A FRAMEWORK AND GUIDELINES FOR MOVING TOWARD SUSTAINABLE WATER RESOURCES MANAGEMENT

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ABSTRACT

Because water is essential for survival, it touches every sector of life – environmental, economic, and social. There are no policies, practices, or procedures in any sector that do not directly or indirectly affect water. Many water resources management frameworks, however, typically focus on only one or two of these sectors. To move toward sustainability, it is critical that water resources management frameworks address the interactions among elements in each of these sectors.

This paper presents a conceptual framework and guidelines that integrates ecological, economic, and social considerations through institutional and legal/regulatory constructs to move toward sustainable water resources management (SWRM). Implementation of the framework is guided by a process flow-chart that considers both crisis management and proactive management activities. Nearly all the information needed to move toward sustainable water resources management is available, but dispersed throughout the literature.

KEY WORDS

Sustainability, water allocation, water supply, planning, water policy, environmental indicators, climate change/variability, water scarcity economics, water quality economics, education, public participation.

INTRODUCTION

Over the past several decades, there has been a growing recognition of the water crisis developing throughout the U.S. and the world (Gleick 1996, 1998a; NRC 1992, 2000, 2001; Postel 1992, 2000a; United Nations 1992). Water quantity and quality are major issues in a world with a population of about 6 billion people that is expected to grow to 8.9 billion by 2050 (Postel 2000b). Globally, about 30,000 people a day, almost 11 million per year, die because of water scarcity or water-borne diseases (Hamlin 2001).

Water resources are expected to be, and in some cases already are, the growth-limiting factor for development at local, regional, national, and international levels (Gleick 1998b, 2000; Postel 2000a, b; UNESCO 2002). In this context, water is subject to multiple quantity and quality demands that often conflict. In 2001, for example, farmers in the West challenged federal marshals to gain use of water for irrigation that was needed to support endangered fish species. In the same year, Anheauser-Busch experience increased prices and reduced availability of barley and aluminum due to the reduced irrigation water and hydropower generation as a result of the western U.S. drought (GEMI 2002). Eastern reservoirs that had firm yields prior to 1970 are experiencing greater than project demands because of urban sprawl and increased population growth. Groundwater depletion and subsidence have reached critical levels throughout the U.S. (Galloway et al. 1999). Some Houston, TX streets have subsided by over 6 ft because of groundwater depletion (Galloway et al. 1999). Sustained use of shared water resources requires that the needs of all stakeholders – industries, municipalities, utilities, homeowners, conservationists, recreational users – are balanced by natural limits on recharge, ecological needs, and other natural processes.

Although the concept of integrated water resources management is not new, having been discussed since the Civil Water (Reuss 1993), it has generally not been applied at the basin or regional scale. What is needed is a framework that integrates the many competing facets of water use so that water can be managed as a sustainable resource. This paper presents a conceptual framework that integrates ecological, economic, and social considerations through institutional and legal/regulatory constructs to move toward sustainable water resources management (SWRM). This conceptual framework is applicable from local to regional scales. Implementation of the SWRM framework is guided by a process-flow chart that considers both crisis management and proactive management.

DEVELOPING THE SWRM FRAMEWORK

The premise underlying the SWRM framework was that it should be developed through synthesis and integration of existing information, rather than through *de novo* research. The SWRM framework incorporates water resources management theories, principles, and guidelines proposed by the United Nations Agenda 21 (United Nations 1992), Global Water Partnership (GWP 2004), Western Governor's Association (WGA 2002), Panarchy Theory (Gunderson and Holling 2002), Pacific Institute, Water Resources Council (WRC 1983), and similar organizations. An extensive review, synthesis, and integration of the scientific literature related to SWRM was conducted and provides the basis for this framework.

While there are exceptions, in general, management considerations within the business, environmental, and social/political (special interest) sectors are made independently (Figure 1a). Conflicts between corporate interests, environmental interests, and societal interests are sufficiently documented in the literature and press. However, because water is essential for survival, it touches every sector of life – environmental, economic, and social. Water resources management in the 21st century must address the linkages and trade-offs among ecological needs and services, human welfare, and desired human uses of water (e.g., aquatic ecosystem goods and services, irrigation, water supply, transportation, recreation, etc.) (NRC 2000). It is though the intersection and interaction of the environmental, economic, and social/cultural sectors that sustainable water resources can occur (Figure 1b). The SWRM framework that was developed uses the principles, tools, techniques, and methods developed within each of the sectors to collectively provide better information, greater insight, and contribute to more informed decisions in moving toward sustainable water resources (Thornton et al. 2006). The elements and interactions in the SWRM framework can be illustrated by proceeding through the process flow-chart for implementing SWRM (Figure 2).

PUTTING THE FRAMEWORK INTO ACTION: STEPS IN THE PROCESS

A preliminary version of the process flow-chart was developed in early 2004. A stakeholder workshop of western municipal planning agencies and wastewater utilities was held in September 2004 to review and comment on this early version of the flow-chart. Following the presentation and discussion of the conceptual framework and flow-chart, a question was asked, "What would it take for your organization to implement this flow-chart and begin moving toward sustainable water resources management?" The response was clear and immediate. Three things (in priority order): 1st – a crisis or defining event; 2nd – leadership, and 3rd – money. The communities in which these stakeholders lived and worked had been in a water shortage crisis during the late 1990's and early 2000's, and action was initiated, but this crisis was eliminated in 2003 when winter snow pack in the mountains increased and water became sufficient to satisfy demands. Community leaders did not use this crisis to move forward proactively to avert future crises, so these communities likely will experience a crisis again in the future. Because many communities, agencies, and/or organizations will not consider moving toward sustainable water resources until they are in a crisis situation, the first part of the process flow-chart begins with that assumption: the community is facing a water crisis (Figure 2).

The following description of the conceptual framework, and associated examples, considers the watershed as the management unit. For sustainable water resources, the appropriate management unit is the regional hydrologic landscape (Winter 2001), not the watershed. Watershed boundaries and groundwater aquifer boundaries are rarely coincident, so watershed management does not necessarily address groundwater management issues. The watershed management unit is selected for illustration because many communities, utilities, states, and federal agencies are managing at the watershed scale. Use of regional hydrological landscapes as the management unit is discussed in greater detail later in this paper.

Path One – Crisis Chart

Step 1. Recognizing the Crisis. Although it is obvious that the first step in resolving a crisis is to recognize it, acknowledging a crisis, in many instances, is difficult (Kash and Darling 1998, Pearson and Clair 1998). Acknowledging a crisis can imply poor management or leadership, lack of planning, loss of control, costly remedies, or similar negative attributes. Rarely do water crises arise overnight (excluding accidental spills, tornadoes, hurricanes, etc.), so some of the criticisms noted previously might be warranted. Water crises can be related to quantity and/or quality, and in many instances, include both, with water quantity shortages contributing to water quality problems. Regardless, the first step is acknowledging the crisis.

Figure 1a. In general, independent management practices are followed in each of the environmental, economic, and social sectors.

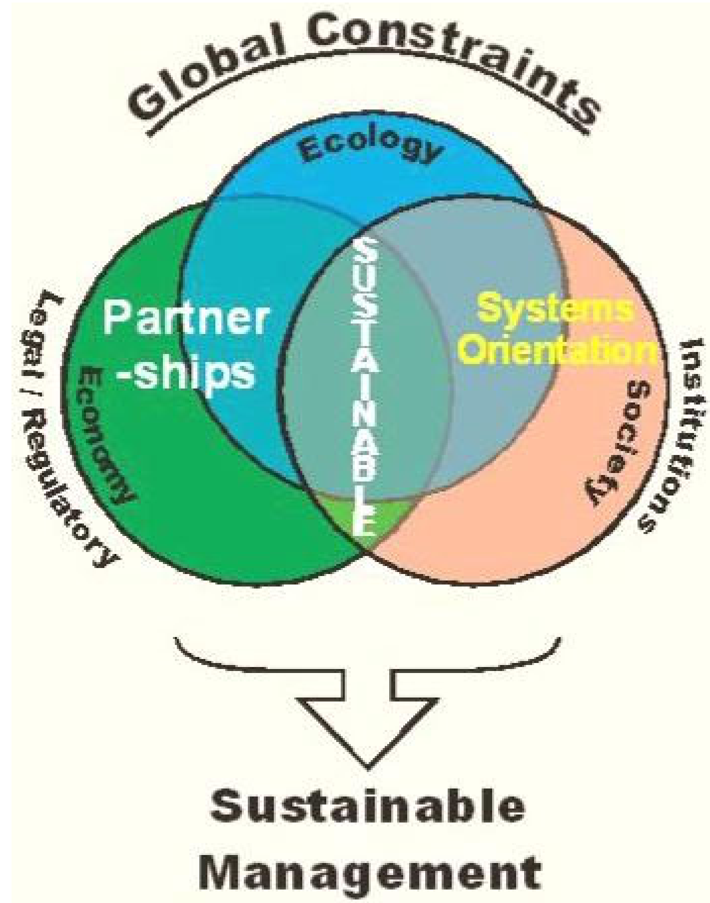

Figure 1b. For sustainable management, the intersections and interactions among sectors must be incorporated.

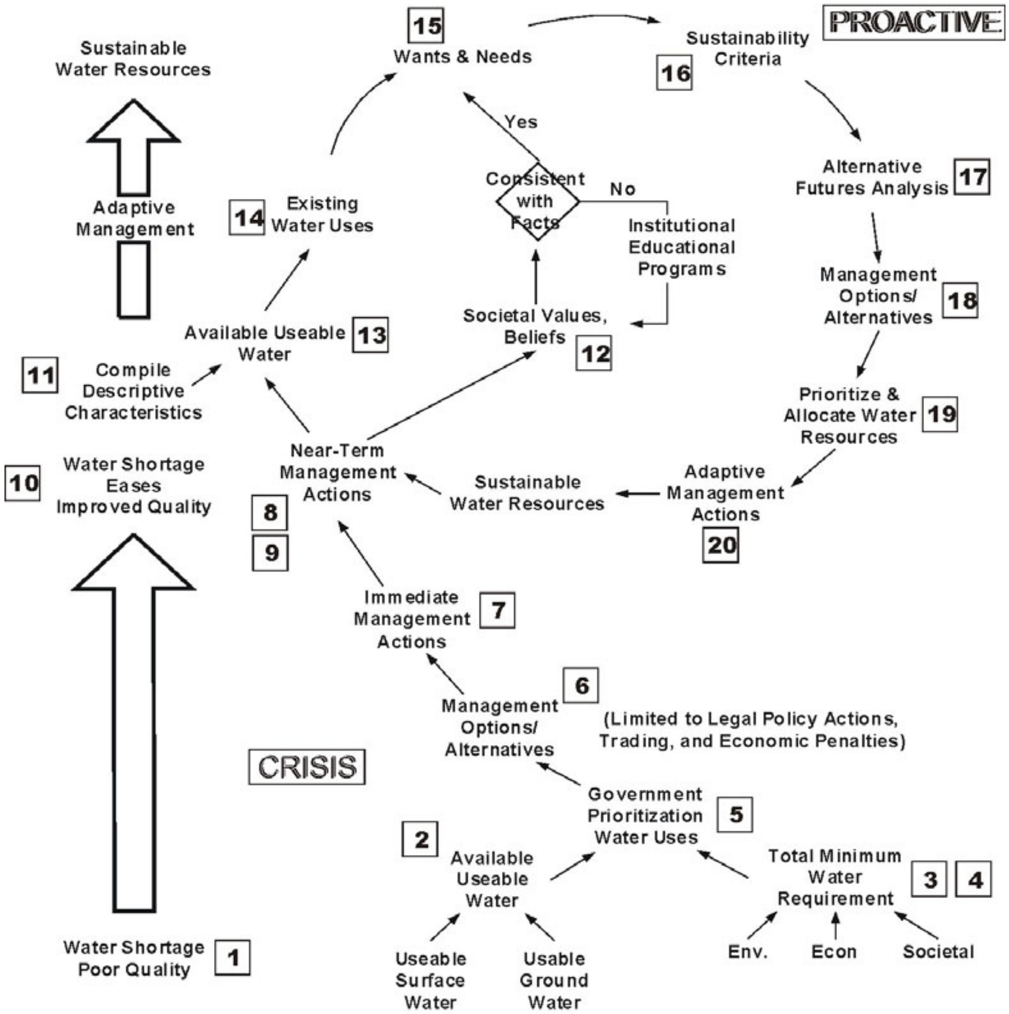

Figure 2. Sustainable Water Resources Management Process Flow Diagram with Two Paths – a Crisis Chart and a Proactive Chart.

Step 2. Estimating Useable Water. Even in water shortage crises, available water does not necessarily mean useable water. Useable water estimates include considerations of both water quantity and quality, for both surface and groundwater sources, including water previously allocated through compacts. Although the management unit in this example is the watershed, similar estimates also should be conducted for the basin and region. Available water estimates can be obtained from water utilities within the watershed or its jurisdictional boundaries. USGS water use summaries by the category (Hutson et al. 2004, Solley et al. 1998), authorized storage volumes in federal government surface water impoundments (e.g., NRCS, COE, BOR, TVA), and groundwater aquifer storage and estimated recharge rates (USGS National Water Data, http://waterdata,usgs.gov/nwis). Water quality information for useable water estimates can be obtained from water utilities in the watershed and local, state, and federal monitoring networks (http://waterdata.usgs.gov/nwis.www.epa.gov/owow/monitoring/reporting.html). In general, if the water body is not on the 303(d) list of impaired waters, water quality is assumed to be adequate to satisfy the designated uses for that water body. If the crisis has developed because the water quality is not sufficient to meet designated uses, alternative sources or additional treatment will be required in the short-term, until remedial actions can be implemented to improve water quality.

Step 3. Minimum Requirements. During a water shortage, minimum requirements are typically determined only for socioecomonic needs and uses. Unless there are endangered species requirements, ecological requirements typically are assumed to be of lower priority than human health and welfare needs.

Gleick (1996 and 1998b) has estimated that humans need 5 L per capita per day (Lpcd) for drinking water, 20 Lpcd for sanitation and hygiene, 15 Lpcd for bathing and 10 Lpcd for cooking, or approximately 50 Lpcd for domestic use. This is about 13 gallons per capita per day (gal/pc-d) or 4,750 gallons per capita per year (gal/pc-yr) as a basic minimum. This estimate is considered to be a true minimum to sustain life in a moderate daily activity. This minimum estimate does not include water needed for food production. In the U.S., we currently use about 54,000 gal/pc-yr for domestic purposes. Canada and Mexico use about 41,000 and 12,000 gal/pc-yr, respectively (Gleick 2000). Minimum water quality requirements for human use can be obtained by using drinking water standards.

Minimum water estimates are also needed for agricultural, commercial and industrial, power generation and cooling water, and similar human uses, as well as wetland, riparian, and stream and river ecosystem requirements. One approach for establishing minimum requirements for non-domestic human uses is to estimate the water use assuming water conservation, recycling/reuse, and similar practices are fully implemented for each use. Gleick et al. (2003) provide estimates of water use for different use categories with conservation, recycling/reuse, efficient irrigation, and similar practices in place. These estimates, then, become the baseline for minimum water requirements. Minimum water quality requirements for non-domestic human uses can be obtained by assuming that State water quality standards (WQS), and federal water quality criteria are being attained. WQS incorporate the designated water body uses, and water quality criteria to protect those designated uses.

There currently is little information available on flow regimes required to sustain aquatic ecosystems. While minimum low flow estimates are available for a few fish species, minimum water estimates for aquatic ecosystem, in general, are unknown. For ecological systems, minimum water requirements are typically established for specific species of interest (e.g., brook trout, salmon) rather than for the ecosystem. If minimum flow requirements have been established for specific species, these can be used ad hoc to determine the minimum water requirements for natural systems. There might be legal, regulatory, policy or similar requirements for minimum ecological water requirements that can be used. For example, minimum regulated low flows have been negotiated below many structures (i.e., dams). Some organizations have proposed the use of the 7Q10 stream flow as the minimum flow to sustain stream biological communities. 7Q10 flow estimates also are often used as the critical low flow for wasteload allocation estimates to protect aquatic life use. The Nature Conservancy has a freshwater initiative that will eventually provide estimates of minimum and maximum flows and required flow durations, by season, for various streams throughout the US (Richter et al. 2003). Unfortunately, estimating minimum flows for aquatic ecosystems is a difficult process even under the best of circumstances, let alone during crisis situations. Minimum water quality requirements for aquatic ecosystems can be obtained by assuming the State WQS, and federal water quality criteria will be attained.

Step 4. Comparison of Useable versus Needed Water. A comparison can now be made between the estimates of total useable water versus the minimum required to maintain socioeconomic and ecological systems. Obviously the key issue is whether there is sufficient useable water to satisfy the total minimum requirements for both socioeconomic and ecological systems. While this comparison is relatively straight-forward, additional information that might affect management decisions includes the uncertainty in each of these estimates.

Step 5. Prioritization. If the total quantity of useable water is sufficient to satisfy the minimum quantity of useable water required for socioeconomic and ecological uses, then the remaining water might be allocated based on market-based economic principles. However, it is difficult to use market-based incentives during crises unless these markets are already established. If the minimum quantity of useable water is less than the quantity required to sustain socioeconomic and ecological uses, the highest priority will likely be to allocate water for human health and welfare. Many states and municipalities have established priorities for allocating water to various uses during periods of shortage.

Step 6. Options and Alternatives. The number of options and alternatives for allocating water among competing and required uses is much more limited under crisis situations than under non-crisis situations because some options and alternatives require time to develop and implement; time that is not available in a crisis. In general, water use restrictions and mandated water conservation measures are enacted to ensure there is sufficient water to meet the minimum required human welfare uses. Fines or other punitive economic measures are used in lieu of market-based economic incentives to control water distribution and allocation and to limit water use for less essential uses such as washing vehicles, or filling swimming pools during drought periods. Many communities have developed specific drought response practices and priorities for periods of water shortages.

Step 7. Immediate Implementation. The timing of various options and alternatives becomes a significant selection factor during crisis periods. Those alternatives and options that can be implemented immediately (fines for lawn watering and vehicle washing, restricted government and public use, etc.) have priority over those that require years for implementation (e.g., improved water distribution infrastructure, improved water treatment for water recycling/reuse, installing low flow toilets and washing machines, implementing improved irrigation systems throughout the basin, etc.).

Step 8. Near-term Options. Some options might not be implemented immediately, but could be implemented within a 2-5 year period. These options include economic incentives for installing low flow toilets and washing machines, initiation of water trading programs, locating and repairing home/business leaks, xeric landscaping, installing rain gardens, etc. (see Gleick et al. 2003). Greater latitude in options are available when there is adequate time for implementation.

Step 9. Retained Management Practices. As management practices reduce or ameliorate the water crisis, an assessment of the practices that were effective in reducing water use should be conducted. The tendency is to return to previous water use practices once the crisis has been resolved. However, if management practices invoked during the crisis are effective in efficiently allocating water among users, these management practices should be retained. Water is a renewable, but finite resource. Management practices that promote efficient water use, contribute to integrating socioeconomic and ecological system needs, and support adaptive management should be retained.

Step 10. Move to the Proactive Chart. As the water crisis is resolved and longer term options and alternatives can be assessed, the community should move from the Crisis Chart to the Proactive Chart so that future crises can be averted. This appears to be a logical step, but institutional and public memory of extreme events (droughts, floods, hurricanes) fades rapidly, (Opaluch, personal communication 2006).

Path Two – Proactive Chart

The time to begin implementing SWRM practices is before water needs reach crisis proportions. The key is to start the process! There are always water issues in a community, even if there is no water crisis. Start with a water issue of concern in your community, watershed, basin, or region. Water can be related directly or indirectly to almost every management practice in the community or watershed. Starting with existing community or watershed issues is preferred because you not only know the actors, you are one of them.

Steps in the implementation process do need to be considered at each scale, from the local community to the regional hydrologic landscape (region). Each of the scales, from local community to region, however, is interactive, so it doesn't matter where along the scale continuum you begin. Cumulative effects of decision made by local communities contribute to regional scale effects, and regional constraints affect what can be attained in local communities. In addition to the regional constraints, it is useful to determine if there are hydrologic effects on your region from El Nino-La Nina (ENSO) cycles, or the Atlantic Multi-Decadal or Pacific Decadal Oscillation (AMO/PDO) (Enfield et al. 2001, Harrison and Larking 1998, Nigam et al. 1999, Pizarro and Lall 2002). These larger-scale cycles influence periods of flooding and drought at regional, basin, and watershed scales.

The information needed for the Proactive Chart is more expansive than during the crisis phase, but in the same genre. There is greater emphasis on the integration and interactions among sectors in the proactive process, than in the crisis process. From our perspective, humans are part of, not apart from the environment. Using a total systems approach to assess and adaptively manage water through time results in sustainable water resources.

Step 11. Initiating the Process – Descriptive Characteristics. One of the first steps in the process is to compile information on the general characteristics of each entity – community, watershed, basin, and region. Because watershed management is actively encouraged by many agencies, our examples relate to the watershed, but the concepts are also applicable for the community, basin, and region.

Maps are useful for conveying much of this information, and generally already exist for many watershed features. At a minimum, a watershed map showing water features (e.g., stream networks, lakes) and a land use map should be prepared. Tables also are useful for presenting information such as summaries of various land use types, and population statistics by socioeconomic sector.

Step 12. Stakeholder Values, Beliefs, Interests and Concerns. Understanding the water related values, beliefs, interests, and concerns of the various population segments in the watershed is critical. In general, you'll need help from social scientists to determine and understand the values and beliefs (mental models) that exist within your watershed (Thornton and Laurin 2005). Most social scientists get excited when approached by non-traditional clients. Everyone wants to feel what they do can make a difference in society. Find them and engage them in the process.

What happens if the stakeholder beliefs about water resources in the watershed are wrong or untrue? Then, educational campaigns need to be developed to provide factual information and educate the public on the issues (Thornton and Laurin 2005). Social marketing techniques can be, and have been, used by both government agencies and civic organizations to change the understanding and behavior of stakeholders on a range of issues ranging from smoking and drunk driving (designated drivers) to littering and water conservation (Kotler et al. 2002).

Step 13. Existing Water Quantity and Quality. Water quantity and quality information are needed for surface and groundwater and atmospheric vapor (precipitation, evaporation). This is the area in which most engineers and scientists are comfortable and experienced. It is also an area where much of the needed information is not readily available. Many stream gauging stations have been discontinued because of funding shortages, so continuous discharge measurements are not available for many watershed streams. Major rivers are gauged, and indexing from gauged to ungauged watersheds might provide an estimate of available water. Annual runoff coefficients can be used with annual precipitation measurements to estimate potentially available water. Land use/land cover information can be used to refine the runoff coefficients to account for evapotranspiration (ET). On a continental basis, ET from forested watersheds returns about 50% of the precipitation to the atmosphere. Water quality estimates can be obtained from USEPA and State environmental protection agencies. Lists of streams [303(d)] that are not attaining designated uses, and likely causes, are available from each state, which provides information on useable water.

Step 14. Existing Water Uses. In addition to the quantity (volume) and quality of water in the watershed, existing water uses need to be quantified. The USGS has general information on water usage by State and Major US Water Resource Region, but this information is typically not available for many watersheds. Other sources of information were discussed under the Crisis Chart discussion and include public works utilities, including power generation and its hydropower or cooling water requirements, State surface water or groundwater withdrawal permits, back-calculating from discharge monitoring reports using consumptive estimates by source, and direct measurement.

Step 15. Water Uses – Required and Desired. The next step in the process is to determine which water uses are required for the survival of the human society present in the watershed and the natural systems on which it depends. Those water uses that are not required are categorized as desired water uses.

At this point in the process minimum water requirements for the required water uses are also determined. The quality of water required for all of the water uses identified here also needs to be considered.

Required Water Uses. These uses were identified in Step 3 in the Crisis Chart.

Desired Water Uses. Initial desired water use quantities can be estimated by compiling existing water use quantities (volumes). Future water use desires can be estimated using demographic projections of population and land use change within the watershed, and prorating future use based on current use. Population and land use projections are available from municipal, county, state and regional planning agencies, U.S. Census Bureau, and from many trade associations. Initial water quality requirements can also be based on existing WQS for the water bodies.

Step16. Sustainability Criteria Comparisons. Four criteria have been established to determine if current water management practices are sustainable:

1. Has the running average groundwater table elevation remained relatively constant over a 10 year period? If the groundwater table elevations have been declining over a 10 year period, the groundwater use is not considered sustainable.
2. Is there sufficient surface water and groundwater quantity to satisfy existing and projected future uses? If there is not sufficient water to satisfy existing or projected future uses, water management practices are not considered adequate to ensure a sustainable water resource.
3. Is the timing of water delivery adequate to satisfy existing and projected future uses? If the timing is inadequate, such that, for example, minimum flows can not be sustained in the stream during the summer or fall season, water management practices are not considered sustainable.
4. Finally, is the water quality adequate to achieve existing and projected future water uses? If the water quality is not adequate to support existing or projected future uses, the water management practices are not supporting sustainable water resources.

Step 17. Alternative Future Analyses. The temptation to move directly from evaluating the sustainability of water resources to assessing options for achieving the required/desired water uses should be avoided. With the data and information compiled through the activities above, sufficient knowledge of the watershed exists to create a vision for what the stakeholders want for the future. This collective watershed vision provides an overall direction for the future and leads to the formulation of goals and objectives for various social entities with in the watershed, and prioritization of these goals when choices among competing goals have to be made. Alternative future analysis can assist in the crystallization of the collective watershed vision.

Alternative futures analyses will require the use of a facilitator and team with experience in conducting alternative futures studies. The process is very similar to the design charettes used by architectural firms in planning new developments or urban renewal projects. It involves engaging as many stakeholders as possible in dialog and visioning activities, and then consolidating the resulting information about desired futures into a handful of scenarios for evaluation. Three scenarios is an optimal number for most communities or watershed associations. Few groups will be able to move toward consensus if there are more than five alternatives from which to choose. Table 1 is a listing of some of the alternative futures studies completed in the US.

Table 1. Example alternative future studies.

Study Name, Location
Eastern US
Alternative Futures for Monroe County, Pennsylvania (Harvard 1997, Steinitz and McDowell 2001)
Modeling Effects Of Alternative Landscape Design And Management On Water Quality and Biodiversity in Midwest Agricultural Watersheds (Iowa) (Santlemann et al. 2001)
Western US
Alternative Futures for Changing Landscapes: The Upper San Pedro River Basin in Arizona and Sonora (Steinitz et al. 2003)
Williamette River Basin Planning Atlas: Trajectories of Environmental and Ecological Change (Hulse et al. 2002)
Southern Rockies Landscape Planning Project (Alburton Environment 2000)
The Development of Alternative Future Growth Scenarios for the California Mojave Desert (Toth et al. 2002)
Biodiversity and Landscape Planning: Alternative Futures for the Region of Camp Pendleton, California (Steinitz 1997)

Step 18. Options for Bridging the Present Toward the Alternative Future. There are a number of options available to stakeholders to move toward their desired future, including water conservation, water reuse, recycling, economic incentives, market trading, social marketing, new technologies, ordinances, policies, laws, and regulations. As stated in the beginning of this paper, there are few sound management practices, social norms, or economic approaches that can not contribute to sustainable water resources management. The following tables include examples of some of the many management options that can contribute to sustainable water resources management (Tables 2 and 3).

Table 2. Examples of Water Conservation, Reuse, and Reclamation Practices.

Conservation	Reuse	Reclamation
Market based (water pricing)	Residential gray-water systems	Sale of reclaimed water to nearby users
Rebates, tax credits for installation of water conserving	Commercial/industrial recycling systems	Tax credits for businesses using reclaimed water

appliances		
Targeted irrigation	Groundwater replenishment	Groundwater replenishment
Tax credits for installation of conservative irrigation systems/tools	Decorative water bodies	Decorative water bodies
Weather based irrigation	Irrigation	Irrigation
Hot water circulation pump	Toilet flushing	Toilet flushing
Low-water use landscaping	Fire fighting	Fire fighting
Fix leaks	Wetland augmentation	Wetland augmentation
	Industrial use	Industrial use
	Car washing	Car washing

Table 3. Selected Examples of Economic Incentives and Water Trading Practices, and Smart Growth Practices.

Economic Incentives	Smart Growth
Scaled water prices based on usage level (volumetric pricing and multipart pricing)	Requirement that developers demonstrate sustainability/availability of water for new development for a specified time period (e.g. 50 years, 100 years)
Rebates, tax credits for installation of conservation or reuse technology	De-development and rezoning
Sale of recycled water through public utility at lower cost than potable water	Economic incentives (e.g., reduced fees, tax rates) for development or redevelopment in identified target areas
Sale of water rights (Long or short-term)	Public education, public service announcements, etc.
Direct sale of recycled water from creator to user	Land trusts, conservation easements, purchase of land for conservation
Pricing water to reflect the true cost and/or value	Land use planning, zoning, ordinances, covenants
	Economic disincentives (e.g. higher fees, tax rates) for undesirable development

Step 19. Prioritize and Allocate Water Resources. If existing water management practices do not meet the criteria for sustainability, it will be necessary to make changes. A first step in deciding what changes to make is to take a careful look at how available water compares to required and desired water usage. Minimum water requirements for social, economic, and ecological sectors were previously estimated. Existing and project future water uses also were previously estimated. A comparison of the required and desired water use estimates with available water quantity and quality estimates will indicate if:

1. Available water is of sufficient quantity and quality and adequate timing to meet the minimum required needs for the three sectors of society – social (human), economic (e.g., commercial, agricultural, industrial), and ecological (e.g., aquatic ecosystems – rivers, streams, lakes, wetlands), and
2. Water is of sufficient quantity and quality and adequate timing to meet the existing and future desired water uses, by sector.

The alternative futures analysis and other knowledge of stakeholder desires and goals are used as guides for deciding which uses have priority. Waster uses need to be allocated based on the full cost and value of water. This is difficult because water is so heavily subsidized that the true cost of water might be unknown. The bottled water industry is providing insight into better estimates for the value of water, which can be used in economic incentives and water trading markets. The goal is to look for synergy among water uses.

Step 20. Adaptive Management. Monitor, Assess, and Adapt. Adaptive management is the foundation of sustainable water resources management. Monitor, assess, adept, monitor represents the iterative approach needed to manage highly complex, non-linear socioeconomic and environmental systems whose behavior can not be predicted (Holling 2000). Management programs need to be evaluated on a regular basis to ensure that they are achieving the goals they were implemented to achieve, are not contributing to additional problems, are based on the best available information about the system, and are utilizing the best available technology and techniques.

Indicators that can provide information to assess progress toward sustainable water resources in each of the sectors of society: ecology (including hydrology), economy, and society/culture, are necessary for successful adaptive management. A preliminary list of indicators is currently being developed as part of the Sustainable Waters Roundtable (http://acwi.gov/swrr/index.html). It includes many of the water resources indicators currently being monitored by local, state, and federal agencies. Monitoring information for these indicators will need to be accessible to multiple users (i.e., through linked information systems) to be useful for adaptive management at multiple scales.

A REGIONAL EMPHASIS

Sustainable water resources are achievable, but within a regional context. While useful strides toward sustainable water resources management can be made at the community and watershed scale, a regional perspective is required to truly achieve sustainability. Cumulative effects of local community decisions that affect watersheds and basins can be dealt with effectively only at the regional scale. To achieve sustainable water resources, we must consider surface water, groundwater, and atmospheric vapor. A regional scale is applicable because, while watersheds are suitable management units for surface water issues, groundwater aquifers don't often follow watershed boundaries, and precipitation and evaporation patterns are the result of large-scale climate patterns. Regional hydrological landscapes consider these three elements of the hydrologic cycle (Winter 2001) and represent the logical management unit for sustainable water resources.

Managing at the regional scale will require changes in how agencies, organizations, civic institutions, communities, and the private sector address water resources management. The need for these changes has been recognized. The Western Governor's Association is already on record as stating that regional as stating that regional coalitions will be needed to move toward sustainable water resources management in the West. This is equally true in the East. These changes will occur over time.

CONCLUSION

Sustainable water resources management is not a theoretical desire – it is achievable. Over 90% of the information needed to move toward sustainable water resources management is currently available, but the information is diffuse and multidisciplinary. Because most of us aren't aware, or don't follow, information in other disciplines, we assume the information doesn't exist. Forming an interdisciplinary team of engineers, scientists, sociologists, economists, health, and other professionals will help bridge these gaps. This is not, necessarily, an easy process and there will be obstacles that must be overcome (Levinson and Thornton 2003), but this interdisciplinary team is a necessity, not a nicety, in moving toward sustainable water resources management. Information is not the issue; resolve to make it happen is the issue. Sustainable water resources are achievable.

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