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Sustainable Water Resources Management

Daniel P. Loucks, *Member IWRA, Cornell University, Ithaca, New York, USA*

Abstract: *Defining and measuring sustainability is a major challenge. This article argues these limitations need not stop us from trying to identify and value the possible impacts of what we are doing, or are thinking about doing, over time periods much longer than the lives of our investments, or even of the lives of those of us living today. Sustainability is a relative concept that must be applied in an environment undergoing multiple changes, changes that are occurring over different temporal and spatial scales. We depend on our water resource systems for our survival and welfare. Yet no one expects them to be restored to, or survive in, their most productive pristine states in the face of increasing development pressures for land in their watersheds and for water in their streams, rivers, lakes, and aquifers. A continuing task of water resource planners and managers is to identify the multiple impacts and tradeoffs resulting from what we who are living today may wish to do for ourselves and our immediate children and what we can only guess our yet-to-be-born descendants may wish us to do, or not do, for them in some distant future. This task must involve professionals from other disciplines in a context much broader than just water management. Once these impacts and tradeoffs are identified, it is then up to the political process to make choices when they are in conflict. All of us need to be a part of this decision-making process.*

Keywords: *Sustainability, water management, risk, change, technology, sustainability guidelines, scale, training.*

Introduction

Sustainable water resources management is a concept that emphasizes the need to consider the long-term future as well as the present. Water resource systems that are managed to satisfy the changing demands placed on them, now and on into the future, without system degradation, can be called "sustainable."

> Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity (ASCE, 1998; UNESCO, 1999).

Just how can water resources management be sustainable when we cannot look into the future with any degree of certainty? We do not know with certainty what all the impacts of even our current decisions will be. We do not know what future generations of individuals or societies will want or value. Nevertheless, we still need to consider what we think they will be as we develop plans, designs, and policies for managing our water resources. If successful, these plans, designs, and policies should help us satisfy not only our immediate demands and desires, but those of future generations as well.

Sustainability is intimately related to various measures of risk and uncertainly about a future we cannot know, but which we can surely influence. Our guesses about the future, with certainty, will be wrong. Hence they will need to be revised periodically. Recognizing that some management objectives will change over time, we must consider the adaptability or robustness of the systems we design and operate today to this management uncertainty and to the inevitable changes in the quantity and quality of the resource being managed.

Because sustainability is a function of various economic, environmental, ecological, social, and physical goals and objectives, water resources management must inevitably involve multi-objective tradeoffs in a multi-disciplinary and multi-participatory decision-making process. I believe no single discipline, and certainly no single profession or interest group, has the wisdom to make these tradeoffs themselves. They can only be determined through a political process involving all interested and impacted stakeholders. The participants in this process must at least attempt to take into account the likely preferences of those not able to be present in this decision-making process, namely those who will be living in the future and who will be impacted by current resource management decisions.

In this paper, taken from a recent report on this subject (ASCE, 1998; UNESCO, 1999), I attempt to identify some of the major issues and challenges raised by the concept of sustainability applied to water resources management and to review ways we can respond to the two core issues regarding sustainability. The first is that we cannot look into the future with any degree of certainty. The second is that even if we could, we might not feel obligated to act on behalf of our descendants based on that vision.

Defining Sustainability

Sustainability, as defined in the Brundtland Commission's report *Our Common Future* (WCED, 1987), focuses on meeting the needs of both current and future generations. Development is sustainable if "it meets the needs of the present without compromising the ability of future generations to meet their own needs."

Since the Brundtland report of 1987 (WCED), sustainable development has become the focus of discussions and debates throughout the world (for example see Barrow, 1998; Bender et al., 1994; Engelman and LeRoy, 1993; Falkenmark, 1988; Flyvbjerg, 1996; Gleick et al., 1995; Haimes, 1992; Hufschmidt and Tejwani, 1993; Institution of Engineers, Australia, 1989; Jordaan et al., 1993; Pearce and Warford, 1993; Pezzey, 1992; Plate, 1994; Prendergast, 1993; Rotmans and de Vries, 1997; Serageldin et al., 1993; Simonovic, 1996; Stout, 1998; Svedin, 1988; Toman and Crosson, 1991; van den Bergh and van der Straiten, 1994; World Bank, 1994; Young, 1992). From the debates that have taken place on sustainable development since that definition was proposed in 1987, one thing is clear: a more specific definition is needed to help those who are engaged in development work to evaluate their efforts with respect to sustainability. Yet in spite of that need, it has been extremely difficult to define just what sustainability is in terms more specific than those suggested by the Brundtland Commission.

While the word *sustainability* can mean different things to different people, it always includes a consideration of the future. But so does planning in general. The Brundtland Commission (WCED, 1987) was concerned about how our actions today will affect, "the ability of future generations to meet their needs." Just what will those needs be? We today can only guess as to what they may be. We can also argue over whether or not it is appropriate to even attempt to meet needs if and when they overstress the system designed to meet them. We simply cannot know for certain just how sustainability can be achieved.

Do we enhance the welfare of future generations by preserving or enhancing the current state of our natural environmental resources and ecological systems? Obviously we do, but over what time and space scales should we do it? How do we allocate over time and space our non-renewable resources, e.g., the water that exists in many deep groundwater aquifers, which is not being replenished by nature? To preserve non-renewable resources now for use in the future, in the interests of sustainability, would imply that those resources should never be consumed as long as there will be future generations. If permanent preservation seems unreasonable, then how much of a non-renewable resource might be consumed, and when? It raises the question: does everything need to be sustained? If not, just what should?

The debate over the definition of sustainability is effected among those who differ over just what it is that should be sustainable and how to achieve it. Without question, determining who in this debate has the better vision of what should be sustainable and how we can reach a path of sustainable development will continue to challenge us all. But this challenge need not delay our attempts to at least achieve higher levels of sustainable water resources management. In doing so, we may consume some non-renewable resources now and leave some for future generations. To achieve higher levels of sustainability of our renewable water resource systems, we must preserve and enhance their renewing capacity, their capacity to produce the desired amounts and qualities of water and to support the environment and ecosystems upon which we are all dependent. This is certainly a necessary condition if such systems are going to be able to satisfy to the maximum extent possible the "needs" of future generations, whatever those needs may be.

An improvement in welfare over time cannot occur without sustainable water resources management policies and practices, those that can meet society's demands for water and the multiple purposes it serves, now and on into the future and to the fullest extent possible. These demands will vary from basin to basin. The demands in each basin will include not only the traditional uses of water flows and storage volumes, as applicable, but also the preservation and enhancement of the social, cultural, and ecological systems that are dependent on the hydrological regime in the basin.

At river basin or regional levels, it may not be possible to meet the needs or demands of even the current generation, let alone future generations, if those needs or demands are greater than what can be obtained on a continuing basis at acceptable economic, environmental, and social costs. Demand management is every bit as important as supply management. Furthermore, since it becomes increasingly difficult to estimate what future needs or demands will be, it seems evident that our obligation is to ensure that whatever we do today to meet today's needs, we should continually strive to maintain and enhance our renewable water resource systems. Assuming future generations will expect at least as much from these same water resource systems as we do, degrading them will reduce their capacity to meet future needs, whatever those needs may be. Degradation prevention applies not only to the ability of water resource systems to provide the desired quantities and qualities of water at acceptable costs and reliabilities, but also to their ability to support the ecological, social, and cultural systems necessary for the maintenance and improvement of human welfare.

Sustainability and Change

Change over time is certain. Just what that change will be is the only thing that is uncertain. But whatever they are, these changes will surely impact the physical, biological, and social dimensions of water resource systems. An essential aspect in the planning, design, and management of sustainable water resource systems is the anticipation of change: changes in the natural system due to geomorphologic processes, changes in the engineered components due to aging, changes in the demands or desires due to a changing society, and even changes in the supply of water, possibly due to a changing climate.

Sustainable water resource systems are those designed and operated in ways that make them more adaptive, robust, and resilient to these changes. Sustainable systems, like any others, may fail, but when they fail, they must be capable of recovering and operating properly without undue costs.

In the face of changes, but with uncertain impacts, an evolving and adaptive strategy is a necessary condition of sustainable water resource management (Holling, 1978). Conversely, inflexibility in the face of new information and new objectives and new social and political environments is an indication of reduced system sustainability. Adaptive management is a process of adjusting management actions and directions, as appropriate, in light of new information on the current and likely future condition of our total environment and on our progress toward meeting our goals and objectives. Management decisions can be viewed as experiments, subject to modification, but with goals clearly in mind. Adaptive management recognizes the limitations of current knowledge and experience and that we learn by experimenting. It helps us move toward meeting our changing goals over time in the face of this incomplete knowledge and uncertainty. It accepts the fact that there is a continual need to review and revise environmental and other restoration and management approaches because of the changing, uncertain nature of our socioeconomic and natural environments.

Changing the social and institutional components of water resource management systems is often the most challenging because this involves changing the way individuals think and act. Any process involving change will require that we change our institutions, the rules under which we as a society function. Individuals are primarily responsible for, and adaptive to, changing political and social situations. Sustainability requires that public and private institutions also change over time in ways that are responsive to the demands of individuals (Viessman,1998).

Understanding how institutions are structured and how they function can help one understand better how water resource system development policies and operating rules might be altered when they become deficient, who has the authority to change such rules, and in what ways the rules may be changed. But to understand fully the boundaries of relevant institutions, water resource professionals must understand how institutions function under stress or under pressures for and against change from individuals within and outside the institution.

To be sustainable, water resource systems must perform reliably as they change. The transition to new technologies, new management practices, and new institutions (or institutional leadership) must proceed in an orderly and equitable manner. Continuity and confidence in the new systems are prerequisites for sustainability, as are a proper respect for operation rules and for maintenance of the physical infrastructure. For example, resettlement due to reservoir construction can involve involuntary moves from ancestral homes and traditional living conditions to areas that are unfamiliar – a cost difficult to measure and rarely fully compensated for by those benefiting from the increased irrigation, hydropower, flood control, and other project purposes.

Sustainability and Scale

If we maintain too broad an interpretation of sustainable development, it becomes difficult to determine progress toward achieving it. In particular, concern only with the sustainability of larger river basins could overlook the unique attributes of particular local watershed economies, environments, ecosystems, resource substitution, and human health. On the other hand, not every hectare of land or every reach of every stream in every watershed need be sustainable or self-sufficient. This highlights the need to consider the appropriate spatial scales when applying sustainability criteria to specific water resource systems (Cooper and Bottcher, 1993).

We also need to consider the appropriate temporal scales when considering the sustainability of specific water resource systems. The achievement of higher levels of water resource system sustainability does not imply there will never be periods of time in the future in which the level of welfare derived from those systems decreases. Given the variations in natural water supplies – the fact that floods and droughts do occur – it is impossible, or at least very costly, to design and operate water resource systems that will never fail. During periods of "failure," the economic benefits derived from such systems may decrease. However, ecological benefits may depend on these events. One of the challenges of measuring sustainability is to identify the appropriate temporal scales in which those measurements should be made.

Sustainability Indices and Guidelines

Sustainability measures provide ways by which we can quantify relative levels of sustainability. They can be defined in a number of ways. One way is to express relative levels of sustainability as separate or weighted combinations of reliability, resilience, and vulnerability measures of various criteria that contribute to human welfare and that vary over time and space. These criteria can be economic, environmental, ecological, and social. To do this, one must first identify the overall set of criteria, and then for each one decide which ranges of values are satisfactory and which ranges are not. These decisions are subjective. They are generally based on human judgment or social goals, not scientific theory. In some cases they may be based on well-defined health standards, for example, but most criteria will not have predefined or published standards or threshold values separating what is considered satisfactory and what is not. For many criteria, the time duration as well as the extent of individual and cumulative failures may be important.

Important guidelines for the planning and management of sustainable water resource systems include:

- Developing a shared vision of desired social, economic, and environmental goals benefiting present as well as future generations, and identifying ways in which all parties can contribute to achieving that shared vision.
- Developing coordinated approaches among all concerned and interested agencies to accomplish these goals, collaborating with all stakeholders in recognition of mutual concerns.
- Using approaches that restore or maintain economic vitality, environmental quality, and natural ecosystem biodiversity and health.
- Supporting actions that incorporate sustained economic, sociocultural, and community goals.
- Respecting and ensuring private property rights while meeting community goals, and working cooperatively with private stakeholders to accomplish these common and shared goals.
- Recognizing that economies, ecosystems, and institutions are complex, dynamic (changing), and typically heterogeneous over space and time, and developing management approaches that take into account and adapt to these characteristics.
- Integrating the best science available into the decision-making process, while continuing scientific research to improve knowledge and understanding.
- Establishing baseline conditions for system functioning and sustainability against which change can be measured.
- Monitoring and evaluating actions to determine if goals and objectives are being achieved.

Sustainability and Technology

All stakeholders involved in or impacted by the planning and management of water resources can be aided by the use of modern information processing technology. This technology includes computer-based interactive optimization and simulation models and programs, all specifically developed to perform more comprehensive multisector, multi-purpose, multi-objective water resources planning and management studies. Without such models, programs, and associated databases, it would be difficult to predict the expected future impacts of any proposed plan and management policy. Without the development and use of computer programs incorporating various models, programs, and databases within an interactive, menu-driven, graphics-based framework, it would be difficult for many to use these tools and databases to explore their individual ideas, to test various assumptions, and to understand the output of their analyses. Such programs that allow the stakeholders themselves to create their own models, rather than to be forced to use someone else's model, can help achieve a shared vision among all stakeholders as to how their system functions, if not how they would like it to function.

Models that help us predict the impacts of possible actions we take today are based on the current conditions of our water resource systems. What we might do to improve or increase the derived benefits, however measured, of our water resource systems is, to a large extent, dependent on the state of those systems that exist today. Those who preceded us have given us what we have today, and we cannot redo any of their actions so as to change what exists today. But the resources and condition of the systems future generations will have to work with may well depend on what actions we take today. There may well be tradeoffs between what we would like to do today for our own benefit and what our descendants might wish we had done. Modeling can help us identify these possible tradeoffs. While models cannot determine just what decisions to make, the tradeoff information derived from such models can contribute to the decision-making debate.

Sustainability and Risk

Sustainability implies a condition in which the frequency and severity of threats to society are decreasing over time. It implies a condition in which our environment and ecosystems are being managed in a way that prepares people to cope with stresses when they occur. Variability in water flow and quality is a natural phenomenon and must be preserved if such systems are to sustain their natural, or near natural, ecosystems. However, very extreme events typically bring substantial economic damages. Thus, the prevention, management, and control of very extreme events have a high priority in the achievement of sustainability. Yet it is usually neither politically feasible nor economically possible to eliminate all potential hazards or to design all water resources systems to withstand any conceivable extreme event. Of interest, then, is the effectiveness of recovering from such events.

In any risk assessment the relevant questions include: What could go wrong? What is the likelihood that it will go wrong? What would be the consequences? What can be done, i.e., what options are available for hazard reduction and response? What are the associated tradeoffs in terms of all costs, benefits, and risks? What are the impacts of current management decisions on future options? Sustainability criteria include risk measures and management as part of the overall assessment of possible system failures and their possible consequences. Water resource systems risk assessment and risk management planning should involve all who have an interest in or who are impacted by those systems.

Long-term demand management involving land use and conservation programs can promote the efficient use of water continuously under normal conditions as well as during extreme events such as floods and droughts. The effect of drought on public water supplies necessitates cooperation between water users and local, regional, and national public officials. But since droughts are infrequent in many areas, water managers are faced with dealing with situations for which they typically have little or no past experience. Developing a national or regional drought policy and plan, then, is essential for reducing societal vulnerability and, hence, increasing system sustainability. Flood management and planning must not only take into account the risks of potential economic and social (psychological) damages resulting from flooding, but also the ecological and economical benefits of alternative floodplain development and use, and how it can be done to reduce potential damages.

Sustainability and Training

A key to sustainable water resources management is the existence of sufficiently well trained personnel in all of the disciplines needed in the planning, development, and management processes. In regions where such a capacity is needed but does not exist, it should be developed. Training and education are a key input, and requirement, of sustainable development. While outside experts and aid organizations can provide temporary assistance, each major river basin region must inevitably depend primarily on its own professionals to provide the know-how and experience required for water resources development and management. "Capacity building" is one of the most essential and important long-term conditions required for sustainable development. Sustainable systems development and evolution cannot be achieved without local expertise, an expertise that needs to be developed and to be transferred to each succeeding generation of professionals.

Another important factor in sustainable water resources management is that the local people must not only be capable, but must also be willing to assume the responsibility for their water resources systems. One of the drawbacks of a centralized dominating government that takes the responsibility for local system design and operation is that the local people become accustomed to looking to "government" for help, rather than to looking to themselves. The ideal local water resources managers are well-trained persons who know the behavior of that system, have experience with its floods and its droughts, and know the concerns and customs of the people of the region, a group to which they belong.

Achieving Sustainability

Everyone involved in water resource systems development and management has an obligation to see that those systems provide sufficient quantities and qualities, at acceptable prices and reliabilities, and at the same time protect the environment and preserve the biodiversity and health of ecosystems for future generations. If our current water resources development and management practices result in degraded environments and ecosystems, those particular water resource systems will surely not be sustainable. There are many examples today of where this has happened. Would these "failures" have occurred if sustainability criteria were considered when decisions were made? Are those who develop and manage water resource systems to meet today's expressed demands for food and fiber and economic livelihood considering the impact of their actions on future generations and their expected demands? Any motivation to consider the future depends on the ability and willingness to understand the interactions of processes on very different spatial and temporal scales. It also depends on an informed and supportive public. Those who are managing natural resources need to ensure that the public as well as their representatives who make decisions are aware of the short and long-term temporal as well as spatial impacts and tradeoffs.

Given the uncertainty of what future generations will want, and the economic, environmental, and ecological problems they will face, a guiding principle for the achievement of sustainable water resource systems is to maintain the options available to future generations. What we do now should interfere as little as possible with the proper functioning of natural life cycles within the watershed. Throughout the water resource system planning and management process, it is necessary to identify and include within the set of evaluation criteria all the beneficial and adverse ecological, economic, environmental, and social effects – especially the long-term effects – associated with any proposed project.

Whatever is done to increase the level of sustainability of our water resources infrastructure will likely involve some costs or require some reduction in the immediate benefits those of us living today could receive. For example, if those living now had to pay for the required remedial measures of any contamination that they produce, they would be less likely to produce it. It is clear that wherever possible, the prevention of pollution in excess of the receiving systems' assimilative capacity is preferable to, and cheaper than, the reduction or elimination of its consequences. The challenge is to create the incentives that result in pollution prevention, that result in behavior that leads to higher levels of sustainability.

Water resources development and management is typically a public sector activity. Yet the money that is needed to develop and manage water, sustainably or otherwise, generally comes from the private sector. The money needed to create jobs, lift people out of poverty, and provide for the demands of growing populations comes from economic growth, domestic saving, and wise investments at the national and international levels. While private profit-motivated businesses cannot be expected to achieve sustainable systems, economies, and environments by themselves, an increasing number of them see that it is in their long-term interests to be partners with governments and non-governmental organizations, as appropriate, working together toward achieving this goal (Frederick, Major, and Stakhiv, 1997).

Everyone makes water management and use decisions, not just the professionals and the politicians. It is the job of the professionals, however, to provide the information upon which informed decisions can be made. As our knowledge increases and as conditions and expectations change, so will our decisions. Professionals, particularly engineers, can contribute to sustainable development in two ways: by introducing environmentally beneficial practices within their own organizations, and by insuring that their projects not only meet their client's needs but at the same time contribute positively to sustainable development.

What to do?

Given all these issues and challenges with respect to the planning and management of sustainable water resource systems, it is appropriate to ask what can and should be done. No single profession pretends to know enough to answer that question. However, with inputs from a multiplicity of professionals and the interested and affected public, resource managers and decision makers can identify more clearly just what may be done to achieve higher levels of sustainability in specific situations.

Whatever is done to increase the degree of sustainability of our water resources infrastructure will almost certainly involve some costs or require some reduction in the immediate benefits those of us living today could receive. And that is the challenge: deciding what should be done today given what is known as well as what is not, and cannot, be known; determining how much cost and sacrifice are warranted; and choosing who is going to pay. These issues need to be debated, and this debate should involve everyone having interests in the systems and decisions under discussion.

This challenge — of determining what to do and then getting it done — faces all who choose to assume some responsibility for water resources planning and management. The challenge is one of determining how water and related environmental resources can be developed and managed — managed not only to meet current demands most effectively and efficiently but also to meet the expected future demands. But how can the demands of current populations be satisfied without reducing the options and abilities of future populations to further develop and manage these resource to satisfy their own desires and demands? If that question can be answered, the remaining challenge is one of identifying and implementing programs that satisfy those demands and desires.

Sustainability is an integrating process. It encompasses technology, ecology, and the social and political infrastructure of society. It is probably not a state that may ever be reached completely, but it is one for which we should continually strive. And while it may never be possible to identify with certainty what is sustainable and what is not, it is possible to develop some measures that permit one to compare the performances of alternative systems with respect to sustainability.

For water resource managers, considerations of sustainability challenge us to develop and use better methods for explicitly considering the possible needs and expectations of future generations along with our own. We must develop and use better methods of identifying development paths that keep more options open for future populations to meet their own, and their descendants', needs and expectations. Finally, we must create better ways of identifying and quantifying the amounts and distribution of benefits and costs (however many ways they might be measured) when considering tradeoffs in resource use and consumption among current and future generations as well as among different populations within a given generation.

Conclusions

Sustainable water resource systems, as we have defined them, are:

> …water resource systems designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity.

They must be planned, designed, and managed in such a way that the life-support system at all biological levels remains functional and that the water and related land resource is not irreversibly degraded over time. This imposes constraints on every stage of development, from project planning to its final operation and management within its overall social and technical system.

Sustainability issues are not new issues, nor is sustainability a new concept. Yet the current interest in sustainable water resources management clearly comes from a realization that some of the activities that we who inhabit this earth today perform could be causing irreversible damage. This damage may adversely affect not only our own lives but also the lives of those who follow us.

In many situations, the overall goals of conserving environmental and natural resources and alleviating poverty and economic injustice are compatible and mutually reinforcing. However, there will always be conflicting views on how these overall goals can be met. Tradeoffs will have to be made among the conflicting views and objectives. The challenge for political leaders and professional resource managers is to make the best of situations where complements are real, while remaining aware that there are very real situations that will require difficult decisions and choices if sustainable water resources management is to be achieved.

It is clear that there are many unanswered questions related to the sustainable development and management of any renewable or non-renewable water resource system. No manager of water resources has the luxury of waiting until all these questions are answered. But those involved in managing the resources can still work toward increasingly sustainable levels of development and management. This includes learning how to get more from our resources and how to produce less waste that degrades these resources and systems. We need to develop improved ways of achieving more economically efficient and effective recycling and use of recycled materials. We need to identify new management approaches that are more non-structural and compatible with environmental and ecological life-support systems. In short, we need to constantly improve our processes and procedures of planning, developing, upgrading, maintaining, and paying for a changing infrastructure that we and future generations need in order to obtain the maximum benefits from the resources we manage and use.

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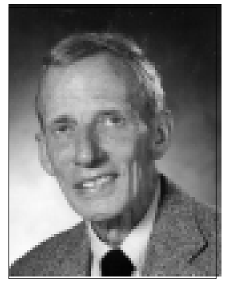
About the Author



Professor Daniel P. Loucks teaches and carries out research in the School of Civil and Environmental Engineering at Cornell University in Ithaca, New York, 14853 USA. Over the past several decades he has contributed to the literature in the development and use of various mathematical and computer models for analyzing water and environmental planning and management impacts and issues and has had the opportunity to serve a number of private, governmental, and international organ izations in various locations in the world. Email: DPL3@cornell.edu.

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