying the structures and processes through which the subsystems and components interact. People from different sectors may use similar or interchangeable terms such as resources, capacities, conditions, stocks, assets, or endowments. The terms we have chosen are meant to provide a common language for the purposes of the Roundtable.

Ultimately, our indicator framework should enable characterization of the relations between system processes and impacts on natural and human conditions over time. For instance, it should illustrate how changes critical to water quality and quantity, such as climate change, impact natural resources and social systems, such as in water flows and fish stocks (Figure 2).

Information Concepts

As we discuss how to select criteria and indicators, we consider various roles and uses of information. The scope and nature of the criteria and indicators to be selected depend on the roles and uses we want them to serve. We use information concepts to help the Roundtable discuss the extent to which it should narrow the range and focus of its work.

We identify three views of the roles and uses of indicators:

- Assessment, Diagnosis, Prognosis, Prescription, Treatment, Reassessment
- Policy Making, Forecasting and Evaluation, and Management
- Research and Education

The first view uses medical terminology to describe the roles of information. It distinguishes between information on conditions (assessment), information that can explain conditions (diagnosis) and information that forecasts future conditions (prognosis). As we know from our experience with the health care system, different types of information are used to perform these different functions. In particular, health assessment uses a relatively small number of indicators of overall health, while diagnosis uses more detailed and specific information about the causes of illness. These differences reflect both the costs of acquiring and using various types of information and the effectiveness of different measures.

The second view takes a management perspective. Here too, different types of information are useful in performing different functions. High-level policy and resource allocation decisions tend to be based on more general information, while operational management uses more detailed, often spatially specific, information.

Research and education use information designed to produce and communicate knowledge of how

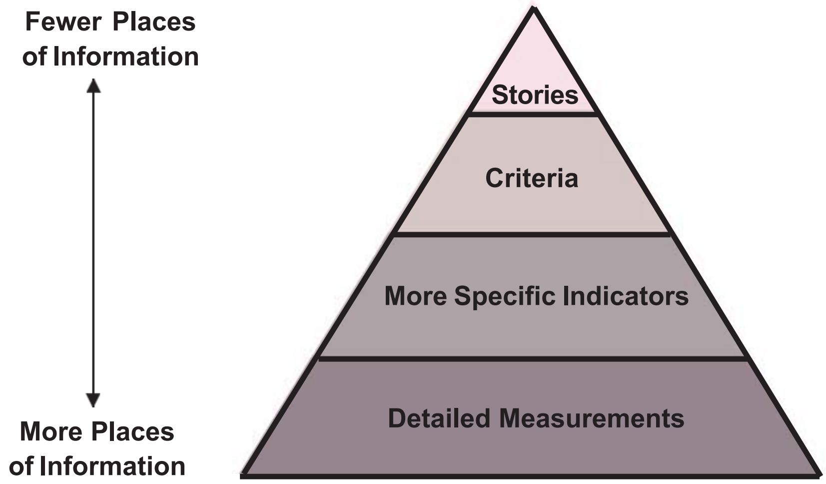

Figure 3. Example of an information pyramid. See text for details.

systems work. Such information is often very detailed and specialized, although in education it is often simplified. The knowledge developed by research often includes improved understanding of the causal relationships in the interactions among the components and subsystems of a system. Thus, water resources research can be facilitated by information organized into criteria and indicators using systems concepts. The interpretation of indicators for assessment and diagnosis of water resources sustainability can be improved using the knowledge produced by such research.

One common aspect of all three views is the role of information as feedback in a cyclical process of decisions>actions>observation of consequences >decisions, and so forth. In health care, treatment is accompanied by feedback from monitoring and continued assessment of the patient's condition. In policy and management, feedback is used in performance measurement, program and policy evaluation, and monitoring of management practices. In research, observation provides feedback on the validity of hypotheses. In all these contexts, continual improvement occurs as feedback promotes learning and evolution. A primary motivation for the identification of criteria and indicators for sustainable water resource management is to improve the quality of the available feedback in order to promote more effective learning and evolution of policies and management practices for sustainability.

The Information Pyramid (Figure 3) shows a hierarchical arrangement with relatively general and simple stories that most people can absorb at the top and increasing detail, specificity, and complexity at successively lower levels in the pyramid. The pyramid metaphor is based on the idea that there are more building blocks, more pieces of information, in the lower tiers of the pyramid (cf. Hammond et al. 1995). At the top of the pyramid is the most widely communicated form of information, relatively simple stories that are told in various media. At the bottom of the pyramid is the most detailed form of information, which tends to be used mostly by experts.

The value of a set of systematically produced, science-based criteria and indicators is the improvement they can bring about in our shared understanding, the common knowledge of the world that we communicate in the stories we tell each other. Such improvements result from using indicators to ground our stories in science-based measurements, helping us to distinguish more realistic stories from less realistic ones. The actions we take in the many contexts affecting water resources management are usually based on the stories that are most widely believed by the people in those contexts.

Criteria help to identify appropriate indicators. We identify three types for discussion:

- A specific target that is accepted as a threshold of success for an objective
- A generally desirable direction of change for a category of phenomena
- A general category of phenomena for which society may later specify the desirable direction of change or a specific target

By way of illustration, here are examples:

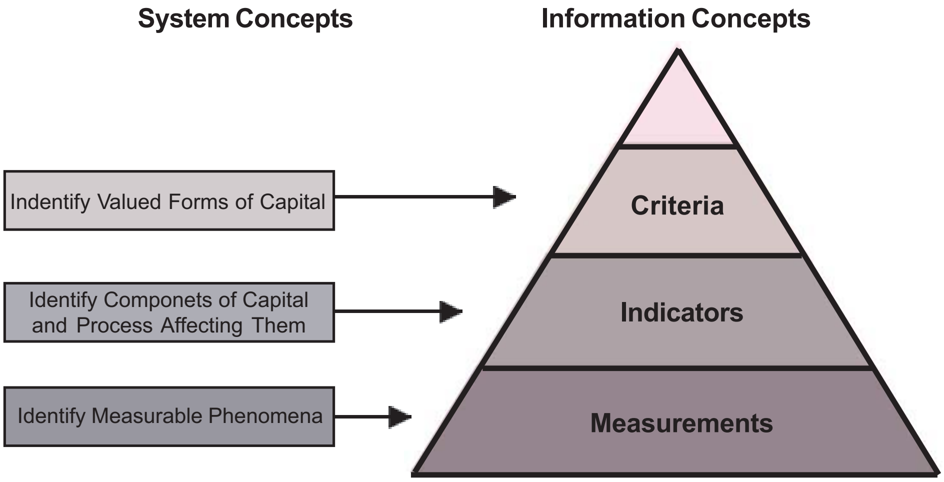

Figure 4. Example of how systems concepts can be linked to information concepts in the context of sustainable water resource management.

- Criteria as target: 10% increase in water for the environment
- Criteria as direction of change: increase water for the environment
- Criteria as category for potential directional goal or target: adequate water supply and timing for the environment

At this juncture, the third approach might be best suited to the Water Roundtable's goal. The second approach was used in the Forest Roundtable's identification of the Criteria and Indicators for Conservation and Sustainable Management of Temperate and Boreal Forests. The second, directional or targeted approach, often encounters controversy because of peoples' different values and desired outcomes. However, consensus on specific targets may emerge from ongoing discussions within the Roundtable.

Identifying Criteria and Indicators Based on Relationships Between Systems Concepts and Information Concepts

Linking systems concepts to information concepts illustrates how the capital maintenance concept of

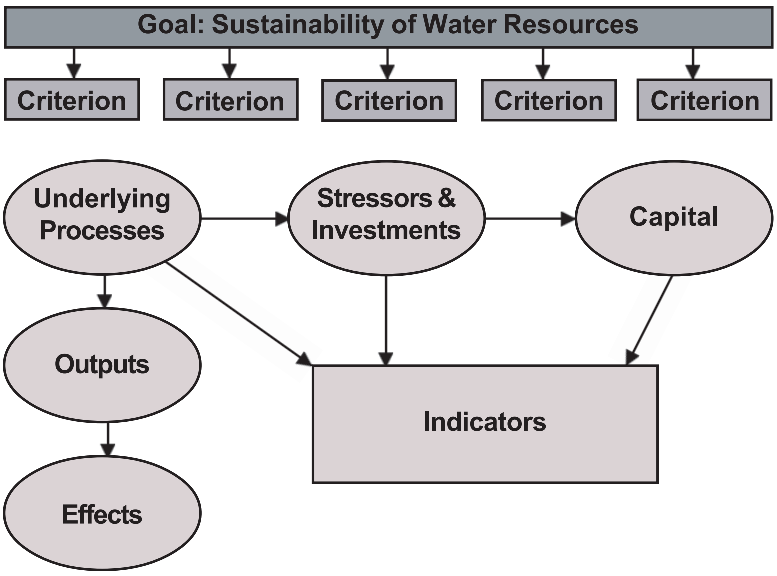

Figure 5. Generic systems model example linking goals, criteria, and indicators. See text for details.

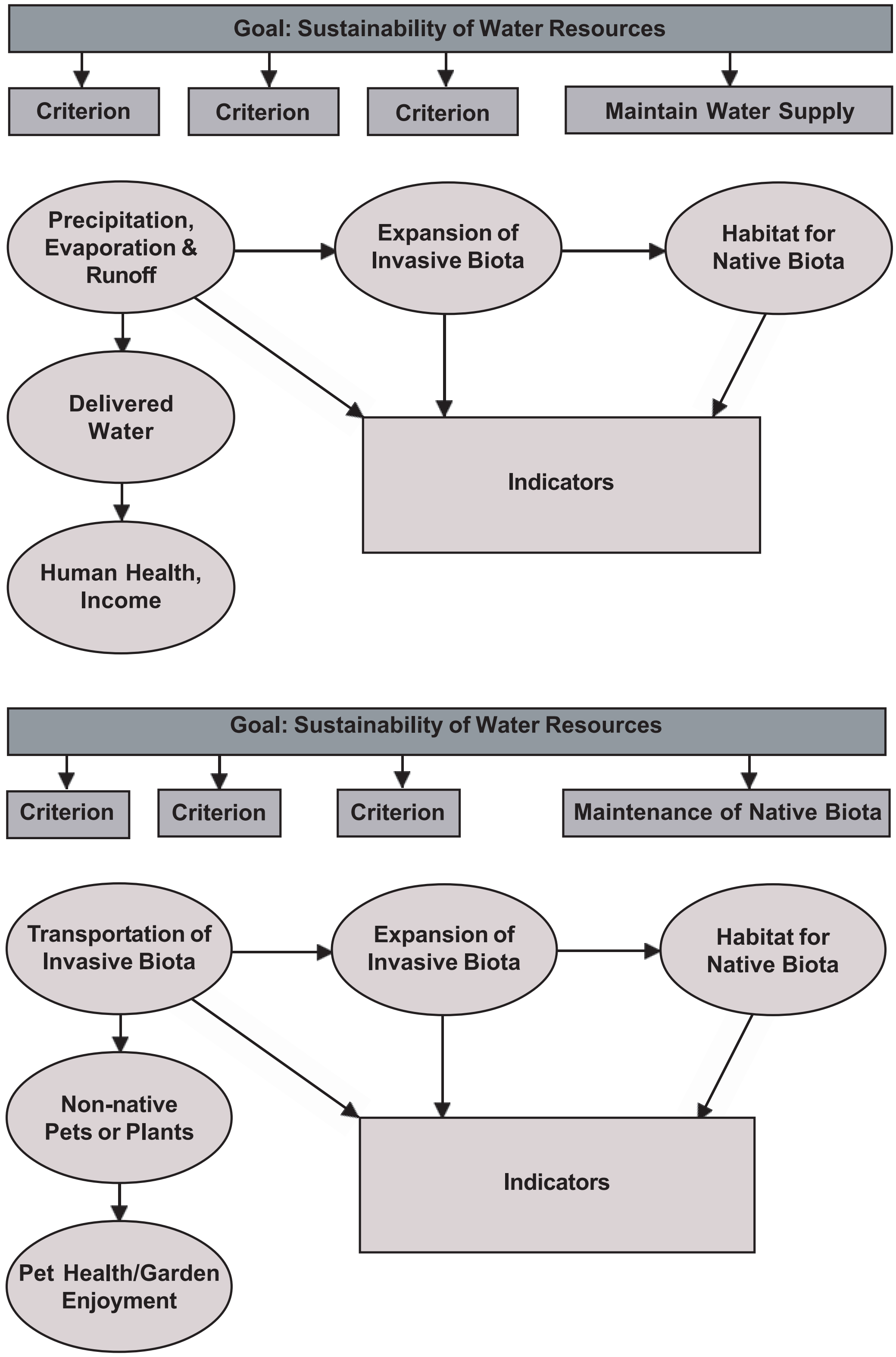

Figure 6. Specific systems model examples. A) Example based on criterion of "maintain water supply"; B) Example based on criterion of "maintenance of native biota". The different underlying processes in each example result in different indicators, outputs, and effects. See text for more detail.

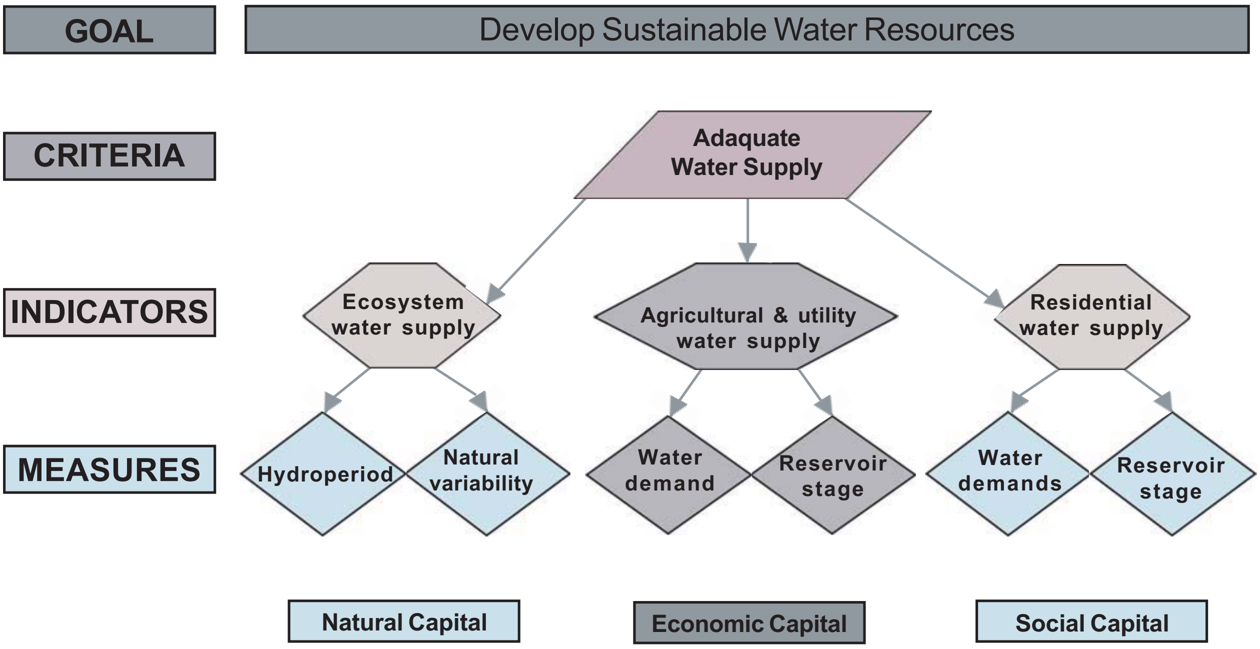

Figure 7. Generic example of conceptual model linking systems and information concepts using the criterion of adequate water supply. Note that indicators are developed for natural, economic, and social capital sectors.

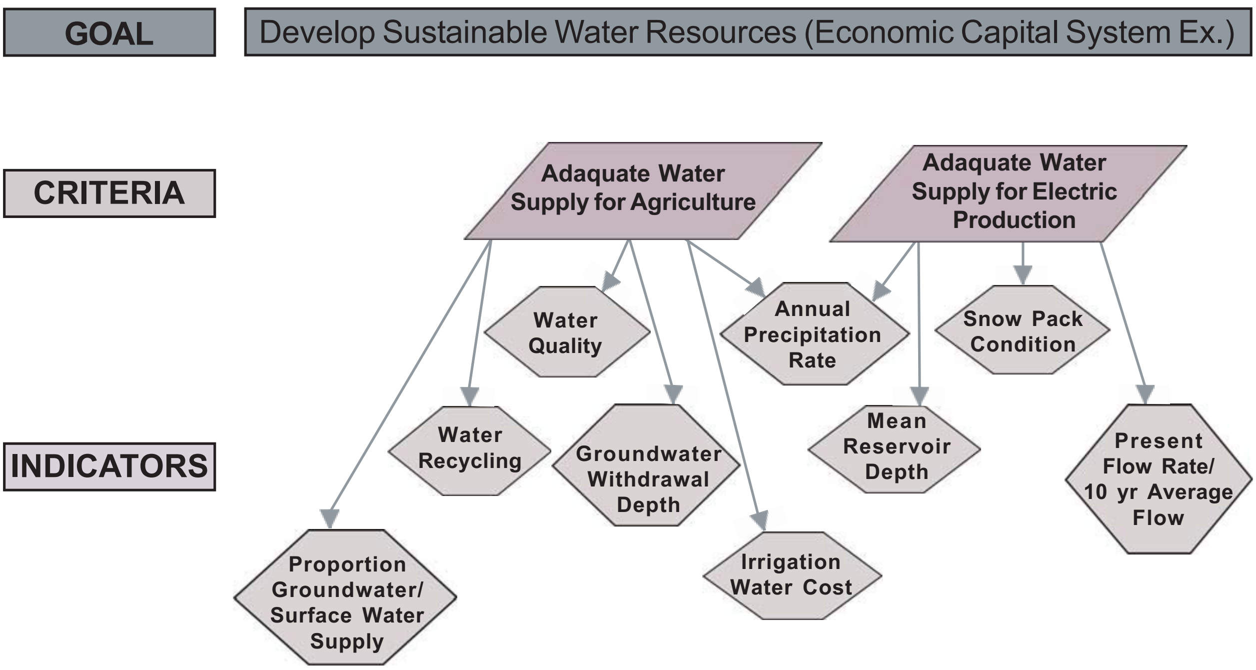

Figure 8. Specific example of conceptual model linking systems and information concepts based on the economic capital system. (middle path in Figure 7).

sustainability can be used in the development of criteria and indicators for sustainable water resources management (Figure 4). Such a set of criteria would be similar to those in the sets of criteria and indicators identified for sustainable forest management, and sustainable rangeland management. Knowledge of the capacities of water resources systems to meet needs would be used to identify a set of criteria associated with general categories of capital. For instance, a *criterion* (or valued form of economic capital) would be adequate drinking water supply to meet human needs. *Indicators* for this could be what quantity of water is available for human consumption and whether the water available is of sufficient quality for human consumption. Water quantity is in turn *measured* through determining variations of flow rates in rivers and streams, and water levels in reservoirs over time. Multiple *measures* of levels of turbidity, chemical pollutants, and other contaminants may be taken to determine whether water quality is sufficient for human consumption.

Indicators could be selected for each criterion using systems models to identify and represent the important components and processes for each category of capital (Figure 5). The needed measurements would be identified for each indicator based on knowledge of the relevant phenomena.

In developing indicators to measure sustainability, we are trying to determine the capacity of various capitals to maintain resources over time. "Outputs and effects" result from the processes that directly impact capital, but they themselves do not necessarily help maintain that capacity. While most of the indicators customarily used to assess policy or program performance address outputs or effects, for sustainability assessment, we must address the extent to which the capacity of social, economic, and natural capital is being maintained or enhanced. Therefore indicators addressing "stressors and investments," and "capital" become the primary focus to assess the opportunities being passed along to future generations.

"Underlying processes" occur in and between the three systems (Figure 1). For example, the water cycle and hydrologic flows of water on the Earth's surface are underlying processes in natural systems. Population growth is an underlying process in the social system and economic growth is an underlying process in the economic system. Clearly though, population growth and economic growth interact with the water flows made available by the natural system.

The horizontal sequence represents the various ways that underlying processes affect capital. They give rise to stressors and investments, the direct causes of decreases or increases in the capacity of the capital related to the criterion. Indicators that address underlying processes, stressors, and investments and the capacity of capital can be used for sustainability assessment and diagnosis.

The underlying processes of primary interest are those related to the outputs of goods, services, or experiences that help to meet human needs. Some categories of outputs to which water resources contribute are: food, drinking water, sanitation, energy, recreation, and wildlife (Figure 6). Knowledge of the most important outputs from water resources can be used to identify the general categories of water-related capital that help to produce such outputs. Of course, outputs have effects on human and nonhuman health and well-being, both beneficial and damaging (Figure 6).

Conclusion

We can take the framework we have developed from systems and information concepts and apply it to operational models that describe ecological, social, and economic processes. For example, if the criterion is, "adequate water supply," specific indicators and measures are identified for each of the three forms of capital (Figure 7). The criteria can be specified for specific uses, so that specific indicators may include such things as mean reservoir depth and snow pack condition, in the case of adequate water for electric production (Figure 8). In natural systems, ecosystem models are often applied that link external drivers and stressors implicit to a variety of indicators (cf. Figure 5). For example, WASP (water analysis simulation package) is frequently used to relate stressors such as excess nutrients to indicators such as phytoplankton response (James et al. 1997).

A water budget is a useful model that focuses on the water itself. A water budget provides an accounting of the amount of water that flows into a given watershed and is taken out for various purposes. It may also account for the extent to which allocation of water meets or exceeds availability. Such a model would need to incorporate all three forms of capital and the underlying processes.

The concepts described in this paper were designed to provide an approach that the Roundtable could use to identify criteria and indicators. Different participants of the Roundtable may prefer different operational models to employ these ideas. Implicit in this approach is the assumption that indicators will be identified and measured based on scientific rigor. As the Roundtable moves forward, it will also be challenged to address issues such as agreement on appropriate indicators; availability and integrity of data sources; and identification of temporal and spatial scales in the development of indicators. Although we recognize that this paper is the start of a much longer process in developing goals, criteria, and indicators, we hope this conceptual framework will help in thinking through these issues and others that may arise.

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Since 1993, Mr. Heintz has worked extensively in the development of natural and environmental resource indicators. He has been a member of the Interagency Working Group on Sustainable Development Indicators (SDI Group) and has participated in ongoing roundtables that are addressing criteria and indicators for sustainable resource management for forests, rangelands, minerals, and water resources. He is currently on detail to the White House Council on Environmental Quality to lead an interagency working group that is developing plans for a national system of indicators on natural and environmental resources.

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Notes

1 The Roundtable on Sustainable Forests
www.sustainableforests.net

2 The Sustainable Rangeland Roundtable
www.sustainablerangelands.cnr.colostate.edu

3 The Sustainable Minerals Roundtable
www.unr.edu/mines/smr/index.html

4 A Venn Diagram is a tool used by mathematicians and logicians to illustrate the relationships between sets of things with some similar and some different characteristics.

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