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Water Resource Sustainable Management: Thinking Like a Watershed

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Abstract: Water resources management is one of the most important challenges to today's society. Functionally intact and biologically complex freshwater ecosystems provide many economically valuable commodities and services to society (ecosystem services), beyond simply direct water supply. Besides being an integral part of the ecosystem, water is also a social and economic good. It is therefore critical that efforts intended to be sustainable fully consider the health, integrity, and function of aquatic ecosystems and that the environmental value of these ecosystems be recognized when making economic and social decisions on water allocation and use. Sustainable development is the centerpiece and key to water resource quantity and quality management, as well as national security, economic health, and societal well-being. Considering a sustainability approach anchors a system of evaluative concepts by organizing our scientific information and our important judgments (core values) to correspond to a world that unfolds on multiple temporal scales. Sustaining water resources requires a multi-dimensional way of thinking about the connections or inter-dependencies among natural, social, and economic systems in the use of water to achieve economic vitality while enhancing/preserving ecological integrity, social well-being, and security for all. Traditionally, water quality improvements have focused on specific sources of pollution. While this approach may be successful in addressing a detailed problem, it often fails to address the more subtle and chronic problems that contribute to a watershed's decline. Because watersheds are defined by natural hydrology, they represent the most logical basis for managing water resources. Besides the environmental pay-off, watershed approaches can have the added benefit of saving time and money. Because acting sustainably requires simultaneous multi-dimensional thinking - thinking that covers both temporal and spatial scales for the different sector concerns of economy, society, and environment - to build a viable concept of sustainability, an individual or group must involve themselves in thinking as Leopold described, like a mountain, or a watershed, in order to adequately protect the natural resources in an ecosystem concept that support our socio-economic desires. Watershed thinking evokes dimension and scale in connection with human responsibility, recognition that there are rhythms and dynamics in nature that we do not experience as immediately relevant to us, but which affect our world by changing dynamics we have hitherto taken for granted. Adaptive management is a decision-making processes that effectively integrates both short-term and long-term economic, environmental, and social concerns. It provides a mechanism to evaluate and fully consider all the other principles discussed here, with the guidance of thinking like a watershed. Examples of watershed thinking are presented to fully characterize the vast utility of this approach. Thinking like a watershed, therefore, is thinking about human values as time-sensitive and as produced by specific processes and dynamics that unfold on identifiable scales.

Key words: Adaptive management, sustainability, watershed management, ecosystem assessment, managerial decisions, sustainability indicators.

It is difficult to think of an element more essential to the health of humans or their economy than water. People cannot live for more than several days without water, shorter than for any source of sustenance other than fresh air. In meeting their demand for water, societies extract vast quantities from rivers, lakes, wetlands, and underground aquifers to supply the requirements of cities, farms, and industries (Saeijs and Van Berkel, 1995). Thus, water resources management is one of the most important challenges to today's global society.

Water consumption has nearly doubled since 1950 (UNESCO, 2003), and the demand for water resources is continuing to increase (Brown, 2006). This is driven not only by increasing populations, but also by the aspirations of these populations for an ever-improving standard of living (Bartlett, 1999). At the same time, the capacity of nature to meet this demand is on a decline through over-harvesting, inappropriate agricultural practices, and pollution, to name just a few. Increasing water shortages or inequitable access to safe water causes poverty and environmental degradation that can lead to social injustices, resulting in civil unrest and human conflict (Vorosmarty, 1997). And with conflict comes regional and national disputes, even war, that can best be avoided by the sustainable use of these resources.

While solutions to water resource shortages seem most imperative in other parts of the world, the summer of 2002 will be remembered for putting Americans (USA) from coast to coast through one of the worst droughts in decades. While experts discussed the links between water shortages, erratic weather conditions, and population growth, there was also mounting evidence that the way we grow - land development patterns - can exacerbate problems with both water quality and quantity. And ironically, water supply is no longer just a western issue in the US. We're drinking, irrigating, and using water faster than precipitation can replenish groundwater from the Great Plains to the Chicago suburbs to the Florida Everglades.

There is also growing recognition that functionally intact and biologically complex freshwater ecosystems provide many economically valuable commodities and services to society (ecosystem services), beyond simply direct water supply. These services include flood control, transportation, recreation, purification of human and industrial wastes, habitat for plants and animals, and production of fish, other foods, and marketable goods. These ecosystem services (benefits) are costly and often impossible to replace when aquatic systems are degraded. Deliberations about water allocation should therefore, always include provisions for maintaining the integrity of freshwater ecosystems, including the need to maintain minimum in-stream flows and to anticipate the impact of hydrologic modifications on downstream environments (Flint *et al.*, 1996). Otherwise, we have few safeguards that will protect the systems that sustain us.

Water runs like a river through our lives, touching everything from our vigor and the fitness of natural ecosystems around us to farmer's fields and the production of energy and goods we consume. Besides being an integral part of the ecosystem, water is a social and economic good. Demand for water resources of sufficient quantity and quality for human consumption, sanitation, agricultural irrigation, and manufacturing will continue to intensify as populations increase and as global urbanization, industrialization, and commercial development accelerates (Flint and Houser, 2001). It is therefore critical that efforts intended to be sustainable fully consider the health, integrity, and function of aquatic ecosystems and that the environmental value of these ecosystems be recognized when making economic and social decisions on water allocation and use.

The Importance of a Sustainability Approach

Sustaining the world's water resources is an urgent environmental and socio-economic challenge. The combination of rising demand for water, inefficient water use and contamination of water supplies is producing dire consequences for ecosystems and the health and hygiene of the world's populations, particularly in developing countries. Constraints on water availability also represent a serious obstacle to economic development. Sustainable development is the centerpiece and key to water resource quantity and quality management, as well as national security, economic health, and societal well-being. Sustainable development implies working to improve human's productive power without damaging or undermining society or the environment (Flint, 2004a) through:

- progressive socio-economic betterment without growing beyond ecological carrying capacity, by
- achieving human well-being without exceeding the Earth's twin capacities for natural resource regeneration and waste absorption.

In acting under the principles of sustainable development, our economic desires/demands become accountable to an ecological imperative to protect the ecosphere, and a social equity imperative to create equal access to resources and minimize human suffering. Carrying out development activities that are sustainable requires simultaneous, multi-dimensional thinking about the *consequences* of present actions in a cause and effect pattern on future public and environmental health through scientific evaluation of the *connections* among environmental, economic, and social concerns when we make *choices* for action (the 3 Cs of sustainability).

Current piecemeal and consumption-oriented approaches to water policy cannot solve the problems confronting our increasingly complex world (Flint, 2004b). Traditionally we apply a sectorial approach to the evaluation of water. Take for example the conflict over the water resources of the Missouri River (Quaid, 2003) in the US among navigation, power generation, and environmental concerns. The only equitable solution to these problems is a systemic approach that considers ecological integrity and the ecosystem services that natural resources can provide. By the consideration of ecosystem services that water resources offer we find it much easier to integrate the social and economic issues into deliberations we struggle with when only concerned about the environmental aspects of water.

Considering a sustainability approach anchors a system of evaluative concepts by organizing our scientific information and our important judgments (core values) to correspond to a world that unfolds on multiple temporal scales (Norton, 2005). Sustainability thus both refers to systemic physical dynamics that will change the world humans encounter in the future and evokes a commitment to consider the important everyday relationships that can develop in these dynamics, which today involve multi-generational impacts. In other words, sustaining water resources requires a multi-dimensional way of thinking about the connections or inter-dependencies among natural, social, and economic systems in the use of water to achieve economic vitality while enhancing/preserving ecological integrity, social well-being, and security for all. The sustainable development of water resources:

- involves policies, plans, and activities that improve equality of access and quality of life for all;
- identifies the multi-dimensional impacts (broadly categorized as environmental, social, economic) of any decision;
- promotes the need for balance among the different dimensions, across sectors, themes, and time scales;
- recognizes the limits and boundaries beyond which ecosystem behavior might change in unanticipated ways;
- advocates consideration of spatial scales, recognizing that[1] interactions occur among different geographical ranges - globally, nationally, regionally, and locally; 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 people in the future and the natural ecosystems upon which they will rely.

If we recognize that sustainable development is the ability of humans to harmoniously coexist in a manner that maintains wildlife, wildlands, decent environments, social equality, national security, and economic well-being at present and for future generations, then we must acknowledge that sustainable development is not only a scientific and technical challenge: it must also be approached as a moral/ethical issue. Achieving sustainability is not merely about a series of technical fixes, about re-designing humanity or re-engineering nature in our continuing desire to compete in the global economy. Sustainable development also is about realigument with nature and developing a profound understanding of the concepts of care that underpin long-term stewardship of the places we call home, better offering people an ability to fully appreciate the environment's relationship to our economic and social systems.

The Value of a Watershed View

There are a number of weaknesses in planning and decision-making that cause problems with regards to the protection and conservation of water resources. These include:

- the concern there is not a growth-based recognition for protecting water resource quality;

• the fact that indicator/threshold programs often lack focus on socio-economic measures; all related to not thinking in the framework of watersheds.

Watersheds are those land areas that catch rain or snow and drain to specific marshes, streams, rivers, lakes, or to groundwater. A watershed is the area of land where all of the water that is under it or drains off into the same place. John Wesley Powell, scientist geographer, put it best when he said that a watershed is:

> "that area of land, a bounded hydrologic system, within which all living things are inextricably linked (in intricate, complex ways) by their common water course and where, as humans settled, simple logic demanded that they become part of a community" (Worster, 2000).

Traditionally, water quality improvements have focused on specific sources of pollution, such as sewage discharges, or particular water resources, such as a river segment or wetland. While this approach may be successful in addressing a detailed problem, it often fails to address the more subtle and chronic problems that contribute to a watershed's decline. For example, pollution from a sewage treatment plant might be reduced significantly after a new technology is installed, and yet the local river may still suffer if other factors in the watershed, such as habitat destruction or polluted runoff upstream, go unaddressed.

Because watersheds are defined by natural hydrology, they represent the most logical basis for managing water resources. The resource becomes the focal point, and managers are able to .gain a more complete understanding of overall conditions in an area and the stressors which affect those conditions, offering a stronger foundation for uncovering the many stressors that affect a watershed. The result is management better equipped to determine what actions are needed to protect or restore the resource.

Besides the environmental pay-off, watershed approaches can have the added benefit of saving time and money. Whether the task is monitoring, modeling, issuing permits, or reporting, a watershed framework offers many opportunities to simplify and streamline the science. For example, synchronizing monitoring schedules so that all monitoring within a given area (i.e. a watershed) occurs within the same time frame can eliminate duplicative trips and greatly reduce travel costs. North Carolina (USA) was able to monitor nearly 40% more waters with the same level of effort after monitoring was conducted on a more coordinated watershed basis. Efficiency is also increased once all agencies begin to work together to improve conditions in a watershed. In its truest sense, watershed protection engages all partners within a watershed, including Federal, State, Tribal and local agencies. By coordinating their efforts, these agencies can complement and reinforce each others' activities, avoid duplication, and leverage resources to achieve greater results.

Watershed protection can also lead to greater awareness and support from the public. Once individuals become aware of and interested in their watershed, they often become more involved in decision-making as well as hands-on protection and restoration efforts. Through such involvement, watershed approaches build a sense of community, help reduce conflicts, increase commitment to the actions necessary to meet environmental goals, and ultimately, improve the likelihood of success for environmental programs.

Thinking Like a Watershed

As stated above, the design and implementation of water development activities that are sustainable require simultaneous multi-dimensional thinking - thinking that covers both temporal and spatial scales for the different sector concerns of economy, society, and environment. The systemic, hierarchical approach to ecosystem assessment was introduced almost two decades ago (e.g., Holling, 1992), but environmental managers, conservationists, and scientists still find it difficult to engage in the multi-sectorial, multi-generational framework of ecological change (Norton, 2005). Consequently many of our intended good actions regarding protection of water resources, while meeting the needs of humanity, result in unintended consequences for many different kinds of ecosystems.

Aldo Leopold wrote an essay describing his lack of foresight when he recommended the strategy of removing wolves from southwest wilderness territories for purposes of maintaining larger deer populations to satisfy hunters, only to see the rangeland and other ecosystem elements impacted by the grazing of too many deer over time. In not considering the cascading effects from wolf extirpation he stated he had not yet "learned to think like a mountain" (Leopold, 1949). Leopold's concept of "thinking like a mountain" implies the need for thinking of time and the future in a way that is new to humans, a way of thinking in which understanding, care for, and moral responsibility all expand beyond the bounds of a single life, unfolding against the backdrop of multiple temporal and moral horizons (Norton, 2005).

The consumptive values of human individuals (i.e., hunting deer) exist on a short-term economic scale and are associated with relatively rapid, individualistic, economically organized dynamics, whereas the resulting impacts to ecosystems and species (the mountain) unfold over the timeframe of evolutionary scale (Norton, 2005). Leopold looked at the death of the wolf as symbolic of the degradation of the ecological systems because the loss of wolves from mountainous areas suggested the mountain and its healthy condition must live in "mortal fear of its deer" (Leopold, 1949). Leopold's call for thinking like a mountain embraced the scale-sensitive, multi-scalar, open, self-organizing systems of nature, implying that a conservationist must manage the entire mountain system and not a single species or single issue, reconfiguring the world into multiple scales.

Leopold discovered that his original evaluation presupposed a relatively stable system that would not be altered by the severe (violent) action of eradicating all wolves and most mountain lions, focused only on the short-term situation that created a temporary increase in deer populations and greater pleasure and opportunities for hunters. In contrast, for Leopold to think like a mountain was his recognizing the importance of multiple temporal scales and the associated hidden dynamics that drive them. These normally slow-scale ecological dynamics, if accelerated by violent and pervasive changes to the landscape, can create havoc with established evolutionary opportunities and constraints and threaten the system with collapse (Norton, 2005). Having moved from the wolf to the mountain by analogy, while "locating himself on the mountain," observing the mountain from within its context, a context that is strained on all sides by dynamics unfolding on multiple scales, Leopold showed concern for system integrity of ecological communities that change at the pace and on the scale of ecological transformation (Norton, 2005), instead of the scale of human satisfaction. He recognized that his original evaluation of the policy of wolf eradication took into account only its impacts on hunters' short-term welfare, a too-short scale of time to see important impacts. He learned that total removal of wolves exerted too violent an impact on the system; in the long run, the result was starving deer, stunted vegetation, and erosion of the mountain sides.

Leopold advocated being sensitive to differences of temporal and physical scale to analyze both the impacts and the associated values that affect managerial decisions. This approach views a natural system from a human perspective, inside-out, as open systems embedded in larger systems that change much more slowly. Therefore, to build a viable concept of sustainability, an individual or group must involve themselves in thinking like a mountain or a watershed, in order to adequately protect the natural resources in an ecosystem concept that support our socio-economic desires. Leopold's breakthrough, and a hierarchical interpretation of it, provides the guidance needed to start thinking and talking in new ways. And in this new way of talking scale counts: important human values will be missed - and destroyed - if we confine our concern to short-term considerations and impacts of our policies on economics alone. Ecological systems, human value systems, and social, managerial systems are all complex. The best way to deal with these layers of complexity is by developing and refining progressive space- and time-relative paradigms of human actions affecting natural systems, on the one hand, and corresponding hierarchical systems that track human values and the impacts of landscape change on those values, on the other (Norton, 2005).

So thinking like a watershed can be seen as an exemplary model of multi-scalar relationships and how they affect - and are affected by - our decisions. This model involves viewing a multi-scalar system from the perspective of an actor inside it and anticipates the spatial-temporal insights of possible system changes (Foster *et al.*, 1998). We can now summarize the key idea suggested by Leopold's analysis of his wolf-eradication policy. It is useful to perceive human decision-makers as embedded in a hierarchical system and to see that the human values delivered by that system emerge on different scales of space and time. Once values are so sorted, it may be possible to associate these variables with natural dynamics essential to their continuation. Watersheds, from Leopold's experience, cannot be independent centers of values that compete with human values. By reconstituting our perception of natural systems as multi-scalar, Leopold encouraged a pluralistic approach to evaluation, an approach according to which humans may, and eventually must, evaluate changes that emerge on multiple scales, including both the scale of individual economic activity and watershed-wide, multi-generational scales.

Given its suggested emphasis on temporal horizons of human impacts, thinking like a watershed links human actions and their impacts to more than one natural dynamic unfolding on different scales in time and space. Today's decisions, often evaluated in the short-term calculus of economics, can lead to long-term impacts that change the system subsequent generations will encounter. Watershed thinking thus evokes dimension and scale in connection with human responsibility, recognition that there are rhythms and dynamics in nature that we do not experience as immediately relevant to us, but which affect our world by changing dynamics we have hitherto taken for granted. This form of thinking reconstitutes the world we experience as a complex world, where impacts of our actions unfold on different scales and dimensions and where humans are seen as capable of more and more "violence" in the management of natural systems (Norton, 2005).

One doesn't stop thinking like a consumer, however, when one learns to think like a watershed. Thinking like a watershed incorporates our local and day-to-day concerns; but it adds also the awesome responsibility that comes with the recognition that our decisions today, in a technologically powerful society, can have impacts on longer and larger scales. If you want to manage for human goals from within a dynamic, open-ended ecosystem, you cannot look at only one level of impacts, at only one component to which your managerial actions will be directed (e.g. the wolf). One must continue to assume that individuals will express their preferences and economists will aggregate them according to "demand" and "supply" models. But no single-level economic rule could adequately characterize a decision in a complex system. Good decision making in complex systems necessarily involves both applying rules (e.g., maximization-optimization) and being reflective regarding which rules are appropriate and necessary to apply in given situations. The latter process requires altering and re-balancing our rules when experience tells us our actions are too violent, too pervasive, or too difficult to reverse. Making such determination requires both good judgment and good science that can be assisted by thinking like a watershed.

The Role of Adaptive Management

Leopold's greatest contribution in thinking like a mountain and its transformation here to thinking like a watershed, is not in musings about extending moral consideration, but in reconstituting the perceptual field of environmental managers. He formulated the world of an adaptive manager, planning, doing, checking, and acting within a complex, dynamic system as a guide to adjusting our behavior. Leopold first recognized that managers cannot view species and ecosystems as simple, "external" objects because the manager is also an actor on the same stage with individuals, species, and ecosystems; the manager necessarily participates on all these levels and scales, having impacts on multiple dynamics that will play out over different time horizons (Norton, 2005). Following Leopold's example hierarchy theory, a form of general systems theory that attempts to understand space-time relationships, was introduced as a formal and reasonably complete method for relating multiple scales to each other (Holling, 1992). Leopold's simile of thinking like a mountain was rich enough to include goals, even deep values. Adaptive management concepts, by incorporating Leopold's simile, embody the formalizations of hierarchy theory within an action context in which social values direct our attention to relevant experience and experiments.

Adaptive management is the search for community practices that maintain the options important to a culture living in a place - a strategy that can both reduce uncertainty regarding particular matters affecting management decisions and reduce disagreement about goals, objectives, and values. Adaptive management starts where we are and struggles toward better policies through social learning, providing a very simple model for conceiving the difference between sustainable and unsustainable communities. Adaptive management is a decision-making processes that effectively integrates both short-term and long-term economic, environmental, and social concerns. It provides a mechanism to evaluate and fully consider all the other principles discussed above. It also provides an excellent opportunity for the integration of both the expert-way-of-knowing and the citizen-way-of-knowing, often referred to as citizen science (Flint, 2004a). This strategy is built upon the premise that people learn from their actions, as well as their mistakes. An adaptive, learning-based approach to the practice of sustainability implies the constant attention to and evaluation (monitoring) of activities to ensure one's continuous awareness and understanding of changes in circumstances, looking for ways to maintain flexibility by identifying feedback loops, making sure they give timely and relevant information, and then paying attention to them, being prepared to abandon unsuccessful strategies (Ruitenbeck and Carder, 2001).

One can see the more positive implications of thinking like a watershed by considering the three central principles of adaptive management. These axioms are the endorsement of an experiential, experimental approach to management; a statement that natural systems, as managed, are multi-scalar (multidimensionality); and a statement that all observations, measurements, and activities are experienced from some identifiable point in a larger, dynamic system (internal location of observers). It should be noted that the first principle stands as the defining characteristic of adaptive management; evaluations as well as descriptions must be tested experimentally through both the use of science in management and a collaborative process in which participation and social learning are an important part. Adaptive management also suggests the constant attention to and evaluation (monitoring) of activities to ensure one's

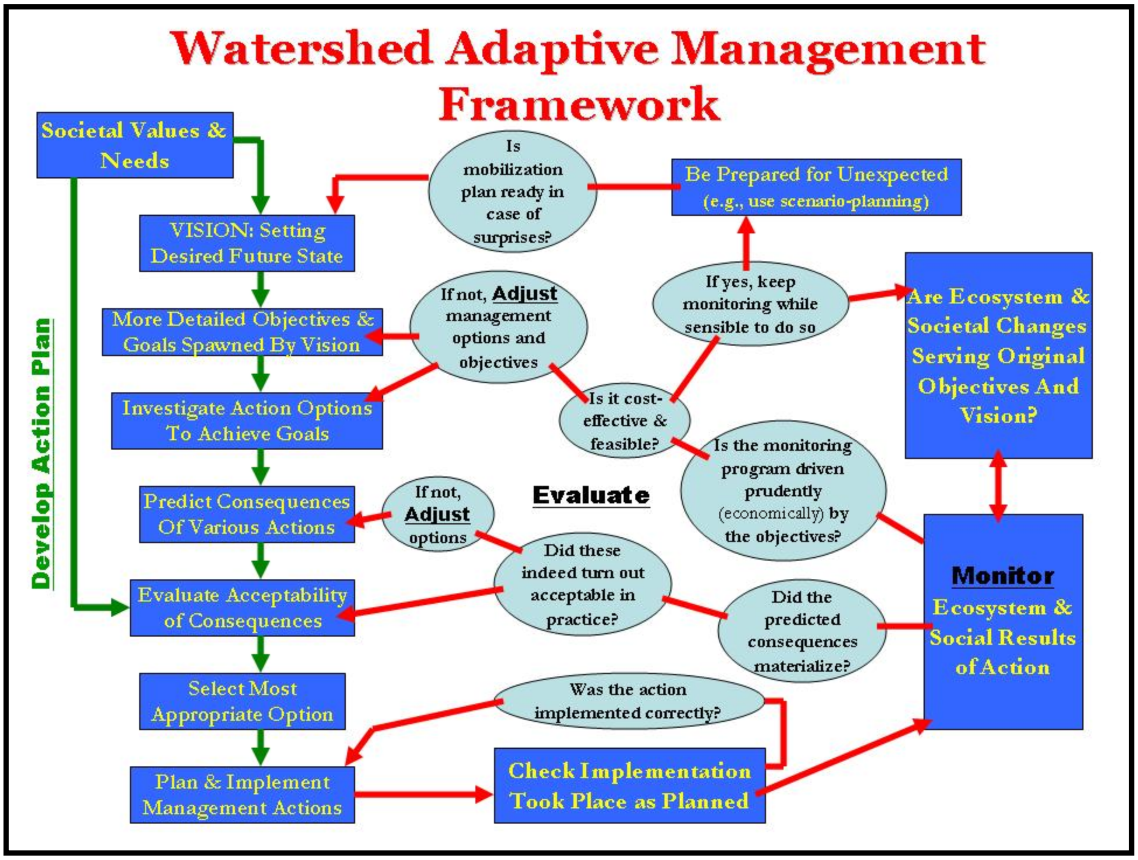

Fig. 1. A conceptual model of decision-making involved in an adaptive management process. Concept developed after ideas from Biggs and Rogers (2003).

continuous awareness and understanding of changes in circumstances, in order to feed-back information to decision-making endeavors. The same philosophy that governs the search for scientific understanding also governs the search for better management solutions and guides revisions of values and evaluations when observation and experience indicate the need for such revisions. It is a necessary and useful tool because of the uncertainty about how ecosystems function and how management affects these natural systems. Such an adaptive approach refers to:

- improving decision-making;
- enhancing linkages among different dis ciplines, including science and policy; and
- maximizing lessons learned from dif ferent experiences.

As illustrated in Fig. 1 (after Biggs and Rogers, 2003), the adaptive management procedure includes the .following components:

- To develop a plan for managing a system or resource.
- To create processes to monitor changes in the system or resource as affected by the management plan.

- To evaluate system trends using the monitoring data.
- To modify the system or resource man agement plan as necessary, indicated by the evaluation process.

Adaptive management offers significant hope for moving beyond the quagmire of traditional decision-making because rather than imagining that the policy formation process is carried out in two realms - the realm of science and the messier realm of policy, goals, and values - citizen science dialogue will bring the realms of science and social values together in a process of adaptive management, having two related phases, an action phase and a reflective phase (Norton, 2005), guided by thinking like a watershed.

Often an ecosystem-scale changes as a response to societal impact occurs more rapidly or is larger than expected because communities in general are non-linearly interacting systems of one or more components, with abundant feedbacks. Most of these changes are surprises, so scientists and managers must be flexible (adaptive) to accommodate these surprises. Surprises become well incorporated into scientific understanding when they form the basis • for further predictions that are confirmed through an adaptive approach. The understanding from these unintended experiments and their surprising outcomes, as gained in the reflective phase ("evaluation" in the diagram above) will lead to "adjustments" in management practices. This is especially meaningful to environmental managers because it provides the ability to formulate and implement policy as well as to more easily understand ecological systems.

Adaptive managers do not claim to know in advance what policies are sustainable or even what the goals of sustainable living are, but rather accept uncertainty and surprise as an unavoidable element of goal-setting and management decisions. Thus, they propose an open-ended, experimental approach to the management of community capacity building in the present circumstance of pervasive uncertainty. It is hoped that this strategy will result in social learning, in the emergence of shared goals and policies, and in greater environmental protection and economic security. The possibility of social learning is therefore the central driving force of adaptive management; and this driving force should sharply focus our attention on the deliberative and political processes associated with an adaptive management partnership. Adaptive management is thus a strategy that can both reduce uncertainty regarding particular matters of fact affecting management decisions and reduce disagreement about goals, objectives, and values.

In this management process the community formulates the overall problem, by thinking like a watershed - the problem to which a unified definition of sustainability will hopefully provide a solution - as one of choosing more than one criterion to form a multi-criteria system of evaluation. This multi-criteria system of evaluation can be applied to proposed development paths, considered as possible paths from where a community now is, to where it might be in the future, if particular choices are made and particular policies are chosen. Adaptive management describes a strategy that starts where we are and struggles toward better policies through social learning. Adaptive management, if supplemented with a good beginning of options and opportunities (graphic understanding for sustainability), provides a very simple model for conceiving the difference between sustainable and unsustainable communities (Norton, 2005).

The Use of Indicators in Water Sustainability Management

Thinking like a watershed, employing the idea of hierarchy theory, which has been introduced into ecology as a way of relating processes that occur on different scales (Holling, 1992), and taking a system's perspective that builds upon much of what we already know, lies at the foundation for understanding interactions among the various forms of environmental, social, and economic capital and the processes that most directly affect them in order to guide better decision-making for the sustainable development of water resources. The building blocks for implementing a system's perspective rest in the development of water resource sustainability indicators. Communities need a believable means of setting sustainability goals and then determining the degree to which these are reached. Policy-makers also need "early warning signals" of poor performance that can enable appropriate adjustments.

Citizen science applications can assist an open public process in developing adaptive management strategies that rely upon monitoring indicators. Experts can contribute to this procedure by helping the community to understand key environmental and economic processes and to identify measurable variables that may be important. Interest groups can play a role, because they will want to insist that the indicators chosen reflect the values they support and that the standards chosen are appropriate from their perspective. In the process of disagreement, managers can identify important areas of uncertainty and differences and propose "safe-fail" experiments to reduce this crucial discord (Norton, 2005). A provisional decision can be made, to proceed with particular, proposed indicators and to apply a proposed set of standards. The reflective phase is then replaced by the action phase, wherein the community again chooses particular actions and policies and sets out to judge these according to appropriate criteria - that were sanctioned in a previous reflective phase.

After a consensus is developed with regard to criteria that describes the future longevity of healthy water resources, indicators to measure sustainability can be defined. The role of an indicator is to make complex systems understandable and perceptible (tangible). It clarifies a problem or condition to show how well a system is working. Indicators point the way and mark progress toward a community vision of sustainable development (Flint, 2004b). An indicator creates a snap shot of a resource's economic, social, and environmental system conditions and provides the opportunity to better understand past trends so that appropriate decisions can influence future directions of development. A good indicator alerts one to a problem before it gets too bad and helps recognize what needs to be done to fix the problem.

Indicators of sustainability link economy, environment and society, and point to where these links are weak. For example, an economic indicator that does not include environmental and social effects will not

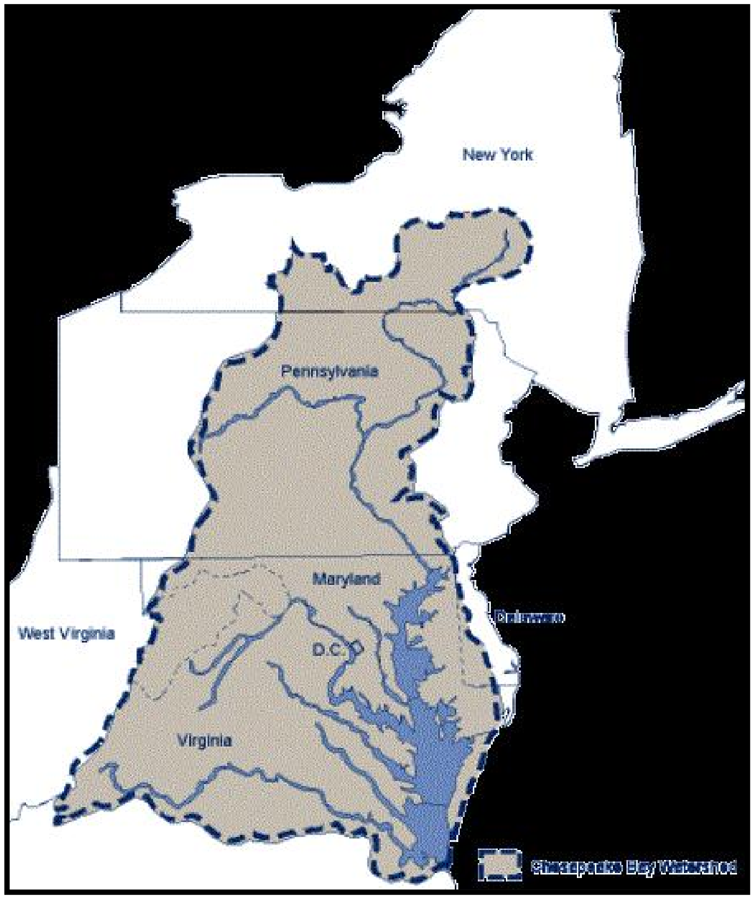

Fig. 2. Map of the Chesapeake Bay watershed in the United States of America.

help move water resource protection in a sustainable direction (e.g., the Missouri River conflict discussed above). Likewise, an environmental indicator that does not take into account economic and social impacts will not provide adequate insight into the best way to improve water resource health and vitality. Indicators will tell decision-makers and society in general how we are doing toward the achievement of sustainable use with regards to water resources.

Examples of Thinking Like a Watershed

Chesapeake bay

We can look at the Chesapeake Bay for an example of environmental decision making as well as adaptive management as an iteractive and constructive process, guided by thinking like a watershed. The process will not start by trying to achieve widespread agreement with a single value or a single way of measuring value; it will rather proceed as participants propose, discuss, and deliberate about what trends and features of their environment should be monitored and which of these can be treated as indicators that correspond to various management goals and community objectives. In this way the values of community members will be extremely important in public discourse and deliberation because people will appeal to their core values as they argue for the importance of particular trends, features, and indicators. They will be saying that, given the values they hold dear, given their aspirations for their place, they think certain goals should be set, as tentative starting points for management actions. They will also be recommending that these goals be stated explicitly in terms of a physical, measurable indicator that allows assessment of the management process over time.

A good example of such a process, including the choice of a widely affirmed indicator, came very early in the attempts to save the Chesapeake Bay from degradation in the face of rapidly escalating impacts of regional urbanization and agricultural intensification (Fig. 2). Following a large US Environmental Protection Agency study in the early 1970s, formation of a multi-state compact to address the Bay's problems, and considerable discussion and deliberation (US Environmental Protection Agency, 1987), the goal was set to reduce the flow of nutrients into the Bay by 40%, a goal that was recently reaffirmed (US Environmental Protection Agency, 2000). Here we have an example of a process - suffused with values and love for the Bay and for the many distinct communities that exist there - generated by a public discourse concerning turbidity in the Bay. The urgency of this discourse drove scientists to do basic research that led to the conclusion that the main continuing threat to the Bay was widespread sources of nutrients: from sewage outflows, and from runoff from farmers' fields, suburban lawns, highways, and parking lots. Through public discourse over a period of a decade or so that included ongoing involvement of scientists and managers, Bay residents evolved a broad "mental model" of Bay pollution based on the hypothesis that the decline of submerged aquatic vegetation was a result of explosions in planktonic populations that were living on excess nutrients and threatening to turn the waters anoxic when they died and decomposed.

This public discourse led to an important re-conceptualization of the problem of Chesapeake Bay pollution (Horton, 1987). Old maps of the Bay were discarded, not because of changes in erosion or political boundary shifts, but because a new perception of the Bay "system" was emerging. The public discussion eventually worked; through the contributions of scientists, politicians, and many others, the public developed a new spatial model that related values placed on the Bay to a new, watershed-scale dynamic. People gradually learned that to think like a bay, one has to first learn to think like a watershed. This process exemplified social learning at its best, because communities that once related to the Bay locally were able to add another scale to their understanding and to their sense of responsibility.

The emergence of this mental model of bay degradation resulted in the identification of an important indicator - bay water clarity - which was, in turn, related to a landscape-scaled dynamic, the rate of nutrient and sediment loading from various sources. Water clarity, as an indicator of success of efforts to save the Bay, was then related in many different ways by many different people to their own values and feelings about what was important to them. The choice of water clarity as a key indicator not only solidified action and resolve on the part of the public, the states, and the agencies; it also expressed concretely the many ways the communities around the Bay valued it. Taking aggressive action to reduce nutrient-loading and sediment erosion, hypothesized to be driving the increase in turbidity (Newcomb and Jensen, 1996), was a positive expression of values placed on a variety of bay-dependent options, including fishing, boating, and maintaining tourism-related businesses. The indicator of water clarity, as was pointed out by scientists during the public deliberations, can be expected to track reductions in nutrients and sediments entering the estuary. The variable of .water clarity singles out possible nutrient and sediment problems from a number of sources in the watershed, including:

- forest practices
- nutrient loading
- agriculture practices
- impermeable surfaces
- transportation
- recreation
- solid waste
- erosion
- spills
- stormwater
- urbanization/land development
- waste water systems
- mining

This variable, in turn, is important in many ways. For example, submerged underwater grasses, which depend on the penetration of sunlight, are the foundation of the complex bay food web, which supports populations offish and shellfish. Water clarity is essential to the widespread practice of "crab dipping", and of course it affects the quality of boating and swimming experiences. People's evaluations, in other words, were summarized and expressed in the choice of a key indicator that could be scientifically or otherwise related to important social values. It is, like percentage of pervious surfaces, a pretty good measure of broad processes that affect many important social values in this region. Rather than measuring the economic value of all of these activities and then aggregating all of the ecosystem "services" derived from the process, trying to achieve a uniquely efficient or welfare- maximizing outcome, the process involved choosing a measurable physical-ecological indicator and setting a specific goal regarding reduction of nutrients by a specific date. In this setting ecological, lexicological (linguistic), biological, economic, anthropological, and sociological evidence was relevant and could be brought to bear upon the public discourse in which indicators and goals were proposed, advocated, criticized, and reformulated.

New York City watershed

The New York City (NYC) Department of Environmental Protection (DEP) delivers a daily average of 4.9 billion liters of safe drinking water to nearly eight million New Yorkers, another million people in upstate New York, and millions of daily commuters and visitors to the city. The City's drinking water is of excellent quality and only

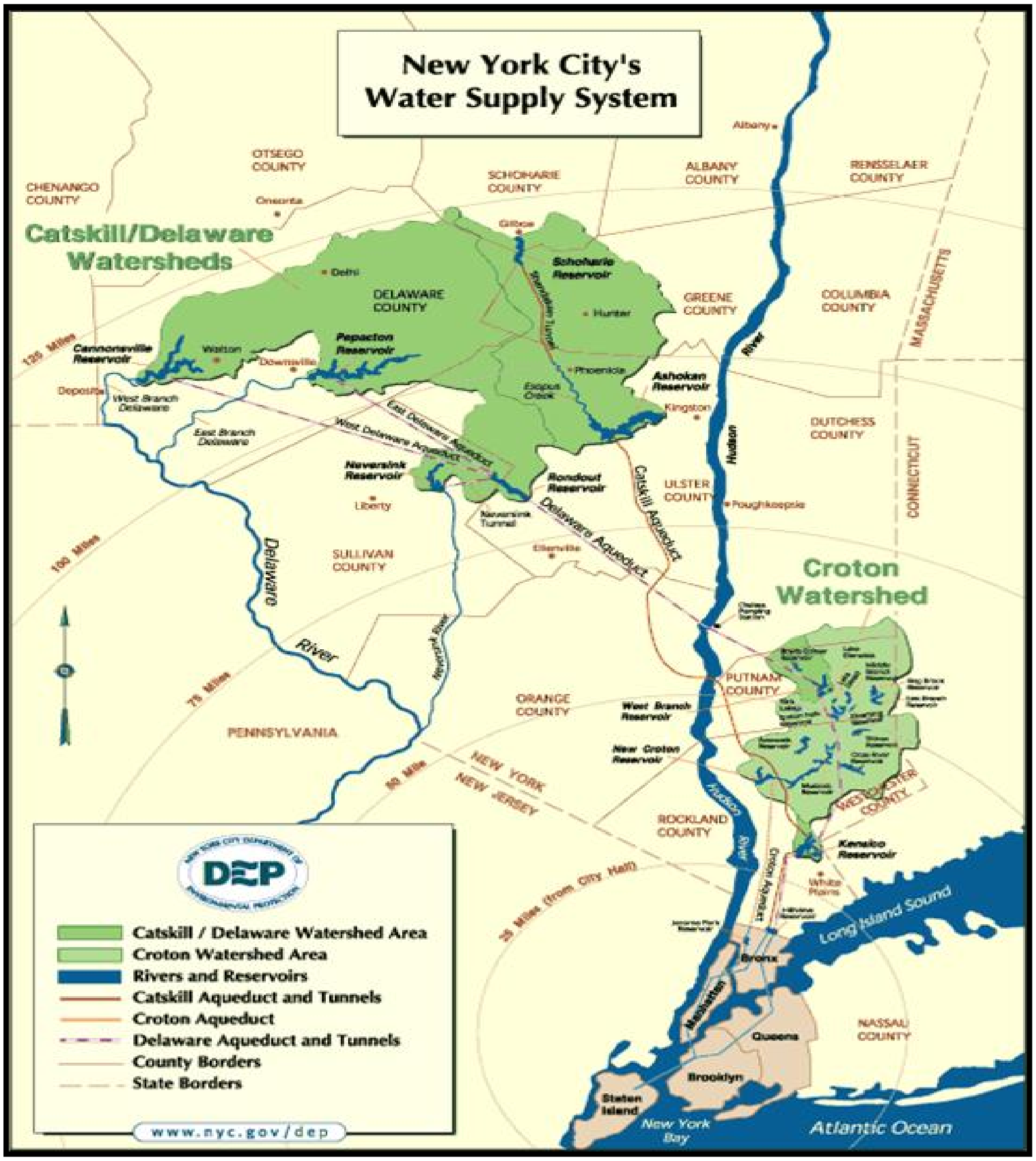

Fig. *3. Map of the New York City watershed in the United States of America.*

requires chlorination to ensure its purity at the tap. But this did not come without years of evaluation and ingenuity. This system, with a storage capacity of 2,082 billion liters, comprises 19 reservoirs and three controlled lakes, an area covering over 4,921 sq. km (Fig. 3). New York City's water supply system is based on a natural yet highly sophisticated principle: rain or snow falls in the watersheds, flows into streams and rivers, and is collected in reservoirs (Miele, 1998).

In 1986, the federal Surface Water Treatment Rule was enacted. This legislation required that surface water supplies, like New York City's, filter their water, prove that their water meets strict quality criteria or, if necessary, implement comprehensive watershed protection programs. At that point in time, New York City, which for decades had believed its unparalleled water immune to the threat of pollution, had to face the fact that certain land uses in the watershed region posed serious threats to the future of its drinking water. The City faced two options: to either develop and implement a comprehensive watershed protection plan, or build a filtration plant, estimated to cost between $ 6 and $ 8 billion. Operating and maintenance costs of this plant — estimated at $ 300 to 500 million per year — would have been passed along to consumers and would have drastically impacted the City's water rates.

In 1990, after an in-depth study, the City decided to develop a comprehensive watershed protection plan. The watershed protection program is an environmentally wise and fiscally smart program that provides the highest degree of water quality protection. This natural approach protects water at the source, while preserving the economic viability and traditional rural life style of the watershed region. The protection plan, however, drew bitter criticism both from upstate communities and New York State itself.

In the watershed, where forestry and agriculture account for almost 90% of land use, family farming has long been the economic backbone of the region. Of approximately four hundred commercial farms in the watershed, 90% are dairy and livestock farms. The climate of the region, highly favorable to quality grass production, forage and corn crops, makes farming a natural activity. Although watershed forestry and agriculture are environmentally preferable to suburbanization, some aspects of these activities present threats to water quality. The City, recognizing this fact when preparing its protection plan, considered regulations that would control farming activities. Farmers in the watershed, however, viewed the proposed regulations as a threat to their economic survival. Outcomes of negotiations in 1997 resulted in the Cky and watershed farmers forging a partnership for the implementation of the watershed agricultural program, a voluntary and locally developed effort. This program was designed to fine-tune "whole farm planning", an environmentally sound strategy to farm management. It involved best management practices that were innovative approaches to prevent agricultural non-point source pollution and increase farmers' productivity. While many approaches to farm management used in the watershed agricultural program were not new, combining them into an integrated strategy represented a significant innovation. The City committed $ 38.2 million to the program.

The total watershed program also included economic benefits for the upstate farmers. The City provided new mechanism for offering markets to the farmers that significantly expanded their traditional production of farm products and also allowed them to develop new products that had an immediate market, such as acreages of gourmet potatoes and other specialty produce they sell directly to New York restaurants.

Forested lands constitute the single largest usage of watershed land west of the Hudson River. Activity in this area can have dramatic impacts on water quality. The success of the Watershed Agricultural Program led representatives from the forest industry, landowners, foresters and timber harvesters, together with New York, City and state agencies, to create a forest management program modeled after the successful agricultural program.

The New York City watershed protection program not only protects water quality and the economic viability of the watershed region, but also serves as a showcase in cooperation and conflict resolution. Furthermore, the program demonstrates the fallacy of the old belief that environmental and economic needs cannot be balanced. In fact, the watershed-wide initiative is living proof that watershed protection programs can do more than protect water quality: they can be powerful tools for enhancing local economies. In conclusion, NYC found an opportunity to save its water rate-payers billions of dollars by avoiding filtration while protecting drinking water quality through targeted land acquisition and other water quality investments and regulations that ensured watershed development would be environmentally sustainable. In turn, communities in the upper reaches of the watershed have been able to build a future that guarantees improved water quality, a better-protected, amenity-rich landscape, and compatible economic development, including enhanced ecotourism opportunities.

Lake Tahoe/Northern Nevada Watershed

As development expands in the Reno-Tahoe-Carson Region there are a number of known impacts that can potentially result in decreased water quality available for human consumption as well as ecosystem health (Flint, 2006). These effects can come from: ;

- new suburb development (sprawl)
- diverse land-uses
- agricultural runoff
- forest removal and related erosion
- sewage outflow
- storm water runoff
- automobile emissions
- groundwater recharge of lower quality water (degrade the aquifer quality)

Degraded water quality from these activities, as well as others, not only impacts human health, but can equally affect the natural environment by interfering with ecosystem services that we rely upon for our quality of life and maintenance of healthy places to live. In the Reno-Tahoe-Carson Region there were two factors that consistently challenged effective management of water resources: (1) the after-thought nature of concern for water quality in planning, especially in the Reno/Sparks area, and (2) the lack of viewing the entire region from a watershed perspective. If the watershed approach to discussing issues and acting throughout the region were adapted the issue of water quality would definitely move from an after-thought to an actual integrated part of the planning process. This is an absolute necessity for the future sustainable vision of the region.

Overcoming the obstacles presented by these issues of after-thought and lack of watershed perspective were addressed by encouraging the communities to give consideration to the fate of a drop of water as it moves throughout the regional watershed. After spending more than 700 years in Lake Tahoe, exposed to the basin activities that occur including logging and related erosion, new home building and associated water runoff, new road building, etc., this drop of water begins its journey down the Truckee River (Fig. 4). In addition to being exposed to the almost doubling of population in Truckee over the next 20 years with associated development, the drop of water must meander along the river banks for a number of miles where there are numerous potential opportunities for land-use activities that will degrade the water quality. In reaching the Northern Nevada valleys this drop of water might be impacted by storm water runoff and associated dangerous chemicals as it continues its trek to Pyramid Lake. It also might be taken out of the Truckee River and used for commercial or residential purposes that will certainly change the quality of the water drop with regards to human waste products, toxic chemicals, hormones, and other potentially dangerous materials. Ultimately this drop of water might find itself encountering the sewage treatment plant or entering the ground in a septic system/leach field complex. The treatment facility will put the drop of water back into the Truckee River to continue its travels to Pyramid Lake. The septic system will put this drop of water into the ground, ultimately to become part of the groundwater.

The people of the Lake Tahoe basin had a relatively good appreciation for the fate of this drop of water in their part of the watershed. The Northern Nevada valley areas, however, did not show as much of an appreciation for the fate of this drop of water and potential changes in its quality. This may be due to the fact they believe they use so little of the available water supply now (less than 12%) and therefore represent minimal potential for degrading the quality of that water. But as growth in the valleys continues, these factors of influence will not continue to remain the same. As this watershed approach to assessment suggests, the time to enact protection for the future quality of water in the region is now when regulatory agencies do not have to "catch-up" with a run-away-train. In considering what the environmental, social, and economic implications from this drop of water story (thinking like a watershed) are, the regional jurisdictions have begun to look at conservation-based development and low impact development (LID) as additions to the Lake Tahoe/Northern Nevada strategic plan for achieving sustainability.

Logging in a watershed

Consider the example where all the landowners in a region of a watershed simultaneously clear-cut their forested areas in response to the significantly increased market value of wood, a strong economic incentive (Norton, 2005). Once the land is cleared the community leaders believe the forest clear-cutting can be mediated by the development of an industrial park and retail

Fig. 4. Map of the Lake Tahoe - Northern Nevada watershed in the United States of America.

stores on the cleared land, thus providing jobs not only for the present generation but also for those members of the community in the future. As Norton (2005) cites, "good investment has given the community a more mature, stable, and even more diverse economy" than taking a different forest harvesting strategy would have. The thinking is that people of future generations will be better off because they have more economic opportunities than a forest economy would offer them. But what about those people and communities harmed according to "non-economic criteria", the constraints placed on their future choices from loss of forested lands? For example, the loss of the forests can translate into global climate change effects over the long-term, as well as increased erosion (Fig. 5), impacts on water storage and recycling, increased flood threats, and the loss of aesthetic appreciation a viable forest ecosystem can provide many. People thus have equal or better economic opportunities than their ancestors, but do they have more social and environmental benefits? The focus on a single economic driver took precedence over thinking like a watershed!

Solutions

Certainly, the watershed stories told above provide ample evidence of potential solutions to our contemporary economic, social, and environmental problems of water resource management. All of these examples speak to the comprehensive, conservation-minded idea of Leopold in thinking like a watershed.

Although we need only about 1.5 to 2.0 quarts of water per person per day to stay alive, the total human population needs the balance of the water resources in the atmosphere, oceans, ice, wetlands, and other aquatic systems to buffer the processes of all living things and natural dynamics on Earth. These masses of water provide crucial functions by absorbing and redistributing energy and waste products from life forms. They shield us against the atmosphere's fluctuations in gaseous content. And they offer transportation and provision of conversion sites for nutrients in food chains. If such resources are spoiled, conditions for human life will inevitably deteriorate. A person's 1.5 to 2.0 quarts of water won't save them because we don't know specific quantities that constitute a sufficient buffer. Policies must reflect and be built on the conservative natural distribution and use of the world's total resources. As we can only gain an understanding on these total water resources by thinking like a watershed, in contrast to traditional, piecemeal approaches to water resource management we often compromise on.

To encourage "thinking like a watershed" in the management and regulatory arena incentives must be developed to cover these added costs to resource protection (Johnson *et al.,* 2001). The costs of watershed management have been almost universally neglected in water pricing. Meanwhile, pollution continues to grow, because regulations are often ineffective, and polluters are rarely charged for damages caused by their effluents. Equitable market-oriented mechanisms are an essential part of sustainable water management solutions. A first step toward sustainable water management is to improve efficiency by setting prices that reflect the true costs of supplying and distributing water. This step would encourage additional conservation of water in diverse use settings. A second step is to include the cost of adaptive, integrated watershed management in the price of water. Ecosystems and land-uses influence water flow and water quality in a variety of ways. Watersheds, however, are routinely ignored in water management. Conserving natural forest and wetland habitats, creating buffer zones along rives and streams, shifting away from farming and road-building on steep slopes, and avoiding agricultural chemical use in sensitive areas can help achieve water management objectives. A third way to achieve sustainable water management is to charge polluters for their effluents. A variety of tools exist to accomplish this step, including permit fees, discharge levies and fines, and "green" taxes. Trading schemes are also considered a promising approach (Johnson *et al.,* 2001).

Another solution to achieving sustainable water resources that certainly requires thinking holistically like a watershed involves considering the relationship of several different watersheds, possibly in different parts of the world, and how they can relate to one another with regards to trade, economies, and depleted natural resources. Consider the story of "Virtual Water" (Lant, 2004). Including soil water

Fig. 5. Effects of watershed erosion on community infrastructure development.

in the analysis of water required to support agriculture, especially in humid regions, suggests that about 90% of water consumption is devoted to food production. One thousand tons of water is required to produce one ton of grain. Grain, being non-perishable, is much less expensive to transport than is the water used to grow it. There is 2-3 order of magnitude variation in freshwater availability per capita among regional watersheds, as well as nations. Consider the long-standing campaign to export water out of Great Lake's watersheds to the southwestern US.

Wolf (2003) and others suggest that arid regions of the world can greatly benefit from importing virtual water in the form of grain and .other food trade items, thus freeing up their own limited supply of water for other purposes than food production. The 1000 tons of water, most of it rain, used to produce the ton of traded grain is what represents the idea of virtual water. For the importing region or country, this represents an increase in net water available to the populace. Virtual water also allows wetter countries to use their comparative advantage to, in effect, export rain via soil water and grain.

Therefore, it is economically sound for countries with water scarcity to import grain rather than develop water for irrigation and sometimes to reallocate water now used for irrigation to higher value uses and replace lost grain production with imports. Middle Eastern and North African countries have been increasing grain imports, and by so doing have so far generally avoided conflict over water resources.

Conclusions

Currently hundreds of organizations work on water, focusing on many different water concerns. Although our institutions serve us well, they face a future in which water quality, water availability and use, fresh and coastal waters, surface and ground water, and physical, chemical, and ecological characteristics must be considered simultaneously in geographical settings of wetlands, watersheds and habitats. This great variety of water resources topics also must be related not only to other environmental and natural resource topics, but also to all the aspects of our national economy and culture.

More than one-sixth of the world's population does not have access to safe water supplies. The potential conflicts from this disparity are frightening. The escalation of a water crisis is due essentially to the unsustainable use and management of water resources and to the destruction of ecosystems such as forests, wetlands, and soil that capture, filter, store, and release water (Iley,.2003). Through our evaluation of water resource sustainability, we can increase public awareness about the challenges the world is facing in relation to water, as well as change the way the water issue is perceived: from being a driver of conflict to being a catalyst for collaboration (e.g. virtual water concept). Ideals of preservation and protection on the one hand, and of economic vitality and opportunity on the other, are not in conflict, but rather in a sustainable future they are linked together. And, we recognize our limited ability to see needs of the future. Therefore, any attempt to define sustainability, including its many interconnections by thinking like a watershed, should remain as open and flexible as possible, through the use of adaptive management, guided by indicators of sustainability that integrate much of what we already know into effective resource management tools.

Humans must accept responsibility for all of the impacts of their actions, especially if those impacts are irreversible and pervasive; and if they do not know those outcomes in advance, it is their responsibility to learn, to engage in pilot projects and limited experiments with time frames long enough to provide information on the intergenerational implications of their actions. This is where the idea of thinking like a watershed intersects with the carrying out of adaptive management strategies. All the essentials of a pragmatic, activist inquiry are present in the multi-scalar, ecosystem approach to thinking through proposed policies according to economic impacts (short-term dynamics) and also according to the long-term dynamics affecting a mountain, a bay, or a watershed.

Leopold's emphasis on economic values in his simile about thinking like a mountain caused him to pay attention to shorter-scaled physical dynamics. If one were to emphasize long-term values, such emphasis might encourage study of longer-term dynamics, for example erosion and siltation of watershed streams. Choosing important dynamics to study and choosing which values to protect stand in a chicken-and-egg relationship (Norton, 2005). One can never eliminate the crucial role that values play in directing our attention toward certain dynamics and away from other dynamics. Importance cannot be judged on purely scientific grounds, so if one has no idea what values to protect, one cannot determine which dynamics to monitor, what to study, and what indicators to emphasize in setting management goals. There are so many natural dynamics and so many possible ways to model them, that failure to focus on a few key dynamics will create a situation of such great uncertainty that management decisions will be impossible. Conversely, to talk about environmental values in universal terms, not based on any specific, local models of actual natural dynamics, will not result in progress toward locally chosen indicators and management goals. Thinking like a watershed, therefore, is thinking about human values as time-sensitive and as produced by specific processes and dynamics that unfold on identifiable scales. Discussions of social values must inform decisions regarding what to monitor and what models should be constructed; meanwhile, information about natural dynamics and likely impacts on them by human activities must inform and shape our understanding of what we value.

References

Bartlett, A.A. 1999. Colorado's Population Problem. *Population Press* 5(6): 8-9

Biggs, H.C. and Rogers, K.H. 2003. An adaptive system to link science, monitoring and management in practice. In *The Kruger Experience: Ecology and Management of Savanna Heterogeneity* (Eds. J.T. Du Toil, K.H. Rogers and H.C. Biggs), pp. 59-80. Island Press, Washington, DC.

Brown, L. 2006. Plan B 2.0. Earth Policy Institute, Washington, DC. http://www.earthpolicy.org/books/seg/PB2ch03_ss6.htm.

Flint, R.W. 2004a. Sustainable Development: What does sustainability mean to individuals in the conduct of their lives and businesses. In *Handbook of Development Policy Studies* (Eds. G.M. Mudacumura and M.S. Shamsul Haque), pp. 67-87. Marcel Dekker, Inc., New York, NY.

Flint, R.W. 2004b. The sustainable development of water resources. *Water Resources Update* 127: 41-51.

Flint, R.W. 2006. Water Quality within the Regional Watershed. In *Northern Nevada SDAT: Sustainability in the Reno/Tahoe/Carson Region* (Ed. AIA Center for Communities By Design), pp. 16-22. American Institute of Architects, Washington, DC.

Flint, R.W., Sterrett, S.B., Reay, W.G., Oertel, G.F. and Dunstan, W.M. 1996. Agricultural and environmental sustainability: A watershed study of Virginia's Eastern Shore. In *Watershed '96 A National Conference on Watershed Management* (Ed. Tetra Tech), pp. 172-175. Water Environment Federation, Washington, DC. 1163 p.

Flint, R.W. and Houser, W.L. 2001. *Living a Sustainable Lifestyle for Our Children's Children.* Universe, Campbell, CA (ISBN: 0-595-20013-3). 288 pp.

Foster, S., Lawrence, A. and Morris, B. 1998. Groundwater in urban development. *Technical Paper #380*, The World Bank, Washington, DC.

Holling, C.S. 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. *Ecological Monographs* 62: 447-502.

Horton, T. 1987. Remapping the Chesapeake. *New American Land,* September-October, 1987: 7-8.

Iley, K. 2003. Saving forests is the best way to cheap, clean water, says study. Environment News Service. [Online] URL http://www.enn.com/news/2003-09-02/s_7928.asp.

Johnson, N., Revenga, C. and Echeverria, J. 2001. Managing water for people and nature. *Science* 292: 1071-72.

Lant, C. 2004. Water resources sustainability: an ecological economics perspective. *Water Resources Update* 127: 20-30.

Leopold, A. 1949. *A Sand County Almanac and Sketches Here and There.* Oxford University Press, Oxford, UK.

Meile, J.A. 1998. Maintaining Water Quality that Satisfies Customers: New York City Watershed Agricultural Program. International Water Supply Symposium, Tokyo, Japan.

Newcomb, C.P. and Jensen, J.O.T. 1996. Channel suspended sediment and fisheries: a synthesis of quantitative assessment of risk and impact. *North American Journal of Fisheries Management* 16: 693-727.

Norton, B.G. 2005. Sustainability: A Philosophy of Adaptive Ecosystem Management. The University of Chicago Press, Chicago, IL.

Quaid, L. 2003. Missouri River Ruling Could Hinder Water Quality. Environmental News Network [Online] URL - http://www.enn.com/news/2003-07-15/s_6555.asp.

Ruitenbeck, J. and Cartier, C. 2001. *The Invisible Wand: Adaptive Co-management as an Emergent Strategy in Complex Bio-economic Systems.* Occasional Paper No. 34, Center for International Forestry Research (CIFOR), Jakarta.

Saeijs, H.F.L. and M.J. Van Berkel. 1995. Global water crisis, the major issue of the 21st Century. *European Water Pollution Control* 5(4): 26-40.

UNESCO 2003. Water for People, Water for Life: The World Water Development Report. World Water Assessment Programme, United Nations, NY. [On-line] URL - http://ens-news.com/ens/mar2003/2003-03 -05-02. asp).

US Environmental Protection Agency. 1987. Chesapeake Bay Agreement. US Environmental Protection Agency, Chesapeake Bay Program, Annapolis, MD.

US Environmental Protection Agency. 2000. Chesapeake 2000. US Environmental Protection Agency, Chesapeake Bay Program, Annapolis, MD.

Vorosmarty, CJ. 1997. The storage and aging of continental runoff in large reservoir systems of the world. *Ambio* 26: 210-219.

Wolf, A., Stahl, K. and Macomber, M.F. 2003. Conflict and cooperation within international rivers basins: the importance of institutional capacity. *Water Resources Update* 125: 31-40.

Worster, D. 2000. *A River Running West: The Life of John Wesley Powell.* Oxford University Press, London, UK.