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**MOVING TOWARD SUSTAINABLE
WATER RESOURCES MANAGEMENT:
A FRAMEWORK AND GUIDELINES
FOR IMPLEMENTATION**

SYNTHESIS REPORT

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ABSTRACT AND BENEFITS

Abstract:

Water has been considered an essential element of life for at least 2,500 years; yet, there is still no integrated framework for sustainably managing water. Recognizing this need, the Water Environment Research Foundation (WERF) funded a research project to develop an integrated, conceptual framework for sustainable water resources management. Through WERF funding, this framework was developed over the past 4 years. Development of the framework was guided by the U.N. Agenda 21, Global Water Partnership, the Enlibra Principles, and Panarchy Theory.

The conceptual framework for Sustainable Water Resources Management considers water as a renewable, but finite resource with global and regional constraints. It integrates ecological, economic, and social considerations through institutional and legal/regulatory constructs to move toward sustainable water resources. Implementation of the framework is guided by a process flow-chart that considers both crisis management and proactive management activities. We believe that sustainability is as much an outcome as a goal. If water resources are viewed within a total systems context and monitored, assessed and adaptively managed through time, sustainable water resources are the outcome.

Benefits:

- ◆ Demonstrates how ecological, economic, and social elements can be integrated to adaptively manage water resources sustainably.
- ◆ Provides guidance to help subscribers move toward sustainable water resources management, to move from concept to into practice.
- ◆ Provides insight into how policy, law, research, and social mindsets influence sustainable water resources in the U.S.
- ◆ Provides criteria for determining if water resources management is sustainable.
- ◆ Provides indicators for monitoring progress toward achieving sustainable water resources.

Keywords: Sustainability, water allocation, water supply, water resources planning, water policy, environmental indicators

MOVING TOWARD SUSTAINABLE WATER RESOURCES MANAGEMENT: A FRAMEWORK AND GUIDELINES FOR IMPLEMENTATION

The Nature of Water

Water is unique on earth:

1. It is a prerequisite for life—every living plant and animal (including humans) needs water for survival.
2. It has no substitute for most of its uses compared to other natural resources; for example, natural gas or wind power can substitute for oil or coal in energy generation. Nothing substitutes for water in growing agricultural crops.
3. It is a fundamental force in the Earth's climate regime.
4. It is a renewable, but finite resource—Earth's hydrologic cycle is closed, so the global amount of water today is essentially equivalent to what it was thousands of years ago.
5. Water, in its broadest context, includes both amounts (quantity) and quality.

Over the past several decades, there has been a growing recognition of the water crisis that is developing in the U.S. and around the globe. Population growth and land use changes have aggravated water shortages during periods of drought throughout the U.S. In 2001, farmers in the West challenged federal marshals for irrigation water being used to support endangered fish species. In the same year, Anheuser-Busch experienced increased prices and reduced availability of barley and aluminum due to reduced irrigation water and hydropower generation as a result of the western U.S. drought. Eastern reservoirs that had firm yields prior to 1970 have been experiencing greater project demands because of urban sprawl and increased population growth. Groundwater depletion and consequent subsidence have reached critical levels in rural areas as well as metropolitan areas such as Houston, TX. Some Houston streets have subsided by over two meters because of groundwater depletion.

Because water is essential for survival, it touches every sector of our lives—ecological, economic, and social/cultural. Water resources management in the 21st century must address each of these sectors as well as the linkages and trade-offs among ecological needs and services, human welfare, and desired human uses of water.

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. Unfortunately, most water management efforts lack both a firm conceptual framework and the processes necessary to integrate multi-sector influences and their cumulative effects on water resources.

Recognizing this need, the WERF has funded a research project over the past three years to develop a conceptual framework for integrated, Sustainable Water Resources Management (SWRM).

An early definition of sustainability was, “the ability to meet current needs without compromising the ability of future generations to meet their own needs” (WCED 1987). Sustainability is not an easy term to define. As this project progressed and our thinking evolved,

we came to realize that sustainability is an outcome of using a total systems approach to monitor, assess, and adaptively manage water resources through time.

Purpose of this Report

This report presents a framework and set of guidelines for developing an implementation plan for SWRM. The framework accounts for the reality that the issue of sustainable water resources may not receive attention until a crisis occurs. But, it also encourages proactive planning to avert a crisis. These paths are summarized in a two-part process flow chart that is presented and discussed (Figure 1 - page 4). The first part of the flow chart (Crisis Chart) deals with SWRM initiated in a crisis situation. The second part of the flow chart (Proactive Chart) deals with initiating SWRM as a proactive effort to avert crisis. Questions and selected examples are provided to help the user understand the rationale and information needs for the implementation plan.

Moving Toward SWRM

The SWRM framework incorporates water resources management theories, principles, and guidelines proposed by the United Nations Agenda 21, Global Water Partnership, Western Governor's Association, Resilience Alliance, Pacific Institute, and similar organizations. An extensive review, synthesis, and integration of the scientific literature related to SWRM were prepared as a companion report to this guidance document. The companion report (00-WSM-6b) provides more detailed information and references for each topic in this report (Thornton et al. 2005).

Because water is essential for life, it is integral to every sector of society – environment, economy, and social/cultural. As a result, SWRM benefits every sector of society (see sidebar). Furthermore, most management practices associated with economic and social/cultural sector issues and non-water environmental issues also affect water resources, either directly or indirectly. Feedback occurs in both directions. Therefore, management tools and practices from these other sectors can also contribute to SWRM. But, these management practices and tools need to be considered within a water resources context. For example:

- Smart Growth practices are designed to manage urban/suburban development and minimize the effects of urban sprawl, which includes effects on water resources. As a result, Smart Growth practices and policies can reduce adverse effects on water infrastructure, aquatic habitat, urban runoff, and pollutant transport.
- Hubs and corridors land management practices used to promote conservation of important ecological areas have direct effects on runoff (e.g., runoff from forested versus agricultural and urban land use); evapotranspiration; riparian area

SWRM Benefits

Because water is essential for life, it affects every aspect of society. SWRM practices are not only affected by management practices in other sectors of society, SWRM can also help multiple sectors achieve desired outcomes, such as

- ◆ restoration jobs/industry,
- ◆ value-added products,
- ◆ improved infrastructure,
- ◆ ecotourism, and
- ◆ cultural preservation;

through

- ◆ stream restoration,
- ◆ forest stewardship & conservation,
- ◆ pollutant reduction,
- ◆ stormwater runoff reduction & reuse,
- ◆ energy conservation,
- ◆ water conservation,
- ◆ water trading, and
- ◆ Smart Growth urban development.

protection; aquatic habitat restoration; and pollutant generation, transport, and retention.

- Microeconomic theory and practices focus on the efficient allocation of scarce resources. Economic practices and policies can be used to determine the true value and cost of water and use these true values and costs to allocate water efficiently among multiple users. There are also procedures and policies available to ensure that welfare needs for water are accommodated in water allocation.
- Civic institutions, such as WERF, can assist agencies, water utilities, and treatment facilities in promoting water conservation, reuse, recycling, and trading practices. Other civic institutions contribute to public education on water-related issues, and provide insight on the beliefs and mental models of their members and community sectors, and social marketing.

SWRM approaches must integrate management practices from all social sectors, and consider how natural and human patterns and processes can interact to sustain water resources. In developing sustainable water resources, humans must be considered part of, not apart from, the environment. Using a total systems approach to monitor, assess, and adaptively manage water *through time*, results in sustainable water resources.

Putting the Framework Into Action: Steps in the Process

Unfortunately, most communities, agencies, and organizations do not consider moving toward sustainable water resources until they are in a crisis situation. The need for a water crisis to initiate change in water management practices was confirmed at a stakeholder workshop held in September 2004. When asked what would be required to implement a framework for sustainable water resources management, stakeholders answered that one or more of the following would be required (in priority order):

1. a crisis or defining event,
2. leadership, and
3. money.

Sustainability is an outcome!

Using a total systems approach to monitor, assess, and adaptively manage water through time ==> sustainable water resources.

Leadership: Making It Happen

In 2002, New York State initiated a future-oriented planning effort (Project 2015) to consider the impact of an aging population on services, products, constituency make-up, and day-to-day work of multiple state agencies. Getting state agencies to work together can be a challenge. In New York, 36 state cabinet agencies had to work together for Project 2015 to succeed. In February 2002, Governor George Pataki called a cabinet meeting at his home on a Saturday to inform all 36 state agency Commissioners they had nine months to develop a coordinated plan to 1) assess the impact of demographic change on their agency, 2) prioritize the major impact areas, and 3) specify action steps or strategies they would implement over the next five years to address their top three impact areas. Governor Pataki made it clear that all agencies would coordinate and participate, there would be a plan on his desk in nine months, and there would be no exceptions. The work of the 36 agencies was presented to the Governor at a symposium in October 2002 (Rosenbaum 2005). Leadership can make things happen, including sustainable water resources management.

Therefore, the first part of the process flow chart is applicable to communities or watershed associations that are facing a water crisis (Figure 1). In a water crisis, management options are restricted to those that can be implemented quickly. These management options are typically developed and implemented by government entities. The following text and questions illustrate the information needed to address a water crisis (water quantity and/or quality) at the watershed scale and eventually move toward SWRM. This document addresses the watershed scale because watershed management is actively encouraged by many agencies and makes sense for moving toward sustainable water resources. However, the questions and guidance presented can and

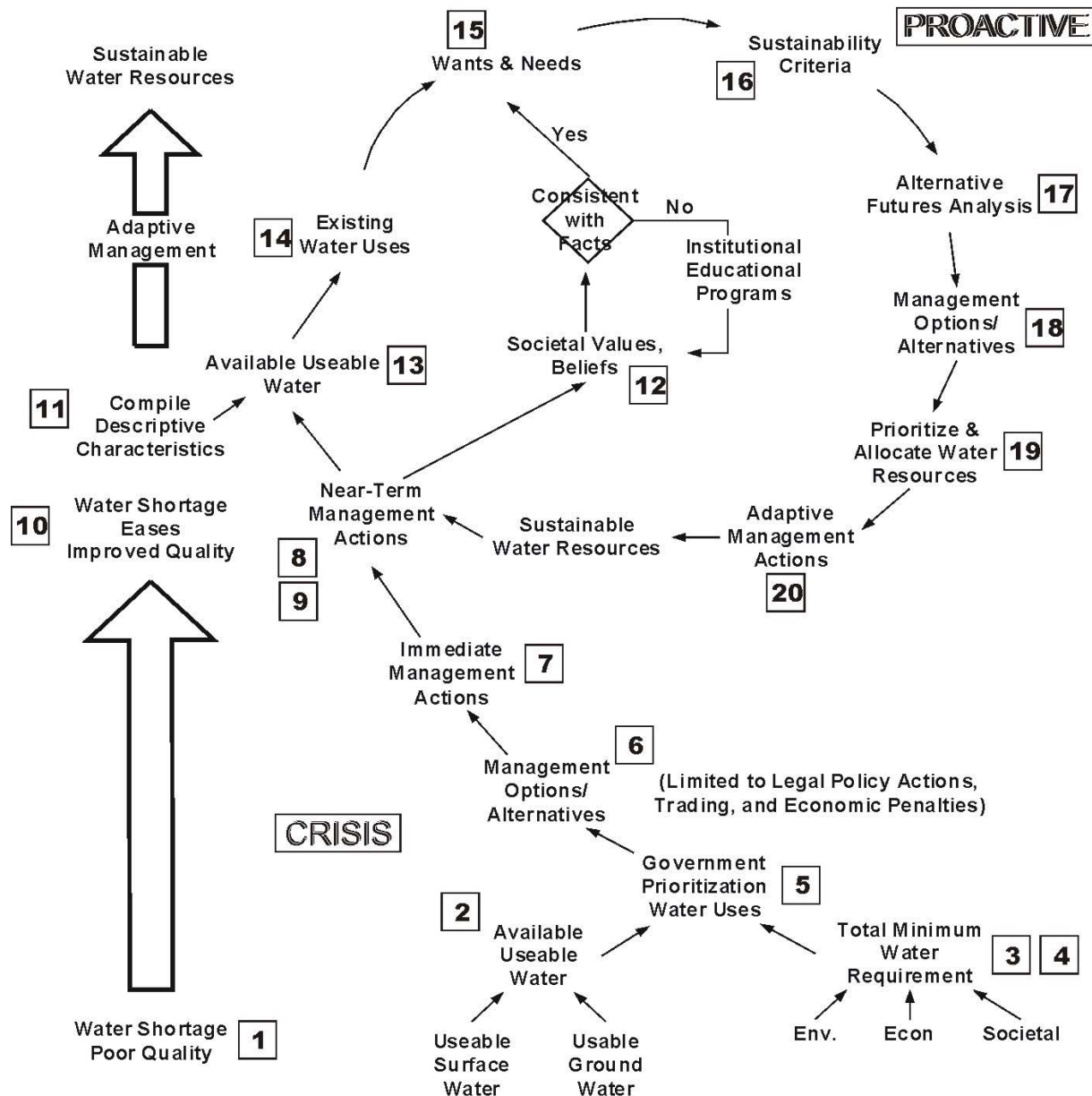


Figure 1. Sustainable Water Resources Management Process Flow Diagram with Two Paths – A Crisis Chart and a Proactive Chart.

Crises Eliminate Options

must be applied to communities, as well as basins and regions. Examples are provided from the Denver Drought Response Plan, which is considered a good model for managing a drought crisis (Rogers, 2003).

When managing water resources during a water crisis, there are fewer management options and opportunities for stakeholder involvement.

Path One - Crisis Chart

1. Recognizing the Crisis

There can be multiple causes of a water crisis. A water shortage that has reached crisis proportions could be the result of drought, community growth and increased water use, aging infrastructure, increased upstream withdrawals, reduced upstream discharges, all of the above, and more. A water quality crisis may occur for exactly the same reasons as a water shortage (growth, aging infrastructure, etc.). In many cases, identifying the causes is secondary to treating the symptoms. You're running out of usable water – do something about it!

“Recognizing the Crisis” Questions

- ◆ What are the recent trends in groundwater table levels and surface water flow?
- ◆ Is the water crisis local or regional?
- ◆ What water uses are most affected by the water shortage or water quality issue (e.g., drinking water, irrigation, thermoelectric cooling water, etc.)
- ◆ What water resources are used for water supply (i.e., groundwater, surface water, as well as specific water bodies)
- ◆ What water management entities (e.g., agencies, utilities) are involved?
- ◆ How many people live in watershed and/or are supplied water?

2. Estimating Available Usable Water

Estimating available usable water includes both water quantity and quality. Both surface and groundwater sources need to be considered, as well as any constraints on supply from outside the watershed.

“Estimating Available Usable Water” Questions

- ◆ What is the recharge rate of water supply aquifers?
- ◆ What contribution to annual and seasonal runoff comes from snow pack and precipitation?
- ◆ How much stored water is available (e.g., reservoirs, tanks, water banks)?
- ◆ What water allotments are provided for the watershed or its communities from sources outside the watershed?
- ◆ What is the current capacity of water supply treatment systems in the watershed?
- ◆ Are re-use or gray-water systems in place? If so, what are their expected water supply capacities?
- ◆ Are there seasonal, monthly, or daily patterns in water quantity or quality that affect availability?
- ◆ What water bodies are known to be unsuitable for water supply, and/or habitat uses?

3. Minimum Water Requirements

During a water crisis, minimum water quantity and quality requirements are typically determined only for socioeconomic needs and uses. Ecological requirements are assumed to be of lower priority than human health and economic sector needs. However, there might be legal, regulatory, policy, economic, or other reasons why the minimum ecological water requirements also need to be estimated at this step.

Unfortunately, estimating minimum ecological water requirements is a difficult process even under the best of circumstances. However, in crisis situations, best estimates of minimum ecological requirements suffice. Estimates of minimum water requirements for aquatic ecosystems might be based on minimum regulated low flow releases below structures (e.g., dams), minimum regulated freshwater inflows to estuaries, guidelines or regulations to maintain the minimum flows required for NPDES discharges, or a percentage of the water required to maintain the minimum socioeconomic needs. While estimates of minimum low flow requirements are available for a few fish species, minimum water requirements for aquatic ecosystems, in general, are unknown.

“Estimating Minimum Water Requirements” Questions

- ◆ What are the existing water uses (include ecological uses along with human health and welfare, agricultural, industrial, and commercial uses)?
- ◆ Which of these water uses are absolutely required to maintain the watershed communities and the natural systems on which they depend (human health and welfare, waste assimilation, food production, fish assemblages, endangered species, critical commercial enterprises)?
- ◆ How much water, and of what quality, is needed to maintain the watershed communities and natural systems on which they depend?
- ◆ What is the minimum amount of water, and of what quality, needed to support the other water uses previously identified (agriculture, commercial, industrial, power generation, cooling, aquatic ecosystems, wildlife, game species)?
- ◆ What is the most important use of water for activities that occur in the watershed?
- ◆ What minimum stream flows, and of what quality, are required by laws, regulations, policies, agreements, and/or treaties?
- ◆ What levels of water quantity or quality reduction are acceptable for particular periods of time? It is likely that more drastic reductions can be accepted for short periods of time than over longer periods. How long will different levels of reduced water quantity or quality be acceptable?

4. Comparison of Available Usable Water and Minimum Water Requirements

A comparison can now be made between the estimates of available usable water versus the minimum amount of water required to maintain socioeconomic and ecological systems. Obviously the key issue is whether there is sufficient usable water to satisfy the total minimum requirements. While this comparison is relatively straightforward, additional information that might affect management decisions is highlighted by the following questions.

“Comparison of Available Usable Water to Water Requirements” Questions

- ◆ What is the confidence in the estimates of available and needed water quantity and quality?
- ◆ What is the sensitivity of decision-making to variations in available and needed water quantity and quality estimates?
- ◆ What is the sensitivity of decision-making to the time scale for water use and water quality reductions?

5. Prioritization

If the quantity of available usable water is sufficient to satisfy the minimum water requirement for socioeconomic and ecological uses, then any remaining water might be allocated using market-based economic principles. If the quantity of available usable water is less than the estimated minimum water required to sustain social (i.e., human health and welfare), economic (i.e., industry, agriculture, commerce) and ecological (i.e., wildlife support, waste assimilation, maintenance of natural resources that contribute to economy) uses, the highest priority will likely be water for human health and welfare (see sidebar). Prioritization of other uses might be based on socioeconomic principles, including non-market valuation approaches for estimating the value of ecological services in conjunction with water requirements for market-based goods and services.

Prioritization: Guidelines for Water Restrictions During Drought

In 2002, the Denver Water Board adopted policy guidelines for developing a drought restriction program. Denver Water will follow these principles in restricting water use during a drought.

1. Avoid irretrievable loss of natural resources
 - Allow watering of irreplaceable trees.
 - Avoid killing perennial landscaping if possible.
 - Tailor water restrictions to landscape needs.
2. Restrict less essential uses before essential uses.
 - Restrict water use for misters, fountains, and other aesthetic water features first.
 - Avoid using water for cleaning driveways, sidewalks, or washing personal vehicles.
 - Curtail outdoor water use, along with restrictions on commercial use, before restricting domestic indoor use.
3. Affect individuals or small groups before affecting large groups or the public as a whole, allowing as much public activity as possible to be unaffected.
 - Preserve community pools rather than residential pools.
 - Restrict golf courses before public parks.
 - Restrict water use on less heavily used areas of parks where grass can go dormant before formal and informal playing fields, where recreational activity would either kill the grass or have to be prohibited.
4. Minimize adverse financial effects.
 - Try not to close businesses, although businesses that depend on purely discretionary water use will be affected.
 - Restrict seasonal commercial use, which is likely to be outdoors.
 - Restrict nonessential uses of water in businesses before affecting fundamental business functions.

“Prioritization” Questions

- ◆ What water uses are vital to maintaining human health?
- ◆ What water uses are vital to maintaining the economy (local, state, or national)?
- ◆ What water uses contribute to ecosystem services (e.g., waste assimilation) necessary to support human health and the economy?
- ◆ What water uses are easiest to reduce and control?
- ◆ What are the costs (including costs to ecosystems) associated with reducing or eliminating existing water uses?
- ◆ What are the benefits associated with reducing or eliminating existing water uses?
- ◆ What legal/agency barriers might limit reallocation of water?
- ◆ What social barriers might limit an equitable allocation of water among all population sectors?

6. Options and Alternatives

The number of options and alternatives for allocating water among competing required uses is much more limited under crisis situations than under non-crisis situations because some options and alternatives require more time to develop and implement than is available in a crisis. In general, water use restrictions and required water conservation measures are enacted to ensure there is sufficient water to meet the minimum required uses. Beach closings and restrictions on fisheries use (e.g., consumption advisories, closing shellfish beds) are commonly used strategies for water quality crises. Fines are used in lieu of market-based economic incentives to control water distribution and allocation. Communities in both the West and the East have used fines to limit water use for washing vehicles, watering lawns, filling swimming pools, etc. during drought periods, and fines are used to enforce bans on commercial fishing in contaminated waters. Some communities, such as Denver, CO, have developed specific drought response practices for water shortages (see sidebar - next page).

“Options and Alternatives” Questions

- ◆ Which uses have current shortages or which users think they have shortages?
- ◆ What technology is currently available that can be utilized to reduce water quantity or quality requirements?
- ◆ What are the estimated water savings associated with practices under consideration?
- ◆ What are the implementation time frames for the practices under consideration?
- ◆ What practices are easiest and/or quickest to implement?
- ◆ Where have these practices been implemented and what was their effectiveness?
- ◆ What is needed to put practices in place (i.e., changes in regulations, modifications to infrastructure, changes in policy, changes in operations)?
- ◆ What are the costs associated with implementing practices?
- ◆ What indicators and measures will be used to decide when more normal water usage can be resumed?
- ◆ Which agencies have authority and priority for water allocations?

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 (e.g., fines for lawn watering and vehicle washing, ordinances requiring low flow shower heads in new/remodeled buildings and facilities, beach closings, fish consumption advisories) have priority over those that require years for implementation (e.g., improved water distribution and collection infrastructure, improved water treatment for water recycling/reuse, installing low flow toilets and washing machines, implementing improved irrigation systems throughout the basin, watershed restoration).

“Immediate Implementation” Questions

- ◆ How long is it likely to take to implement practices under consideration?
- ◆ Which practices are likely to require the shortest time to implement (i.e., less than one to two years)?
- ◆ How long is it likely to take these practices to yield results?
- ◆ Which practices yield results most quickly (i.e., less than one to two years)?
- ◆ Which practices are quick to implement and yield results quickly?
- ◆ What costs are associated with implementing these practices (monitoring, enforcement, etc.)?
- ◆ What funding sources are available for implementation?

8. Near-term Options

Some options might not be implemented immediately, but could be implemented within a two- to five-year period. These options include economic incentives for installing low-flow toilets and washing machines, initiation of water and pollution trading programs, locating and repairing home/business leaks, low-water landscaping, using rain gardens, studying pollution sources, etc. A greater number of options are available when there is adequate time for implementation.

9. Retaining Management Practices

As water options and alternatives reduce or ameliorate the water crisis, an assessment of the practices that were effective in reducing water use or improving water quality should be conducted. The tendency is to return to previous water use practices once the crisis has been resolved, but if management practices invoked during the crisis are effective in efficiently allocating water among users, and/or improving water quality, 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 systems, and support adaptive management should be retained.

10. Move to the Proactive Chart

If the water crisis has been resolved and longer term options and alternatives can be assessed, the water resources management process should move from the Crisis Chart to the Proactive Chart so that future crises can be averted.

Path Two – Proactive Chart


The time to begin implementing SWRM practices is before water needs or water quality issues reach crisis proportions. When you are not in a crisis situation, management options increase, and stakeholders can actively participate in development of the management plan.

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 community or watershed issues is preferred because you not only know the actors you are one of them.

Denver Management Options for Drought Response

The Denver Water Drought Response Plan identifies several management options for meeting water needs when supply is reduced. These include options for increasing water supply, decreasing water demand, and monitoring and evaluating water supply and use, as listed below:

1. Increasing water supply
 - Call back water rights others have been allowed to use.
 - Pay a water user downstream of Denver Water diversion to not place a river “call”.
 - Seek waivers of minimum bypass requirements.
 - Develop groundwater sources.
 - Pump water not available through gravity flow.
 - Implement legal clauses allowing reservoir storage to be drawn below currently mandated minimum levels.
2. Decreasing water demand
 - Impose water use restrictions.
 - Add drought surcharges to water use charges.
 - Implement programs to enforce water use restrictions.
 - Provide incentive programs to encourage and reward immediate reductions of water use.
3. Monitoring and evaluation of water use
 - Historical water demand.
 - Weather-adjusted water demand.
 - Reservoir levels.
 - Water supply forecasting.
 - Snow pack readings
 - Precipitation monitoring
 - Monthly updates



**Proactively planning and
adaptively managing for
sustainability is
Smart.**

Steps in the implementation process need to be considered at each scale, from the local community to the 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 decisions 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 the hydrologic effects on your region from large-scale weather cycles. These large-scale cycles, such as El Nino and La Nina, influence periods of flooding and drought at regional, basin, and watershed scales.

The information needs of the Proactive Chart process are similar, but more extensive than for the Crisis Chart process. The Proactive Chart has greater emphasis on integration of, and interactions between, the social, economic, and ecological sectors, than in the Crisis process.

11. Continuing the Process – Descriptive Characteristics

One of the steps in the Proactive Chart process should be to compile information on the general characteristics of communities, watersheds, basins, and the region. Continuing the watershed management theme, the questions provided relate to the watershed scale, but they are also applicable for the community, basin, and regional scale.

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.

“Descriptive Characteristics” Questions

- ◆ How big is the watershed?
- ◆ Where is the watershed located (site map)?
- ◆ How many people live in the watershed?
- ◆ What cities, towns, and counties are located in the watershed?
- ◆ What communities not located in the watershed affect the watershed?
- ◆ What are the population demographics in the watershed?
- ◆ What is the socio-economic status of communities in the watershed?
- ◆ What is the history of the watershed and its people?
- ◆ What are the soils and geology of the watershed?
- ◆ What ecoregions occur in the watershed?
- ◆ What land uses/land covers (e.g., agricultural, forest) occur in the watershed?
- ◆ Have there been, or are there occurring, significant changes in land use in the watershed?
- ◆ What is the wetland extent in the watershed, and where are wetlands located?
- ◆ What water bodies are located in the watershed?
- ◆ How are water rights determined in the watershed?
- ◆ Is the system evaporation or precipitation dominated?
- ◆ How do upstream areas affect downstream communities and ecosystems?

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. All of us develop mental models to simplify, understand, explain, and predict things in a complex world. Everyone carries unspoken mental models that have been formed through their culture, background, education, and personal experience. These mental models reflect what we believe and value, and guide our actions. Because they are not always based on fact (e.g., water is an infinite resource; turn on the tap and water always comes out), it may be necessary to change mental models before behavior can be altered to support sustainable water resources. Changing a false mental model into a factual mental model requires first finding out what mental models exist in the community and watershed. In general, you'll need help from social scientists to determine and understand the values and beliefs (mental models) that exist within your watershed. Most social scientists get excited when approached by non-traditional clients. Everyone wants to feel that what they do can make a difference in society. Find them and engage them in the process.

If the stakeholder beliefs about water resources in the watershed are factually incorrect or unrealistic, educational campaigns need to be developed to provide factual information and educate the public on the issues. Social marketing techniques can be, and have been, used by 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.

“Stakeholder, Values, Beliefs, Interests, and Concerns” Questions

- ◆ What stakeholder issues are of current concern (e.g., transportation corridors, crime, economic growth, public education)?
- ◆ What do stakeholders want to preserve or improve in the watershed?
- ◆ What are stakeholder interests in water-based recreational opportunities?
- ◆ What are stakeholder opinions about their water supplies?
- ◆ What are stakeholder opinions about their wastewater facilities?
- ◆ What are stakeholder opinions about the relationships between a sound economy and a healthy environment?
- ◆ How much do the stakeholders understand about their water sources?
- ◆ How much do the stakeholders understand about water reuse and recycling?
- ◆ What are stakeholder opinions on water conservation? Energy conservation?
- ◆ What are stakeholder opinions about education?
- ◆ How many stakeholders are fishers? Bird-watchers? Hunters? Hikers?
- ◆ What are stakeholder interests in cultural and/or historical resources?
- ◆ What bond issues, public referendums, etc. have been on the ballot over the past 10 years? Which passed?
- ◆ Which civic institutions have public education as part of their mission?
- ◆ Which agencies have experience with public intervention efforts?
- ◆ Which civic institutions have experience with social marketing?
- ◆ Who are the credible spokespersons? Movers and Shakers.

13. Available Usable Water

Water quantity and quality information are needed for surface water *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 not all the needed information is readily available.

“Water Quantity and Quality” Questions

- ◆ How much precipitation falls in the watershed annually? Seasonally?
- ◆ How much water is lost through evapotranspiration?
- ◆ How many stream gauges exist in the watershed? Where are they?
- ◆ What contribution to annual runoff comes from snowpack? Winter rains? Summer monsoons?
- ◆ What groundwater aquifers occur within the watershed footprint?
- ◆ What is the spatial extent of groundwater aquifers in the region?
- ◆ How many groundwater monitoring wells exist in the watershed? Where are they?
- ◆ What is the rate of aquifer recharge?
- ◆ What is the normal, annual hydrograph?
- ◆ What are low flow and high flow recurrence intervals?
- ◆ When was the last drought, flood?
- ◆ What is the relative contribution of stormwater to wastewater discharge?
- ◆ How is stormwater managed?
- ◆ What are the trends in surface water and groundwater quantity over the past 50 years?
- ◆ What is the surface water quality?
- ◆ What is the contribution of wastewater discharge to summer baseflow in watershed streams?
- ◆ What nonpoint pollution sources are located in the watershed and how are they distributed spatially?
- ◆ What is the impact of nonpoint source pollution on water quality?
- ◆ Are there 303(d) listed streams (pollutant impaired waters) in the watershed? Why are they listed? Where are they located?
- ◆ What is the groundwater quality?
- ◆ What are the trends in water quality over the past 25 years?
- ◆ What are the designated uses (state water quality standards) for the streams in the watershed?

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 Global Environmental Management Institute has developed a checklist of common areas of water use (www.gemi.org/resources/checklist-common-uses.htm). The USGS collects and publishes information on water usage by state and major U.S. Water Resource Regions, but this information is typically not available for watersheds.

“Existing Water Use” Questions

- ◆ What are the existing water uses in the watershed?
- ◆ How much surface water is withdrawn for public water supplies?
- ◆ How much of the public water supply is for residences? Commercial? Industrial?
- ◆ What is the per capita use of water in the watershed?
- ◆ How much groundwater is withdrawn annually and for what uses?
- ◆ Are groundwater withdrawals metered and monitored? By whom? Are records available?
- ◆ How much water is used for irrigation? Source? Is this use metered or monitored?
- ◆ How much water is consumed by each use?
- ◆ What proportion of the water withdrawn returns to the stream or aquifer? Where is it returned?
- ◆ How much water is reused or recycled? By whom (e.g., golf courses)?
- ◆ What water conservation programs are in place?
- ◆ What requirements, if any, exist in the watershed for the use of low volume toilets, washing machines, etc.?
- ◆ What is the quality of the return water from various uses?
- ◆ How much water is dedicated to minimum low flow in streams?
- ◆ What water allocation compacts exist, with whom, and for what required downstream discharges?
- ◆ What are the trends in water use over the past 25 years?

Determining Stakeholder Values, Beliefs, Interests, and Concerns in the Upper San Pedro River Watershed

The Udall Center for Studies in Public Policy, University of Arizona, worked with elected officials, environmental activists, and community leaders in the U.S. and Mexico to identify local issues and concerns related to water in the upper San Pedro River watershed. The primary findings were:

United States

- There is widespread appreciation for the river.
- Residents of the watershed want to provide substantive input to water management and planning for the river.
- Opinions are divided over the nature and extent to which the river is in jeopardy.
- There is virtually unanimous support for water conservation and aquifer recharge.
- Many people see a need for growth management.
- Multiple jurisdictions, both local and national, should share in the river's management.
- The burdens of water conservation should be equitably shared among water users.
- There is a need for more study of the Mexican portion of the watershed.
- Mexico should be included in cooperative planning and management processes for the watershed.

Mexico

- There is concern about potential negative effects on Mexican farmers and ranchers from conservation and restoration efforts. Alternate options for livelihoods should be provided.
- Mexico desires that they benefit from protecting the San Pedro River to a degree similar to the United States.
- The use of groundwater for the copper mine is resulting in lowering of groundwater levels and affecting water levels in San Pedro River.
- There is support of conservation and restoration in the watershed on both sides of the border.

15. Water Uses – Needs and Wants

The next step in the process is to determine which water uses are required for the survival of the human communities present in the watershed and the natural systems on which society depends. These are water use needs. Those water uses that do not satisfy this criterion are categorized as desired water uses, or wants. Minimum water requirements for the water use needs are also determined. In addition, the quality of water required for all of the water uses identified here also needs to be considered.

Water Use Needs

Gleick (1996, 1998) 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 or 4,750 gallons per capita per year (gal/pcy) as a basic minimum. This estimate is considered to be a true minimum to sustain life in a moderate climate with 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/pcy for domestic purposes. Canada and Mexico use about 41,000 and 12,000 gal/pcy, respectively (Gleick 2000). Minimum water quality requirements for human use can be obtained by using water standards for aquatic life (because drinking water standards are typically for treated, not raw water).

Estimates of minimum water requirements are also needed for agricultural, commercial, industrial, power generation, cooling water, and similar human uses, as well as wetland, riparian, 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. The companion report (Thornton et al. 2004) includes 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 can be obtained by assuming that state water quality standards (WQS), and federal water quality criteria will be attained. WQS incorporate the designated water body uses, and the water quality criteria to protect those designated uses.

There currently is little information available on flow regimes required to sustain aquatic ecosystems. 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 to determine the minimum water requirements for natural systems. The Nature Conservancy has a sustainable waters program that will eventually provide estimates of minimum and maximum flows and required flow durations, by season, for various streams throughout the U.S. (www.freshwaters.org). Minimum water quality requirements can be obtained by assuming that State WQS, and federal water quality criteria will be attained.

Desired Water Uses

Initial desired water use quantities could be estimated by compiling existing water use quantities (volumes). Future desired water use 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.

“Minimum and Desired Use” Questions

- ◆ What are the estimates of water quantity and quality needed for minimum support of the current human population in the watershed? For the desired uses?
- ◆ How much water is needed, at a minimum, and of what quality, to support existing agriculture in the watershed? What are the desired water use levels for agriculture?
- ◆ How much water is needed, at a minimum, and of what quality, to support existing commercial and industrial uses in the watershed? What are the desired use levels for industry and commerce?
- ◆ How much water is needed, at a minimum, and of what quality, to support existing power generation and cooling water uses in the watershed? What is the desired use level?
- ◆ How much water is needed, at a minimum, and of what quality, to support ecological systems in the watershed (e.g., rivers and streams, lakes and reservoirs, wetlands, riparian areas, threatened and endangered species, special places)? How much water, of what quality, is desired for ecological systems?
- ◆ What minimum flows are required by laws, regulations or policies (e.g., endangered species, water allocation compacts)? What are the desired flows?
- ◆ What water quality is required by laws, regulations, or policies (e.g., state and federal water quality criteria)?
- ◆ What are the projections of future demands for water? What water quality is needed to support these demands, by use categories above?
- ◆ What agencies have water quantity and/or water quality within their jurisdiction?
- ◆ What civic institutions have water quantity and/or water quality within their mission?

What Makes a Use a Need?

In the San Pedro River watershed of Arizona, protection of water dependent natural systems is one of the primary management goals, and has been federally mandated for that portion of the river contained in the San Pedro Riparian Conservation Area. Therefore, estimates of the water needs for natural systems are an important element of management in the watershed. Several attempts have been made to estimate water needs for natural systems in the San Pedro River watershed. A water budget prepared by Putnam et al. (1988) for the period 1968-1976 estimated that approximately 55,000 ac-ft of water was used by natural systems in upper San Pedro River watershed. The Arizona Department of Water Resources estimated in a 1991 report that in 1990 approximately 61,000 ac-ft of water was used to maintain natural ecosystems in the San Pedro River watershed. The Semi-Arid Land Surface Atmosphere program has been researching water needs of the San Pedro River riparian ecosystem since 1998, and is contributing valuable information to current water management and budgeting efforts.

16. Sustainability Criteria Comparisons

Four criteria have been established to determine if current water management practices support sustainable water resources:

1. Has the groundwater table elevation remained relatively constant over a ten-year running average? If the groundwater table elevation has been declining over a ten-year period, the current management of 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, existing 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 cannot be sustained in the stream during the summer or fall season, then existing water management practices are not considered sustainable.
4. 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 existing water management practices are not supporting sustainable water resources.

If any one of these criteria is not met, it will be necessary to make changes in current water management practices to achieve sustainability. If all of these criteria are met, current water management practices are sustainable. If any of these criteria cannot be evaluated, collecting the information necessary to evaluate those criteria should be incorporated into the management plan. Whether current water management practices are sustainable, unsustainable, or undetermined, the next step is to determine the stakeholder vision and goals for the watershed.

17. Alternative Futures Analyses

The temptation to move directly from the determination of sustainability to assessing options for achieving the required/desired water uses should be avoided. The first step in deciding what changes to make is to take a careful look at stakeholders' desires and goals for the watershed and its water resources. With the data and information compiled through the activities above, sufficient knowledge of the watershed exists to create a vision of 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 within the

watershed, and prioritization of these goals when choices among competing goals have to be made. Alternative futures analysis can assist in moving toward a consensus 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 charrettes 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. The sidebar describes an alternative futures study. Below is a listing of several alternative futures studies completed in the United States.

Insights from Study of Alternative Futures for Upper San Pedro River Watershed

An alternative futures study of the upper San Pedro River watershed was performed by the Harvard University Graduate School of Design with the Desert Research Institute, University of Arizona, Instituto del Medio Ambiente y el Desarrollo Sostenible del Estado de Sonora, and United States Army. In this study, watershed conditions in 2000 were compared to potential conditions in 2020 resulting from scenarios in three categories. The three categories were Plans Scenarios, in which existing development and growth plans were followed; Constrained Scenarios, in which development and growth was constrained to those areas currently developed; and Open Scenarios, in which development and growth occurred with less control than currently exists. Impacts on watershed land use/development, hydrology, vegetation, wildlife habitat, habitat for threatened and endangered species, species richness, and aesthetics were evaluated. The study also identified areas of high potential for conflict between development pressure and conservation needs. Insights from this study included:

- All alternatives resulted in loss of groundwater storage and drying of the San Pedro River, even with reductions in per capita water use,
- Policy decisions affecting irrigated agriculture in Arizona have the greatest impact on watershed hydrology, and
- Development control policies have the second greatest impact on watershed hydrology.

Example Alternative Futures Studies

- ◆ Alternative Futures for Monroe County, Pennsylvania
- ◆ Modeling Effects of Alternative Landscape Design and Management on Water Quality and Biodiversity in Midwest Agricultural Watersheds (Iowa)
- ◆ Alternative Futures for Changing Landscapes: The Upper San Pedro River Basin in Arizona and Sonora
- ◆ Willamette River Basin Planning Atlas: Trajectories of Environmental and Ecological Change
- ◆ Southern Rockies Landscape Planning Project
- ◆ The Development of Alternative Future Growth Scenarios for the California Mojave Desert
- ◆ Biodiversity and Landscape Planning: Alternative Futures for the Region of Camp Pendleton, California

18. Prioritization of Water Needs and Wants

The first step for prioritizing water uses is to compare available usable water with required and desired water usage. Minimum water requirements for social, economic, and ecological sectors were estimated previously (see Step 15). Existing and projected future water uses also were estimated previously (see Steps 14 and 15). A comparison of the required and desired water use estimates with available water quantity and quality estimates will indicate if:

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

The Alternative Futures Analysis and other knowledge of stakeholder desires and goals are used as guides for deciding which water uses will have priority. Water uses are prioritized based on their level of support for stakeholder watershed goals.

“Prioritization and Allocation” Questions

- ◆ Which water uses support stakeholder goals for the watershed?
- ◆ Which water uses are required to maintain human health, welfare, and the desired quality of life?
- ◆ Which water uses support ecological systems and contribute to maintaining desired ecosystem goods and services?
- ◆ Which water uses are required to support the economy and the desired quality of life?
- ◆ What water quantity and quality are required for these uses? What are the current or desired water quantity and quality for these uses?
- ◆ What are the stakeholder priorities for water use in the watershed?
- ◆ How will available water be allocated among the needed and wanted uses for water, under different hydrologic conditions (i.e., drought conditions, normal conditions, wet conditions)?
- ◆ Who is responsible for allocation, implementation, monitoring, and enforcement decisions?

19. Adaptive Management

Monitor, Assess, and Adapt. Adaptive management is the foundation of sustainable water resources management. Plan=>Do=>Check=>React=>Plan... represents the iterative approach needed to manage highly complex, nonlinear socioeconomic and environmental systems whose behavior can not be predicted. Management programs need to be evaluated on a regular basis to ensure that they are achieving the desired societal goals, are identifying and addressing existing problems, are based on the best available information about the current state of the system, are utilizing the best available technology and techniques, and are identifying emerging problems.

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, laws, regulations, ordinances, policies, compacts, and treaties. The following tables include examples from the many management options that can contribute to SWRM.

As stated in the beginning of this document, there are few sound management practices, social norms, or economic approaches that can not contribute to sustainable water resources management. For example, Smart Growth practices can decrease the percent impervious area and increase forested watershed area, thereby improving water quality by decreasing runoff volume, restoring natural stream flow and watershed hydrology, increasing groundwater recharge, and decreasing stream sedimentation and water pollution. While protecting water quantity and quality, these practices can also stimulate economic development in desired areas.

Indicators that 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 short list of indicators is included below (see Thornton et al. 2005 for a more comprehensive list). Many of these water resources indicators are currently monitored by local, state, and federal agencies. Monitoring information for the indicators will need to be accessible to multiple users (i.e., through linked information systems) to be useful for adaptive management at multiple scales.

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 appliances	Commercial/industrial recycling systems	Tax credits for businesses using reclaimed water
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

Selected Examples of Economic Incentives and Water Trading Practices
<ul style="list-style-type: none"> ◆ Scaled water prices based on usage level (volumetric pricing and multipart pricing) ◆ Rebates, tax credits for installation of conservation or reuse technology ◆ Sale of recycled water through public utility at lower cost than potable water ◆ Sale of water rights (long or short-term) ◆ Direct sale of recycled water from creator to user ◆ Pricing water to reflect the true cost and/or value

Sustainable Water Resources Indicators (Desired Trend Direction)

- ◆ Long term trends in groundwater level (Increase Level)
- ◆ Water use, by use sector (i.e., residential, commercial, irrigation, natural systems) (Stable or Decrease)
- ◆ Precipitation (monthly, annual) (Natural)
- ◆ Long term trends in stream flow (flow or stage gages) (Natural)
- ◆ Forest fragmentation (Decrease) or % forest cover in watershed (Increase)
- ◆ Water quality (conductivity, dissolved oxygen, temperature, turbidity, fish tissue containment concentrations, chlorophyll a) (Increase in WQS attainment)
- ◆ Number of 303(d) listed streams (Decrease)
- ◆ Net number of jobs created (Increase)
- ◆ Percentage impervious surface in watershed (Decrease)
- ◆ Median household income (Increase)
- ◆ Migration (people moving into and leaving the watershed) (Stable)
- ◆ Percentage population in watershed below poverty level (Decrease)
- ◆ Amount of water returned to system (treated waste water, groundwater recharge) (Increase)
- ◆ Amount of nonpotable water reused (Increase)
- ◆ Water saved as a result of conservation measures (Increase)

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, basins, and aquifers 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 needed because, while watersheds are suitable management units for surface water issues, groundwater aquifers often do not follow watershed boundaries, and precipitation and evaporation patterns are the result of large-scale climate patterns. In most cases, the USGS Water Resources Regions correspond reasonably well with regional aquifer boundaries (Figure 2) and weather patterns; as such, these Water Resources Regions might serve as the logical starting point for developing regional management units for sustainable water resources. Factors such as local variability in transmissivity and connectivity of regional aquifer units, and intra-basin water transfers will affect how regional management units are ultimately defined (see sidebar).

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 coalitions will be needed to move toward sustainable water resources management in the West. This is equally true in the East. In the West, regional water quantity management already occurs through the Colorado River Compact. In the East, regional water quality management occurs through the Chesapeake Bay Compact. Over time, these regional management entities will address other water resources issues (i.e., water quality in the Colorado River basin, and water quantity in the Chesapeake Bay basin), and other regional water resources management entities will come into being.

Start Now

Sustainable water resources management might appear to be overwhelming, but all the information in this document and the companion report was readily available in the literature. What is new is the synthesis and integration, the framework and the guidelines. The key to SWRM is to start. Pick an issue, form a team, start the process. Nearly all the information you need is available. Work through the guidelines. Move toward a sustainable outcome.

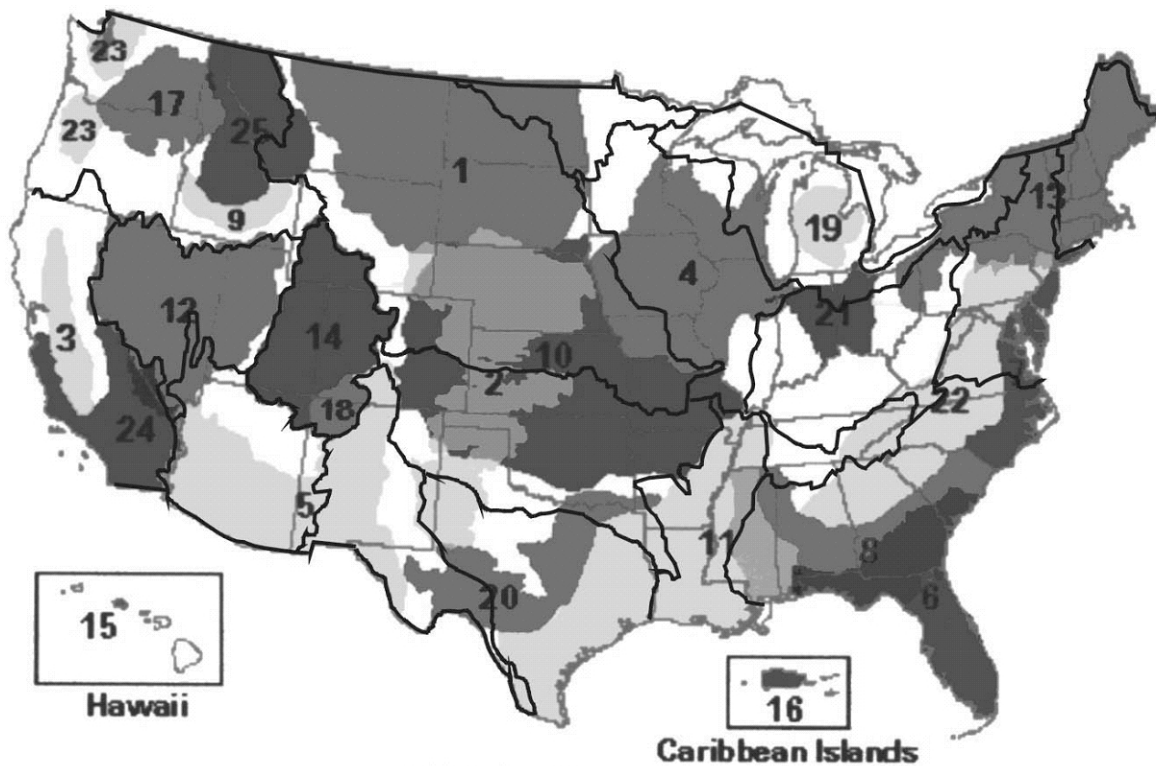
Sustainability is an outcome!

Using a total systems approach to monitor, assess, and adaptively manage water through time ==> sustainable water resources.

Developing Regional Management Units

The San Pedro River watershed in Arizona is part of the Lower Colorado USGS Water Resources Region. This surface water region contains a large portion of the Southwest Alluvial Basin regional aquifer, and part of the Colorado Plateau regional aquifers. The Southwest Alluvial Basin regional aquifer is a system of mostly local aquifers, with little connectivity between aquifers, therefore, we suspect that including only a portion of this regional aquifer would not impair our definition of this as a regional management unit, reflecting a closed land water system. The Colorado Plateau regional aquifers, however, are a system of connected aquifers. As a result, the Lower Colorado water resources region is not as close to a closed water system as we would like. A more appropriate regional management unit for this system would be the entire Colorado River basin – this brings all of the Colorado Plateau regional aquifers into the management unit, resulting in a more closed water system. Some aspects of the Colorado River basin are already managed at the basin scale, i.e., water quantity by the Bureau of Land Management, and the Colorado River Water Users Association.

The Spring Creek watershed in Pennsylvania is part of the Mid-Atlantic Water Resources Region. The Spring Creek watershed is also part of the Chesapeake Bay watershed, which is currently being managed by the Chesapeake Bay Program, primarily for water quality. Since this Chesapeake Bay management unit is already in place, it could also be a reasonable regional management unit for SWRM. An analysis of the aquifers underlying the Chesapeake Bay watershed indicates that the watershed is very nearly a closed hydrologic system, and as such, is suitable as a regional management unit for SWRM.



Regional Aquifers

- | | |
|------------------------------------|--|
| 1. Northern Great Plains | 14. Upper Colorado River Basin |
| 2. High Plains | 15. Oahu, Hawaii |
| 3. Central Valley, California | 16. Caribbean Islands |
| 4. Northern Midwest | 17. Columbia Plateau |
| 5. Southwest Alluvial Basins | 18. San Juan Basin |
| 6. Floridan | 19. Michigan Basin |
| 7. Northern Atlantic Coastal Plain | 20. Edwards-Trinity |
| 8. Southeastern Coastal Plain | 21. Midwestern Basins and Arches |
| 9. Snake River Plain | 22. Appalachian Valleys and Piedmont |
| 10. Central Midwest | 23. Puget-Willamette Lowland |
| 11. Gulf Coastal Plains | 24. Southern California Alluvial Basins |
| 12. Great Basin | 25. Northern Rocky Mountain Intermontane |
| 13. Northeast Glacial Aquifers | |

Major Water Resources Regions (East to West)

- New England
- Mid-Atlantic
- Ohio
- Tennessee
- South Atlantic-Gulf
- Great Lakes
- Upper Mississippi
- Lower Mississippi
- Souris-Red-Rainy
- Missouri
- Arkansas-White-Red
- Texas-Gulf
- Rio Grande
- Upper Colorado
- Lower Colorado
- Pacific Northwest
- Great Basin
- California

Figure 2. Major USGS Water Resource Regions (black outlines) Overlaid on USGS Regional Aquifers (numbered shaded areas).

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