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Science and Practice of Integrated River Basin Management: Lessons from North and Central American UNESCO-HELP Basins

INTRODUCTION

The Hydrology for the Environment, Life and Policy (HELP) program, a cross-cutting component of the UNESCO International Hydrological Programme (IHP), has as its goal to facilitate dialogue among hydrologists, social and economic scientists, water resource managers, water lawyers, policy experts, and river basin stakeholder communities in setting a research agenda driven by local management and policy issues. HELP seeks to improve the benefits to society by applying the principals of integrated water-resources management to complex, interdisciplinary issues within catchments.

Integrated Water Resources Management (IWRM), according to the Global Water Partnership, is "a process which promotes the coordinated development and the management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." IWRM is a holistic approach that includes both the natural and human system, in contrast to the previously fragmented management approaches. Within HELP, the definition of IWRM expands this holistic view by balancing competing demands from diverse interests such as agriculture, industrial, domestic, and environmental stakeholders within the context of climate change and population growth. The goal is to end up with a more equitable, efficient, and sustainable river basin management process that addresses water resource challenges and builds the capacity of stakeholders to adapt new strategies that will make both the ecosystem and socioeconomic system more resilient to climate variability and change and population growth.

The separation between the scientific and management sectors was a paradigm lock that prevented optimal management of the water resources. HELP provides a framework within catchments for scientists, stakeholders, managers, and law and policy experts to come together and break this lock in order to address locally defined water-related issues. The HELP initiative developed around a global network of basins in which the science of process hydrology is strengthened by its linkages with multiple issues involving water law and policy tools, water resource management, and stakeholder needs. Furthermore, HELP offers a platform for sharing experiences across an international network of catchments.

In reality, HELP basins are independent water-resource management organizations that volunteer to be a part of the international HELP network. Their "day jobs" are defined by their sponsoring organizations that include government, university, and multistate compacts, and river basin authorities. However, they share their "lessons learned" on a voluntary basis as a result of their formal activities with the HELP international network of basins.

This Monograph is the culmination of a workshop held in 2010 in which the managers from the six North American basins (San Pedro, Willamette, Upper Washita, Lake Champlain, Iowa-Cedar, Luquillo) and a Central American basin (Panama Canal), see Figure 1, met to exchange ideas and "lessons learned" in various applications of IWRM within the HELP philosophy. Three major themes were examined:

1. Climate change: Creating watershed resilience
2. Use of social learning in IWRM
3. Knowledge and information management for IWRM

Each of these themes is explored in detail and enhanced with case studies of IWRM applications from the participating North and Central American HELP basins.

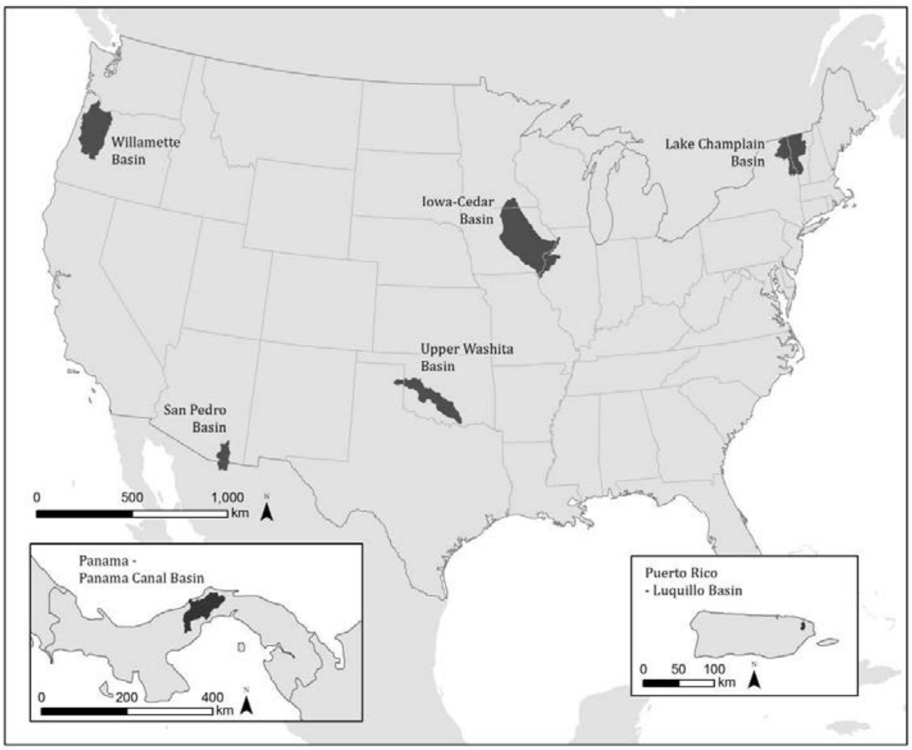

Figure 1. Locations of the UNESCO-HELP Basins in North and Central America.

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Chapter 1

Climate Change—Creating Watershed Resilience

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Introduction

Climate change is occurring. There may be several reasons for this: one is the possibility of natural processes comparable to the ice ages that affected the earth; two may be the fact that only now do we have accurate and long enough records of temperature and precipitation; or three may be the anthropogenic impact of human activities to increase the concentration of greenhouse gases. This chapter does not attempt to answer “why or how.” The purpose of this chapter is to examine how hydrologists, water managers, lawyers, environmentalists, and individual citizens take a leading role in assisting societies to cope with and adapt to these changes. The chapter examines these coping mechanisms within the HELP framework of dialogue among all stakeholders.

Climate change is likely to intensify the circulation of water on, above, and below the surface of the earth, thus shifting spatial and temporal availability of snowmelt and runoff. In mid-latitudes, drought and floods are likely to be more frequent, severe, and widespread (Parry et al., 2007). Higher air temperatures will lead to higher ocean temperatures, elevating sea levels and providing energy for the formation of hurricanes and tropical storms. While there is uncertainty regarding the magnitude and geographic distribution of such impacts, it is certain that societies will need to meet the challenge of climate-change-induced water stresses.

Knowing that climate change is occurring, this chapter seeks to determine how water resource communities can react and adapt to it with minimal disturbances to the environment and how we, as humans, manage and adapt to it. Traditional water management, historically an engineering approach, has been built upon a concept of stationarity. Stationarity is a concept which assumes that meteorological and hydrological systems are constrained by an envelope of variability that long-term records define. In other words, what happened yesterday will happen tomorrow, within statistically defined variability. Milly et al. (2008) examined the consequences of climate change on water management, and they questioned the assumption that has been the backbone of water management: that the past is the foundation for future management and development. Very simply, the realization of climate change invalidates all of these previous assumptions. Equally important are anthropogenic non-climatic factors, such as land use/land cover changes and water engineering that lead to the violation of stationarity (Kundzewicz, 2011). In brief, stationarity is dead.

A. Climate Change and the Human Response: Historical Relevance

Viewed within a geologic and historical context, the effects of climate change on landscapes reveal multiple interesting linkages. For example, paleoclimatic studies linked to geomorphic studies show that rivers agrade and degrade as changes in precipitation, temperature, plant community, and evapotransporation influence hill slope, stream, and soil subsystems (Bull, 1991). These linkages in turn influence human response patterns. On timescales ranging from decades to centuries, climatic variations are quite pertinent to modern society. The relationship between paleoclimatic data and climate change indicates that those cultures that could not adapt to climate change were not able to outlive the climate change impacts (Bradley, 1985). For example, archeological evidence shows the Anasazi population in the Southwest society evolved over 700 years. Trade routes developed to distribute agricultural products, beads and other goods, but they abandoned Chaco by mid 12th century (Stuart, 2000; Benson et al., 2007). While a number of individuals migrated to other areas, the core settlement of their society, Chaco Canyon, stands empty, a monument to a society unwilling or unable to change.

To understand the dynamics of this event, we need to detail the conditions of the changing landscape of the Chacoans and their response. Early Chaco Canyon inhabitants experienced a high groundwater table and a river that flowed across the valley bottom. At that time, the Anasazi could easily divert the river water to farm fields. Coupled with clearing of vegetation by the occupants, the gradual climate change to drought-prone conditions triggered a shift in river morphology. Channel incision resulted from short, infrequent storms, increasingly drier soils, and reduced vegetation to intercept runoff. Deep arroyos formed; irrigation from surface channels or groundwater was no longer possible. Food shortages, followed by societal infighting, led to the Chaco's eventual collapse (Diamond, 2005). However, if we add the concept that stationarity is dead, the droughts that occurred during the last days of Chaco Canyon (in concert with the Anasazi's clear-cutting the landscape, increasing erosion, and thus a lowering of the water table) may not necessarily be representative of the droughts to come—they could be either shorter or longer on average because of human impacts on our global climate—the scale (including temporal and magnitude) is no longer as predictable as it used to be (Gungle, written commun., 2011).

- The story of Chaco is one of human environmental impact (deforestation and soil loss) coupled with climate change (drought). Drought and streambed erosion occur over time spans much longer than human lifetimes or oral memory. However, some severe droughts or catastrophic erosion can happen during a human lifetime and can have devastating effects on the resilience of human society. A recent study by Pederson et al. (2011) shows that the late 20^{th} century snowpack declines in western North America are unprecedented over the past millennium. Given future scenarios of warming in California, one can expect an accelerated trend toward earlier peak timing, which "will reduce the warm season storage capacity of the California snowpack" (Kapnick and Hall, 2010). In addition, "simulations of potential future climate and vegetation indicate that future fire conditions in some parts of the northwestern U.S. could be more severe than they are today" (Whitlock et al., 2003).

B. Impact Assessment Studies: Sources of Uncertainty

Despite the utility of historical and tree ring data, several sources of uncertainty are associated with climate change impact assessment studies. These sources include:

- Climate data uncertainty
- Modeling uncertainty
- Scenario uncertainty
- The uncertainty in human system responses to climate change

1. Climate data uncertainty

Two sources of uncertainty are associated with climate data. The first source is observational measurement uncertainty. The accuracy of a measurement is subject to the calibration and initial set-up of instruments.

The second source of uncertainty concerns the question of whether the sampled data are representative over space and time. Several precautions are necessary to reduce uncertainty. First, a careful selection of sampling points is required. If the data are not collected frequently, the potential temporal cycle may be masked. Second, the observation period must be appropriate. Climate data need to be collected over a long enough time to model accurately a potential cycle of changes in climate. Unfortunately, due to a variety of reasons, many weather and climate data are collected in specific locations for a specific time interval. Data gathered in this way may not be ideal for capturing the whole range of spatial and temporal variability of precipitation and temperature on a larger scale. By far, climate input data (intensity of rainfall, volume of rainfall, timing of rainfall, future variability, etc.) present the greatest sources of uncertainty in hydrologic impact studies involving projected estimates of climate change. Even though adequate sample design is implemented, past data may not be sufficient to evaluate potential shifts in water supply and demand.

2. Modeling uncertainty

Hydrologic models are powerful tools for simulating the effects of climate change on soil and water resources. Scenario simulations are useful for determining possible resilient systems. However, as several sources of model input uncertainty affect results, modelers need to include uncertainty analysis in model evaluations. These uncertainties include:

- Input measurements (e.g., failure of a rain gauge)
- Model parameter estimation (e.g., inaccurate estimation of evaporation rate)
- Mathematical equations used to simulate processes (linear assumption in rainfall-runoff processes)
- Lack of knowledge about some physical processes and operational procedures (spatial and temporal rate of groundwater movement)
- Calibration and validation accuracy (overfitting of model)

To increase the confidence of model simulation results, transparency regarding these uncertainties is important. Modelers must communicate to stakeholders that hydrological models are not deterministic. Due to the several sources of uncertainty noted above, model outputs cannot be precise. Therefore, providing an interval estimate for a given quantity of model output may be preferable to providing a point estimate. This approach increases the probability that the value of the quantity will be contained by the interval (Haan et al., 1998). Use of multiple models is one way to quantify model output uncertainty. Additionally, multiple scenarios can be used to explore the range of possible future paths of water resource system changes.

A second way to reduce output uncertainty is to learn about and consider all important physical and operational processes that may affect the component of interest. For example, when the model is being calibrated for streamflow (combination of surface runoff and baseflow), it is important that the modeler checks to ensure that the outputs of evapotransporation, crop/plant biomass, surface runoff/baseflow ratio are within the ballpark for the area of study. Effective model calibration and validation includes checks to ensure that a given model is simulating all important processes correctly. If not, modeling may obtain calibration and validation statistics with parameter value combinations that do not correctly represent the processes. This can lead to invalid outputs and erroneous conclusions about the impact of land management and climate change on water resources.

Therefore, to build confidence in climate change assessment, it is important to ensure process-oriented model calibration and validation based on the study area information. Also important are stakeholder inputs (specifically those who have extensive knowledge of the study area). Sharing local experience with scientists also increases stakeholder confidence and trust in model outputs and results.

3. Future scenarios and uncertainty

To run a hydrologic simulation model for future flow conditions, we need future climate change scenarios. We have defined scenario as “a plausible future condition based on socioeconomic trajectories that can be specific to time and location” (Liu et al., 2008) . In climate change impact assessments, greenhouse gas emission scenarios (tightly linked with the choice of fossil fuels and technology) determine future temperature and precipitation conditions. Because different scenarios assume different future paths, the degree of warming and precipitation also vary.

Awareness and action at the local level are essential conditions for successful adaptation. Stakeholders and agencies responsible for water management must work together to provide outreach and education to build community capacity for resilient planning and decision-making. Key steps include explaining climate risk issues, sharing sources of information, developing necessary linkages across water sectors, planning and testing actions, and evaluating experience for future learning.

Water, as the most important component of life, creates a common bond between all species on the planet. As climate changes, the hydrologic supply will change in some dramatic ways. For human communities, this change will present water quantity, quality, demand, and timing issues and choices. Communities must understand the new conditions and decide how to adapt to them. Those communities that do not adjust may experience hardships through drought or flooding, as studies revealed as early as 1999, the close of the decade when scientists say climate change kicked into a higher gear. The events examined were similar to more recent disasters: deluges that triggered deadly floods in Pakistan, Bangladesh, central Brazil, and recently in Nashville, Tennessee (Kunkel et al., 1999; Fankhauser et al., 1999).

Future scenarios in the Washita River Basin include model simulations of the impact of climate change (both increase in temperature and increased frequency, severity, and extent of droughts and floods) on the quantity and quality of surface and groundwater resources. In a large river basin such as the Willamette River Basin, the impacts of climate change will be very different across sub-basins (Chang and Jung, 2010). In rain-dominated basins where the magnitude of runoff is projected to increase in winter and decrease in summer, there is no shift in the timing of peak runoff. In rain-snow transient basins, where less snow will be available for sustaining summer flow, summer flow is projected to decline further. In snow-dominated basins with deep groundwater systems, summer flow can be sustained. However, the uncertainty of future runoff projections is high, particularly for summer runoff. As is the case with most previous studies, the Global Climate Model (GCM) uncertainty is by far the biggest source of uncertainty in climate change impact assessment as each GCM uses different assumptions and equations to project future climate (Praskievicz and Chang, 2009).

4. Resilient systems

Resilient systems withstand the forces that arise from normal fluctuations and cycles in the environment (Walker et al., 2002) and other stresses. A resilient water-resource system will adapt to system stresses with limited social and ecological disruption. Historically, many human societies have adapted to climate variability and change. Because each society and its individuals have different perceptions and ways of coping with climate change, the degree of climate adaptation also varies by society. A society with mechanisms to adapt to climate stresses would survive, either by creating new resilient social systems in the same location, or by migrating to other places. Typically, these choices are governed by complex interactions and feedback between the tightly coupled human and natural systems, occurring at multiple scales. While climate change occurs globally, the impacts of climate change vary regionally and locally. The degree of climate impact depends on the internal capacity of a water resource system to cope with external climate stress.

Whether it is climate change, crop production, housing trends, the winner of the World Cup Tournament, or water availability, the future is to some degree uncertain. Uncertainty is inherent in any planning effort. With uncertainty comes risk. Risk exists when there are multiple potential outcomes and at least one of them is less desirable. Contributing further to this inherent uncertainty and risk are the influences that decision-makers have upon future conditions. In order to make the most prudent decisions available, decision-makers need adequate knowledge and tools to assess the probable impacts of their actions. Effective planning and decision-making in an uncertain and complex world is the challenge faced by water managers and decision-makers.

Sustainable management of water resources requires assessment of both uncertainties and risk. Risk analysis is a method for assessing the level of uncertainty and the magnitude of consequences. Current risk-analysis protocols generally consist of three components:

1. Risk assessment (analysis of the technical aspects of the problem to determine uncertainties and their magnitudes).
2. Risk communication (conveying information about the nature of the risks to all interested parties).
3. Risk management (deciding how to handle risks).

Risk analysis provides a more accurate representation of our knowledge of a particular situation, even as it describes the degree to which that knowledge is uncertain[i]. Understanding effective risk analysis and the degree of future uncertainty will enable water resource managers to create multiple scenarios in response to differing future conditions.

The following illustration indicates how risk-analysis techniques can assess the risks of various management approaches to the same problem. If *uncertainty* of future conditions and the *consequences* of future conditions are both low, then standard deterministic planning and decision-making techniques are appropriate. On the other hand, a highly uncertain future with potentially severe consequences will warrant alternate, more adaptable approaches to water resources management.

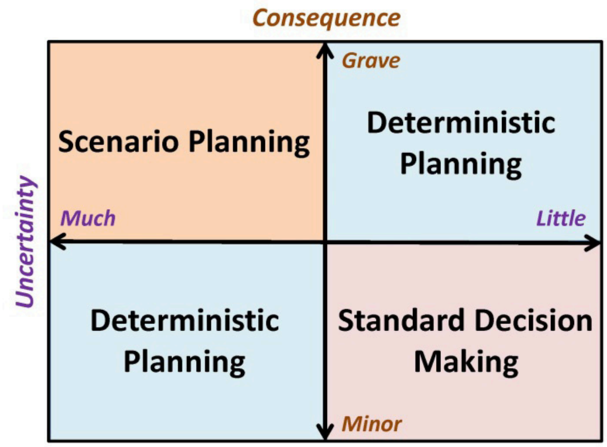

Figure 1-1. Risk analysis influence upon decision making.

5. Integrating uncertainty into IWRM

The Global Water Partnership defines IWRM as "a process which promotes the coordinated development and the management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." (Agarwal et al., 2000). This holistic approach seeks to integrate the management of the physical environment within that of the broader socio-economic and political framework. IWRM has been adopted by major international organizations, such as the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the World Meteorological Organization (WMO), as the "inspiring principle" for the Water Framework Directive in 2000.[1] Yet, as promising as IWRM appears, IWRM as a concept and practice requires further improvements and clarification to ensure:

1. Fuller understanding of the dynamics of natural processes within natural systems.
2. Better understanding of the complex dynamics of coupled natural and human systems.
3. Effective development of appropriate enabling technologies for handling the data.
4. Production of simulation outcomes for immediate practical applications.
5. Definition of regional constraints stemming from the existing cultural or institutional environment.

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[1] IWRM has also been adopted by the European Union and respective individual countries (e.g., Kidd and Shaw, 2007; Snellen and Schreval, 2004). UN-Water (2008) reported 58 countries around the world that had adopted IWRM. A search of published papers in journal citation reports indicates that more than 350 peer-reviewed papers discuss IWRM as of June 2011.

A search for the word “uncertainty” in the UNESCO-published IWRM Guidelines produces no results—it does not appear once in the document. Expanding the scope of IWRM to incorporate uncertainty is essential to effective, adaptable, and sustainable water management. A recent review by Wichelns (2008) stressed the benefits of adaptive water management in an uncertain climate.

Several recent U.S. initiatives within federal and local governments are beginning to address the gap between existing practices and those that more closely reflect the IWRM approach. One of the most relevant examples is the formation in 2007 of the International Center for Integrated Water Resources Management (ICIWaRM). The center was established by the United States Army Institute for Water Resources (IWR) in collaboration with U.S. institutions and organizations sharing an interest in the advancement of IWRM around the globe. The center was formalized in 2009 as a UNESCO category 2 water center. An integral part of the Americas’ efforts to implement IWRM is the network of HELP basins that adopt strategies and implement IWRM practices.

6. Adaptive Integrated Water Management (AIWM)

AIWM is an approach for dealing with uncertainty and complexity within the IWRM framework. AIWM was developed under a European Commission-sponsored research project entitled “New Approaches to Adaptive Water Management under Uncertainty (NeWater)” (Medema et al., 2008). It recognizes that current water management regimes will not be able to implement IWRM without first making a transition to more adaptive water management. AIWM, a synthesis of IWRM and Adaptive Water Management (AWM), addresses uncertainty and complexity by increasing and sustaining the capacity to learn new information about socio-ecological processes and data while managing, and to manage while learning. Our abilities to predict the future are limited, as are our abilities to predict our impacts upon that future. AIWM promotes a shift from management that emphasizes prediction and control to management as a learning approach. Learning is an iterative process based on experience and insight. With AIWM, the results of implemented strategies are monitored, and insights shared. Those insights are applied to further test and improve both analytic methods and management approaches. This transition from traditional management regimes to AIWM will encounter many institutional and socio-economic obstacles. Pahl-Wostl et al. (2007) highlights the merits of the AIWM approach and outlines implementation strategies and barriers.

The communication between scientists and stakeholders is an important step toward development of community understanding and ownership of risk. Scientists have a responsibility to educate the community they serve regarding the risks for that community and possible actions the community can take to reduce that risk. Stakeholders and private citizens have a responsibility to assure that the community decision makers understand their views and desires for addressing risks and resource concerns.

C. Case Studies Integrating Risk Analysis and Uncertainty into Climate Change Adaptation

Evidence of how water management may be able to accommodate and adapt to climate change is beginning to accumulate in large river basins (Krysanova et al., 2010). The following are but three examples based on North American HELP basin experiences that address this very issue.

Case Study 1: Impact of No-Till on Erosion in the Washita River Basin during Tropical Storm Erin

D. N. Moriasi, J.L. Steiner, L. Wright, and P.H. Moershel

In humid temperate climates, topsoil erosion from agricultural fields is one of the major concerns for farmers and land managers. The following example illustrates how innovative agricultural land-management practices can be used for mitigating the agricultural risk of runoff and soil erosion that has become more frequent in a warming climate.

The Washita River Basin (WRB) in west-central Oklahoma covers an area of 8,319 km^2 (Steiner et al., 2008). The U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) has conducted watershed research in the WRB since 1961 (Garbrecht et al., 2007) in two subwatersheds. The two watersheds are the Little Washita River Experimental watershed (LWREW) and more recently, the Fort Cobb Reservoir Experimental Watershed (FCREW) (Figure 1-2a).

The land use in the 830 km^2 FCREW includes cropland, pasture and rangeland, forests and shrub land, water, and roads and miscellaneous (Steiner et al., 2008).

Between 2001 and 2008, The Oklahoma Conservation Commission (OCC) and Natural Resources Conservation Service (NRCS) actively promoted no-tillage in the FCREW, implementing 21,086 acres of no-till lands in the watershed.

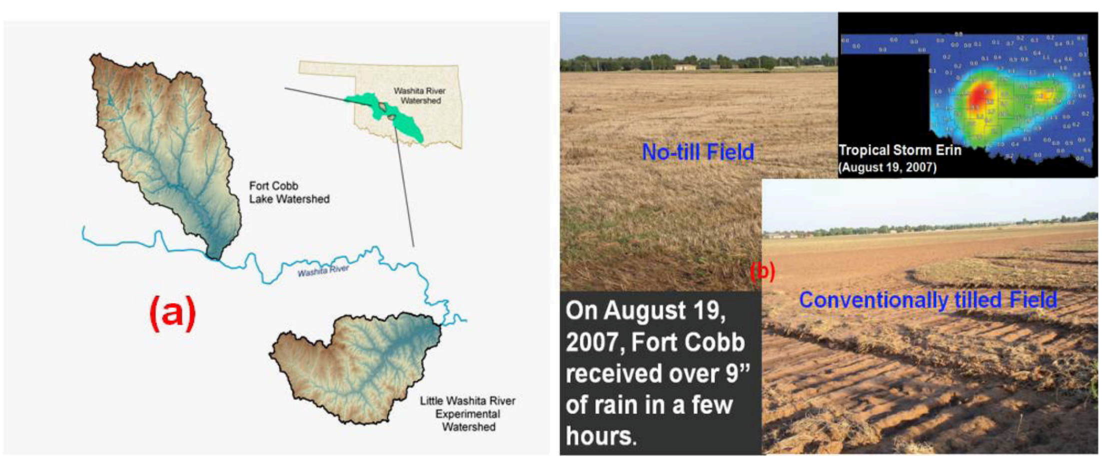

Figure 1-2. (a) USDA-ARS research watersheds within the Washita River Basin. (b) Impact of no-till agriculture on soil erosion during tropical storm Erin (photo courtesy of Larry Wright and Jean L. Steiner).

On August 19, 2007, Tropical Storm Erin dropped over 9 inches of rain in a few hours in the FCREW (Figure 1-2b). As shown in Figure 1-2, the no-till field did not erode but the conventionally tilled field suffered massive erosion down to the plow pan. The resilient no-till land management system was able to withstand the storm whereas the conventionally tilled field could not. This example shows the importance of designing and implementing agricultural management systems that can withstand the impacts of climate change.

Case Study 2: Urban Water Demand in the Willamette River Basin

Heejun Chang (PSU)

In growing cities in the Willamette River Basin of Oregon, climate-induced urban water demand and growing population poses a potential challenge for regional water providers. In the Portland metropolitan area, for example, climate variability is closely associated with summer water consumption patterns. An increase in temperature of one degree Celsius increases per capita water consumption by 281 liters per household (Chang et al., 2010). Most global climate models predict increases in summer temperature by 4 to 6 degrees Celsius by the end of the 21st century. Therefore, the vulnerability and risk of the regional water system to climate warming is likely to increase as water demand increases, while water supply may diminish during seasons of high water demand. While regional water providers have traditionally used historical weather and climate data to manage their water systems, as discussed in an earlier section of this chapter, future climatic conditions may significantly differ from what we experienced in the past. Additionally, population growth, potentially accelerated by climate refugees, will give additional stress to the regional water providers. In particular, small, suburban water providers in growing municipalities are vulnerable and uncertain to such changes in climate. Regional water providers are currently exploring various options to cope with climate change, and one viable strategy is to use land planning to adapt to climate change (House-Peters and Chang 2011).

Urban land use and water consumption patterns are tightly coupled (House-Peters and Chang, 2011). An empirical study of land use and water consumption shows that high-density urban development promotes lower per household water consumption (see Figure 1-3; Chang et al., 2010). Because outdoor water consumption is approximately half of residential water consumption in summer months, reducing outdoor water consumption through native plant species and other conservation measures is a first step for climate adaptation. A simulation study shows that different neighborhood designs could save water consumption by as much as 1,340 liters per household per month in a suburban city near Portland (House-Peters et al., 2010). This example illustrates how climate impacts could be mitigated through smart municipal planning.

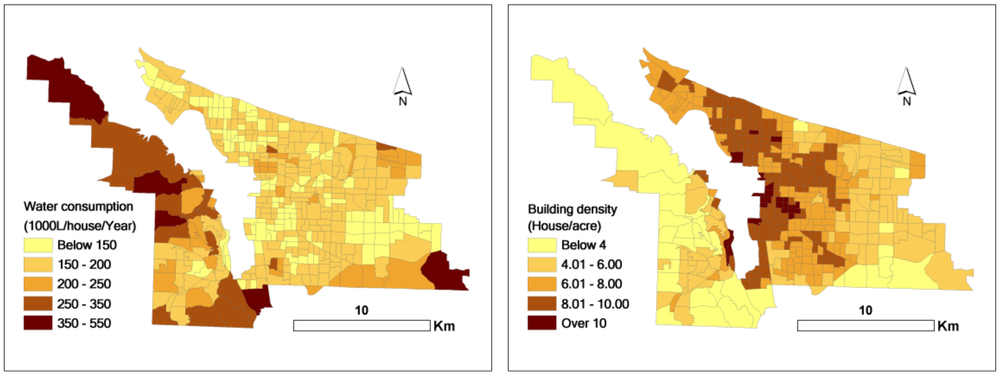

Figure 1-3. Water consumption and housing density (source: Chang et al., 2010).

Funded by NOAA-SARP (National Oceanic and Atmospheric Administration - Sectoral Applications Research Program), an interdisciplinary team of scientists from Portland State University and Arizona State University have been working with regional water providers to explore options for climate adaptation in the municipal water demand sector. During a couple of workshops with water and land managers in the Portland metropolitan area, we found that all stakeholders stressed the importance of land management for mitigating urban heat island effects and potentially reducing water consumption, which can be used for adaptive water resource management strategies in a changing climate. Scientists presented the initial results of a survey completed by water managers and land planners and simulated outputs from LUMPS (Local-scale Urban Meteorological Parameterization Scheme) to the stakeholders. Stakeholders better understand uncertainties associated with climate projections and impacts on municipal water demand, and they in turn provided alternative, feasible land-planning scenarios that can be used for a climate adaptation strategy. The valuable lessons from these workshops are that scientists identify water resource problems at the beginning of the research design and communicate the interim findings at an open stakeholder workshop to better redefine their work. Throughout this process, the science team would like to deliver not only useful but also useable information to water providers and land use planners. Additionally, they would like to facilitate mutually beneficial dialogues between the two communities that traditionally lacked coordination.

Case Study 3: Water Augmentation in the San Pedro Basin as a Drought Response

Anne Browning-Aiken and Holly Richter of Upper San Pedro Partnership

In 2005–06, the Upper San Pedro Partnership in southeastern Arizona recognized the need for further development of watershed management strategies in order to fulfill its mission of creating sustainable management of the long-term water needs of the basin, including the San Pedro Riparian National Conservation Area (SPRNCA) and Ft. Huachuca, the basin's economic engine. The Partnership had already taken measures to reduce water use, to reuse water, and to recharge groundwater, but since these strategies were not sufficient to fulfill their goals, especially during an extended drought, they turned to augmenting the water supplies.

Since the Partnership had identified a number of alternative augmentation strategies, the watershed group decided they needed criteria for selecting the best options. They also needed a time scale that would allow for a selection of strategies appropriate for short, medium, and long-term planning. The Partnership came together to conduct a screening process based on twenty-six criteria, covering effectiveness, ease of implementation, and cost. During the screening process, this team developed hybrid alternatives and submitted them for consideration as well. Alternatives were categorized into three groups for review: intra-basin, inter-basin, and local storm water capture. The screening process took 14 months. The next section demonstrates the complex nature of this process.

Alternatives suitable for short-term implementation

The following alternatives offer benefits to the watershed in both the short and long term. In addition, no significant legal or regulatory impediments to implementation were apparent. Hence, further assessment was recommended by continuing into feasibility studies that would fully address all technical, legal, and social issues.

- <u>Urban runoff and recharge near SPRNCA</u>

  Concept—This alternative would collect storm water off streets, parking lots, and other impervious surfaces from an 8-square-mile, highly urbanized area in Sierra Vista. A pipe system would then convey the water to a treatment plant to remove trash, pollutants, and other debris. Finally, a "clearwell" reservoir would store the water for recharge near the SPRNCA. The appropriate location and method of recharge would need to be resolved as part of the feasibility study.

  As currently conceived, this alternative could yield an estimated 1,800 acre-feet per year (AFY).

- <u>Copper Queen Mine to SPRNCA for recharge</u>

  Concept—Groundwater currently inundating the workings of the Copper Queen Mine (CQM) would be recovered, treated, and transported for recharge near the SPRNCA. A report by Southwest Ground-water Consultants, Inc. showed an estimated recovery of 4,000 AFY over 21 to 25 years. The Bureau of Reclamation currently estimates that 1,800–2,600 AFY of water could be recovered for a similar time frame, with the rest disposed of through evaporation ponds. However, there is significant variability in the water quality. Although conventional treatment technology could be used, piloting would be required as part of the feasibility study to customize the process.

Alternatives suitable for long-term implementation

The following alternatives would take longer to implement (10+ years), but if determined to be feasible, they offer substantial benefit. In fact, these were the only augmentation alternatives that could meet the estimated 2050 requirements—these are not introduced earlier within a single project. Key benefits are the cessation of pumping in the Sierra Vista area, which would benefit the regional aquifer, and a recharge component that would benefit the watershed in both the short and long term.

- Central Arizona Project (CAP) direct delivery with recharge

  Concept—These alternatives involve the acquisition of various CAP water allocations for the Sierra Vista area. An extension to the CAP system would be constructed from the CAP terminus in Tucson. The water would then be available for municipal, industrial, and agricultural demand, as well as environmental mitigation/restoration in the Sierra Vista subwatershed. Potential yields range from 20,000 to 40,000 AFY. The CAP alternatives are not popular, even among Partnership Advisory Committee (PAC) members. However, moving them forward to a feasibility study was important to avoid losing the potential for obtaining an allocation in the future. PAC members also noted that CAP alternatives offer the most significant challenges, including the following:

  - Competition for CAP allocations will be extreme and lengthy
  - Significant legal and regulatory issues exist at the state and federal level
  - Significant funding requirements will exist
  - Community opposition is likely
  - Significant risk and uncertainty are present

Even without considering the other alternatives, this example illustrates the importance of the location of the water source. The further the alternative water source is from the basin, the more numerous and difficult are the challenges that must be overcome. The CAP alternative would require extending an open canal set in the desert for most of its trip from the Colorado River at the north end of Arizona. During a period of extended drought, with current projections suggesting a cutback in CAP allocations, this alternative is probably too expensive. In any case, by putting all alternatives on the table and discussing them in terms of their ease of implementation, the Partnership is using scientific alternatives to make management decisions.

Case Study 4: Developing Risk-Informed Climate Change Adaptation Strategies in the Iowa-Cedar Basin

Charles Siptzak (USACE-Rock Island), Jason Smith (USACE-Rock Island), Daniel Moriasi (USDA)

A tributary to the Upper Mississippi River Basin, the Iowa-Cedar Basin is located in the southeastern extent of the state of Minnesota and the eastcentral portion of the state of Iowa. The basin includes major urban centers such as Cedar Rapids, Cedar Falls, and Iowa City. The basin experienced monumental flood events in 1993 and 2008 that led to an extensive emergency response and major damage to property and infrastructure in the major urban centers. The interagency team, comprised of 19 governmental and non-governmental organizations (see Figure 1-4), developed a roadmap that outlines the steps necessary for developing a comprehensive plan for the basin under three alternate land-use-change scenarios (scenario 1 - maximize agricultural commodity production, scenario 2 - maximize water quality, and scenario 3- maximize habitat and species diversity). With these scenarios, the team plans to assess the impact of climate change on the basin and its various functions with respect to communicating vulnerabilities and risks to local decision makers.

To integrate stakeholder knowledge with technical modeling efforts, the team is using the Shared Vision Planning (SVP) “Circles of Influence” approach that allows users to compare the results of various land use decisions on their watershed interests (water quantity, water quality, aquatic ecosystem, agriculture, recreation, etc.) under varying climate scenarios. Participants’ input during model development ensures the model is customized to answer their questions, which may include how a certain best management practice may impact the system or how altering the stream channel geometry in a tributary may impact the system. Feedback and discussion by all participants from the workshops are being used to further develop the SVP model/decision support tool, with a focus on evaluating climate change scenarios against the defined vulnerability thresholds and adding alternative policies and adaptation measures.

The work is leveraged from other ongoing work in several agencies. For example, it leverage from a Section 205 U.S. Army Corps of Engineers (USACE) study on Indian Creek near Cedar Rapids and the USACE Coralville Reservoir Climate Change study. This pilot study also complements the White House Council on Environmental Quality–U.S. Environmental Protection Agency (CEQ EPA) Pilot: Rebuilding Iowa. USACE will collaborate with Iowa State University climate scientists to more thoroughly understand and assess the effects of climate change on the Iowa-Cedar watershed.

Figure 1-4. Iowa-Cedar Interagency Coordination Team Participants.

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Chapter 2

Use of Social Learning in IWRM/AIWM to Improve Watershed Governance

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Introduction

Successful and sustainable water governance in UNESCO HELP basins reflects the direct experience and knowledge of stakeholders involved in the day-to-day and year-to-year business of addressing water governance challenges and issues. Water governance is a broad concept, has multiple definitions, and operates at many levels (Biswas and Tortajada, 2010). Recently in Singapore, at the first Global Forum on Water Policy and Governance, a distinguished group of water professionals similarly concurred that:

> …governance [was] a complex process that considers multi-level participation beyond the state, where decision making includes not only public institutions, but also the private sector, civil society and society in general. Good governance frameworks refer to new processes and methods of governing and changed condition of ordered rule on which the actions and inactions of all parties are transparent and accountable. Good governance frameworks refer to new processes and methods of governing and changed conditions of ordered rule on which the actions and interactions of all parties concerned are transparent and accountable. (Tortajada, 2010, p. 298).

To establish a set of consistent ideas about water governance, the authors of this chapter listed the elements they considered necessary for success in an uncertain future.

Successful water governance with climate uncertainty includes:

- Equitable stakeholder representation
- Capacity for building trust in each other leading to effective collaboration
- Confidence that the stakeholder group can achieve its mission and goals
- Outreach and education to build a common understanding among stakeholders
- An accepted means for measuring accountability
- Key moments as catalysts for action and collaboration/partnership
- Use of science and technology to address social conflicts and to increase stakeholder understanding of issues
- Integrated watershed information systems
- Effective adaptive management/planning with uncertainty

Social learning has been identified as one of the "key processes" of successful water governance in other watershed studies. Social learning as a water governance process offers stakeholders a framework for working together to:

1. Understand each other's value systems for water decision-making
2. Develop trust
3. Define jointly the nature of the problem they are addressing
4. Engage in fact-finding
5. Develop and assess different strategies for addressing problems
6. Carry out a plan and assess its success in achieving their goals (Pahl-Wostl et al., 2008; Mostert et al., 2008).

The following mini case studies in this chapter illustrate how these social learning functions operate in practice and provide examples of how stakeholder planning for resilience can help society adapt and mitigate the effects of climate change.

Case Study 1: Participatory Governance Process at the Panama Canal Watershed

Eda Ruth Soto, Especialista en Protección Ambiental

The Panama Canal case study demonstrates the importance of representation and participation or "having all the people at the table." The Panama Canal Authority (ACP) developed a stakeholder consultation process from 2001 to the present to establish, implement, and monitor advances for a basin-wide integrated water-resources management plan for the Panama Canal Basin (PCB). ACP is also responsible for the administration, maintenance, use, and preservation of water resources in the Panama Canal basin. In this role, the ACP approves strategies, policies, programs, and projects that may affect this area and coordinates the conservation of its natural resources. In 2000, ACP and the Panamanian government established an Inter-Institutional Commission for the Panama Canal Basin (called CICH by its acronym in Spanish). Its mission is to coordinate efforts and resources to promote sustainable development in the PCB, with participation of stakeholders.

To establish the community participation structure, CICH members invited local communities to organize local committees. CICH members supported these committees throughout the process with advice and training. Committees received additional support from community participation specialists hired with bilateral cooperation. From 2002 to 2004, the CICH established 30 local committees. These committees designed the sub-basin participatory assessments, further facilitating appropriation of funding and capacity building.

Based on the sub-basin participatory assessments, short-term action plans addressed priority issues regarding local development. These plans were adopted by governmental institutions for implementation with governmental funding. As of December 2009, specific committee interventions included implementation of projects related to water provision, education, health, and urban infrastructure and roads, for an estimated investment of US $12,188,794. The Panama Canal Fund provided most of the financing.

These short-term actions proved to be a critical part of the process for establishing a strong and trusting relationship between communities and governmental actors. While implementing the immediate watershed action plans, stakeholders carried out a parallel process involving two pilot sub-basins. A pilot subbasin management program would demonstrate, on a smaller scale, best management practices through the implementation of projects to improve water monitoring, water and sanitation, cropping practices, cattle raising practices, the safety of agrochemical handling, environmental education, and stakeholder participation. Under a bilateral cooperation program, USAID and ACP implemented about 25 projects between 2004 and 2007.

As a result of the stakeholder's participation pilot project, the first Sub-basin Council was established in 2005. The Sub-basin Council provides a space for consultation, information, consensus building, and coordination towards the participatory management of the territory and its natural resources, with a primary emphasis on water. The Council goal was to achieve a balance between social, economic, and environmental interests.

Table 2-1. Process for stakeholder engagement and basin management planning for the Panama Canal Basin.

Process	Outcomes	Period
Establishment of local committees	Improvement of participation at grass-roots level	2002-2004
Design of participatory assessments and short-term action plans	Sub-basin diagnostics and establishment of local development priorities	2003-2004
Implementation of pilot sub-basin management programs	A small-scale integrated water resources management model; establishment of a stakeholder participation body at the sub-basin scale (Sub-basin Council)	2004-2007
Consultation for long term plan for sustainable development and IWRM	Basin scale integrated water-resources management plan; improvement of participation of all stakeholders	2007-2009
Establishment of the long-term plan's implementation, evaluation, and accountability mechanism	Achieving the Panama Canal basin plan's scenarios and goals	2010…

The process also established Annual Operations Plans for basin regions, as well as investment plans for the first 3 years, with about 140 project profiles. Currently, CICH members are coordinating efforts for allocating required funding from several sources. They are also setting up a monitoring and evaluation mechanism to ensure continuous improvement and achievement of the plan's scenarios (set to 5 and 25 years). Finally, an accountability mechanism will provide updates on the plan implementation.

Case Study 2: Trust Building and Confidence: Lighting the Southern Plains Agricultural Resource Coalition

Larry Wright, Great Plains Resource Conservation and Development Association

In 2004, the Southern Plains Agricultural Resource Coalition (SPARC) was born through inspired collaboration by farmers, economists, market specialists, agribusiness representatives, and professionals from the Natural Resources Conservation Service, Agriculture Research Service, Oklahoma State University Food and Agriculture Products Center, Oklahoma Department of Agriculture, Oklahoma Conservation Commission, Southwestern Oklahoma State University Center for Economic and Business Development, Kerr Center for Sustainable Agriculture, and the Noble Foundation. "We had an idea for an organization that would be bigger than any one person and would pull together resources from a variety sources to serve the farmers in the western half of our state," says Larry Wright of the Great Plains Resource Conservation and Development (RC&D) Association, who coordinated the development of SPARC. Members of SPARC pledged to work together to form this new organization with a focus on improving soil quality and economics in the region. The Conservation Technology Information Center (CTIC) helped facilitate the development process so the group could create a strategic plan.

"My good fortune was in knowing CTIC. They offered to facilitate the process to help create this organization," says Wright. "It all began with a meeting where over 90 registered attendees expressed an interest in learning about no-till and sustainable agriculture." How did they express their interest? The network and partnerships maintained by RC&D helped to facilitate a diverse and active interest.

At that first SPARC meeting, 20 individuals offered to be a part of the steering committee that would develop the group's strategic plan. The plan and the group evolved over the next 12 months, as the committee met monthly with CTIC and other key agricultural interests in the region. Through the facilitated meetings with CTIC, SPARC developed a mission statement, defined the area and people served by the group, prioritized resource concerns in the region, named the goals to be reached for each of the concerns, and specified action steps that would lead to those goals. SPARC constructed a master schedule that provided the group with categorized action steps along with timelines, estimates of required funding, and names of people responsible for seeing the action steps completed.

SPARC's plan was to create market demand for products grown by conservation-minded farmers. SPARC hoped to tap into the growing consumer demand for food produced in environmentally responsible ways. "Consumers make the difference," says Wright. "Just as consumers demand and receive convenience food, consumers want quality food grown in responsible ways. That demand will drive the market for our products."

Since completing the plan and formalizing the organization with a board of directors and committees, SPARC members made presentations about its efforts at several conferences. They began looking for funding for additional market research and the development of a "flagship product," a product made with winter wheat grown by SPARC producers using sustainable cropping systems. Market-based environmental stewardship is a new tool to achieve environmental goals. Such an approach can encourage implementation of conservation practices and systems by providing added financial incentives. This is a win for agriculture and the environment.

Communities have numerous decisions to make regarding risks associated with climate change. A community that understands their levels of risk and uncertainty may begin to look at design choices for how to address resource concerns and manage resources in the future. Similarly, the global community has a responsibility to understand the impacts of resource management choices on the present and future well-being of life on the planet. As communities seek to reduce the risks of devastation from changing weather patterns, rising tides, and increased floodwater depths, partnerships between scientists, stakeholders, and decision-makers, such as SPARC, are ever more important.

Case Study 3: A Pivotal Event and a Public Process to Build Trust—San Pedro Basin, North America

Anne Browning-Aiken and Kirk Emerson (Udall Center for Studies in Public Policy)

In 1997, the Commission on Environmental Cooperation (CEC) launched the Upper San Pedro River Initiative in Arizona and Sonora, Mexico. This project was based on an environmental side agreement to the North American Free Trade Agreement (NAFTA). The purpose was to "initiate a process where diverse stakeholders from the region can develop and implement economically and environmentally sustainable strategies for enhancing and preserving the riverine ecosystem of the Upper San Pedro watershed" and to "inform the broader public about the regional importance of preserving migratory bird habitat and the challenges and opportunities in conserving and protecting valued transboundary resources (CEC, 1997)."

The initiative had two parts:

- An interdisciplinary Technical Report on the physical and biological conditions of the river basin, and
- A public input process to gather responses to the technical report and create public dialogue about the future of the river basin.

This case study focuses on the public input process. The process may be useful as a guide to facilitating public input into water planning and management. From the start, the participants designed the input process. Stakeholders included community members, local and county government, federal agencies, the business community, and agricultural and environmental interest groups. The Udall Center for Studies in Public Policy at the University of Arizona acted as a coordinator for the process. Together they developed a set of ground rules for public discussion so that people would feel comfortable sharing their views. An eight-page summary of the CEC Initiative and Technical report was inserted into all local newspapers with requests for public comments.

During the 60-day comment period, members of the Udall Center attended local meetings where participants discussed the Initiative and the Technical Report. Participants raised several issues that reflected the low level of trust between the community and "outsiders." Scientists had conducted research without consulting the community, and some participants voiced fears about property rights and concerns that the state, the U.S. Government, or even the United Nations would intervene in this regional conflict over water.

The Udall Center realized it had to rebuild the fabric of trust among community members and between the community and scientists attempting to help them understand water problems. Since the Udall Center at that time was also viewed as an "outsider," the Center decided to train a group of local mediators to design a community dialogue, with an emphasis on social learning. The dialogue method emphasized listening and reflecting on the reasons for the fears, frustrations, and confusions people expressed about the existing water problems in the basin.

The trained local mediators conducted three public workshops using the following process steps:

1. Mediators explained the purpose and ground rules.
2. Authors of the Technical Report gave brief presentations summarizing their findings.
3. Each audience (200 people) broke up into groups of 10–20 people to discuss items in the report and the next steps the community could take to address issues raised in the report. Udall Center and local mediators facilitated each of the small groups.
4. Each discussion group offered comments and suggestions to the larger group.
5. Authors of the Technical Report had an opportunity to respond to questions and comments from the small groups.
6. Summaries of public input from meetings, discussions, and from separately submitted comments were included in a series of Appendices of the Public Input Digest.
7. Local media played a strong role in publicizing the process through talk shows, articles, letters, and a poll of public values and discussion of ideas regarding the San Pedro River and its management.

Dr. Emerson of the Udall Center described the results: "It gave some life to the Upper San Pedro Partnership, which had just started as a collaborative basin group," and "it established a platform for the community to develop leadership to address its water problems."

Case Study. Oklahoma Geological Survey (OGS, 2006). 4: Communities Partner with a Federal Agency—The Luquillo Basin

Juan Vaquer, Executive Director, Amigos del Yunque

This case study describes how a new partnership between a community-based nonprofit organization and the El Yunque National Forest in the Luquillo Basin of Puerto Rico originated. This partnership came about through the stewardship objectives of the Forest Service and HELP Program initiatives to promote community awareness and participation in the management, protection, and advocacy efforts for this important watershed area in the Caribbean.

Over the years, the U.S. Forest Service (USFS) has managed El Yunque as a model project for tropical reserves throughout the world, using the best science management available to protect in perpetuity the natural resources in the forest. El Yunque's sister institution, the Tropical Forestry Institute in San Juan, working closely with the Forest Service, has conducted and disseminated research throughout the world.

Recent budgetary constraints cut back on USFS funds and personnel. This came at a time when population and development pressures around the forest increased. The most recent statistics demonstrate these trends. In less than a year the number of visitors to the forest—already Puerto Rico's second top tourism attraction—jumped by nearly 50 percent, from about 900,000 to 1 million visitors per year to over 1.4 million. At the same time, new highways and other infrastructure improvements made the area more attractive and accessible for the development of new housing and tourism projects. Recreational use of the forest by local visitors and tourists from outside the island increased greatly. This influx has also added pressures on the natural habitat in the forest, affecting wildlife, particularly the endangered Puerto Rican parrot, and introducing invasive species. Calls for more information, media requests and increased needs for coordination put pressure on the forest's management, the Puerto Rico Tourism Company, and the Municipality of Rio Grande (which has several large hotels within its jurisdiction and where the gateway to the forest is located). The first critical catalyst occurred when these entities sponsored the creation of a "friends organization," a new community-based organization, *Amigos del Yunque*, similar to ones already in operation in other national forests throughout the United States.

The second, and perhaps more critical catalyst, was the nomination of El Yunque to compete as a finalist for the New 7 Wonders of Nature Campaign, begun in 2007–2008. The local municipality of Rio Grande, in which the largest part of the forest is located, the Puerto Rico Tourism Company, and the Forest Service joined forces to actively promote the effort. Puerto Ricans from all walks of life participated, both in and outside the island. Press coverage and Internet activity generated a lot of enthusiasm, particularly in social media sites such as Facebook, and throughout the blogosphere. The result was that El Yunque ended up on the list of the top 70 locations out of over 400 nominated around the world. El Yunque, one of the smallest and least known nominees, surprisingly made the list of finalists. The final seven "wonders of nature" are presently being selected through a global Internet voting platform (www.n7w.com) in a worldwide campaign that ended in November 2011.

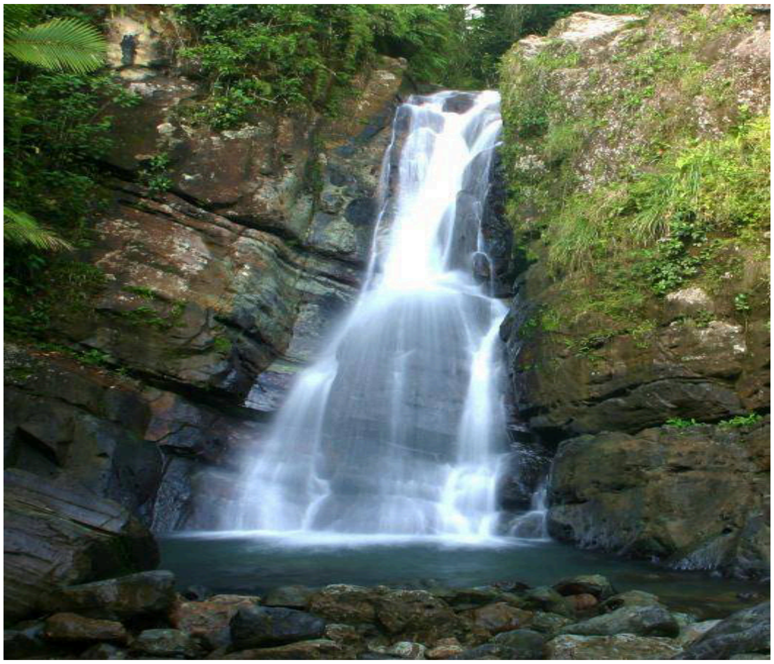

Figure 2-1. Luquillo Basin waterfalls.

As a result, Amigos del Yunque became a nonprofit corporation set up in late 2009 to support the El Yunque National Forest (EYNF). Among its goals are to:

- Support the EYNF with its stewardship responsibilities.
- Promote awareness among citizens of Puerto Rico about the forest's needs and programs.
- Help to educate the public about the forest's unique features as a natural reserve.
- Provide advocacy support in addressing issues that affect the forest's protection as a natural treasure for the present and future inhabitants of the island.
- Foster community economic development projects and programs that enhance the gateway community.
- Provide better opportunities to nearby residents.
- Promote economic activity that is harmonious with the preservation of the forest.
- Improve communication and contact with the surrounding communities to assure their participation and collaboration with the forest's programs and preservation efforts.

Of particular interest to the EYNF is the prospect of Amigos del Yunque's increased community support through an active volunteer program at the forest.

Case Study 5: Use of Science and Technology to Bring Ecosystem Science to the Public in the Luquillo Basin

Felipe Cano, El Yunque National Forest Biologist

Because the El Yunque National Forest (EYNF) is part of the U.S. Forest Service (USFS), national forestry laws mandate the use of adaptive management concepts for the natural resources of this area. The goal is to apply the best science-based management approaches for sustaining in perpetuity the natural resources within the 28,000 acres of the EYNF.

Figure 2-2. Luquillo (El Yunque) Forest Service managers and researchers. Source: Browning-Aiken, 2009.

One of the most important projects in the Luquillo Basin monitors long-term rainfall trends and its role in the ecology of the basin. USFS researchers Dr. Fred Scatena and Dr. Tamara Hartsill-Scalley have discovered through their research that rainfall is merely the first step in the complex web that routes needed nutrients to the vegetation. This intricate system incorporates all levels of the environment that are necessary for the continuation of all life. Researchers used 35 fixed gauges to collect both bulk rainfall and throughfall (rain that penetrates through the canopy) weekly and before and after major storms. (Heartsill-Scalley, 2007). In this scientific project, as in all proper scientific monitoring, valid conclusions depend upon a rigorous analysis of the data. All statistics for this study were computed using SAS software (Version 9; SAS Institute, 2003) and considered significant with an alpha of 0.05 (Heartsill-Scalley, 2007). Through these robust scientific survey methods, the USFS provided the foundation for baseline data on the amount of rainfall and the type of minerals that move through the forest ecology. Interestingly, many of the results confirmed the connectivity of the Luquillo Basin with other locations in the world, through the movement of minerals traced from the Sahara Desert and from erupting volcanoes in the Lesser Antilles islands.

Land managers shared these research results through public events with selected audiences: parents who had children in the 7th and 8th grades of school, and adults who wanted to understand how their lifestyles were linked with the natural surroundings. Researches and land managers offered their research regarding complexity, effects, and consequences of changing rainfall patterns on this ecosystem and the people who live in it. These presentations were delivered in a straightforward manner, using simple analogies in Spanish, and effectively educated the audience on ways to keep river systems diverse and productive over time.

In addition, the EYNF assisted in the Forest, Oceans, Climate and Us (FOCUS) activity, involving three middle-school classes from three municipalities adjacent to the EYNF. An estimated 90 children took field trips into the rivers of the EYNF, one of them being the Mameyes. EYNF land managers used electrofishing to capture samples of the aquatic inhabitants (shrimp, gobies, eels, and fish) and allowed students to take photos and observe the specimens. Managers then released the wildlife species back into the river. Through this technique, many future decision-makers were apprised of the native natural resources and the need for their survival. The students then used art (drawings/paintings) to display what they had just learned and experienced. Local communities turned out to see what the children had done.

The story of the EYNF is one of successful collaboration between the research and management branches of the USFS. This partnership led to a productive use of resources toward public education and generated ideas and implementation techniques that would empower these communities. Efforts to contact and inform present-day decision-makers will continue as well. Finally, researchers provided a simple table that other watersheds may use in their efforts to ensure sustainable IWRM for their water resources.

Table 2-1. El Yunque National Forest criteria.

Action Item	**Purpose**	**Opportunities**
I. Main message/idea and its intended goal (e.g., mission statement)	Is there a type of significant change/crisis? (e.g., water quality, rain patterns or aquifer concerns, human use, invasive aquatic species)	Collaboration or partnership with researchers, non-governmental organizations, local community groups.
II. Source of scientific support: Data	Does any type of monitoring data support the need for change?	Scientific study conducted by a professional or institute.
III. Audience identification	What is the background of your intended audience?	Use the specifics of the situation to cooperate with researchers and transfer their data or observations to lay persons.
IV. Educational approaches	How will you convey information to your audience?	Interactive approaches (visuals, field trips). Collaborate with similar endeavors.

V. Execution	What are the details of managing meetings or field trips?	Use meeting formats appropriate to the situation, timeliness, and knowledge of local culture.
VI. Monitoring	How will you measure the efficiency of your approach to determine whether to change it?	Questionnaires or observation of effects on natural resources.

Case Study 6: Lake Champlain Basin

Meg Modley, Aquatic Invasive Species Management Coordinator, Lake Champlain Basin Program

Mind the Gap—The Lake Champlain Basin Program and the New York State Canal Corporation partnered to prevent the spread of aquatic invasive species into the Champlain Canal. Clear communication, time, and trust were three key ingredients needed to bridge a gap of misunderstanding and to address a critical water-resource management issue: the introduction and spread of aquatic invasive species through a New York canalway.

In 2007, the Lake Champlain Basin Program (LCBP) met with the New York State Canal Corporation (NYSCC) to discuss the threat of aquatic invasive species (AIS) movement in and out of the Lake Champlain Basin through the Champlain Canal. It took a significant time investment to understand each other's priority issues, develop a common shared language, resolve previous misunderstandings, and build a foundation of trust upon which a partnership developed. Five years ago using the word "barrier" with the NYSCC might have been enough to end discussions or terminate a meeting, but now it is a term that both partners use frequently with common understanding and trust.

In 2005, a report by Malchoff, Marsden, and Hauser (Malchoff et al., 2005) reviewed the feasibility of barrier options for aquatic nuisance species in the Champlain Canal, ranging from a do-nothing option to closing the canal to prevent the movement of AIS. Lake Champlain Sea Grant and the University of Vermont conducted the study, evaluating different types of barriers including bubble, electronic, heat, chemical, and physical, which could be implemented to reduce the introduction and spread of aquatic invasive species. At the time, NYSCC likely viewed the study as an attempt to reduce or close the canal to tourist and commercial traffic, not understanding the threat AIS pose to the region. The barrier options were not well-received by the corporation, likely because the NYSCC was not included as a key stakeholder in the study's development.

A few years later, LCBP reopened communication with the NYSCC. Lake Champlain was home to 48 nonnative aquatic species, many of which were invasive and likely entered the Lake through the canal. A new director helped revive a focus on partnership and collaboration, though there was still a sense of bad blood and misunderstanding in the air. LCBP and NYSCC made considerable efforts to reach out to each other. Phone conversations quickly turned into in-person meetings where the NYSCC and LCBP and partners shared information about their organizations and goals for water resource management in the canal system. Expert scientists, engineers, local officials, state agencies, non-profits, and managers worked together to better understand the threats that AIS pose to the region and the challenges of mitigating AIS introduction and spread through the canal. Essential partners often traveled long distances to meet with the NYSCC and homemade lunch dishes were prepared to share.

LCBP and NYSCC took turns chairing the meetings and worked together to develop the agendas. For 3 years, partners spent time learning about how the Champlain Canal operates, what kind of traffic it supports, greenways, budgeting and staffing, its cultural heritage, and recreation paths under development. LCBP and partners shared the known science about AIS, noting canalways as the leading vector of introduction of AIS to Lake Champlain, and reviewed steps that might be taken to reduce the introduction and spread of AIS. NYSCC and LCBP developed a Memorandum of Understanding (MOU) that outlined shared goals of the two groups and trust began to develop. Ironically, the MOU was never officially signed but the process of developing the MOU served the purpose of defining commitment to work together.

Soon NYSCC and LCBP began working jointly on education and outreach campaigns that were delivered as public service announcements from the Director of the NYSCC explaining the threat of AIS transport through the canalways. Lock tenders began to assist in early detection programs for AIS, alerting LCBP to sightings of new species, and educational pamphlets about preventing the spread of AIS were developed to be distributed to tourists that use the canal. There are also plans to post signage alerting canal users how to take actions to clean their boats and equipment to prevent the spread of AIS. Since the NYSCC and LCBP began working together, two new AIS have been identified as threats; the Asian clam (Corbicula fluminea) was found in the Champlain Canal, and Spiny waterflea (Bythotrephes longimanus) has been identified in Great Sacandaga Lake, which is hydrologically connected to the canal. LCBP and NYSCC worked together to study, monitor, and address impacts of these two species.

NYSCC and LCBP, along with other federal, state, and local partners, held the Champlain Canal Aquatic Invasive Species Stakeholder Meeting on November 6, 2008, in Fort Edward, N.Y., to discuss the threats and challenges of aquatic invasive species management and to gain stakeholder input. Over 75 stakeholders attended the meeting and a dozen statements were made in support of taking action to address AIS spread through the Champlain Canal to prevent negative economic and ecological impacts. The consensus of those consulted was to pursue a U.S. Army Corps of Engineers feasibility study as specified in the Water Resources Development Act of 2007. In March 2009 the NYSCC wrote a letter to the USACE requesting that the Champlain Canal barrier feasibility study be pursued.

Without time spent to build this careful relationship, the NYSCC and LBCP might not be working together to leverage resources and support to protect the water resources of the region. These two organizations got together over hot soup and listened to each other's points of view, used the best science available, developed a common language and shared goals, and were able to overcome misnomers and fears. Now the NYSCC and LBCP are working in partnership to prevent the introduction and spread of AIS in Champlain Canal.

Figure 2-4. Director of the New York State Canal Corporation talking to congressional representatives from New York and Vermont on a canal tour of the Champlain Canal to discuss aquatic invasive species issues. Source: Meg Modley, 2005.

Case Study 7: From Fish Fins to Phosphorous Criteria: Tracking Accountability in the Lake Champlain Basin—how stakeholders assess the success of their cooperative actions

Michaela Stickney, Lake Champlain Basin Program Coordinator, Lake Champlain Basin Program and Vermont Agency of Natural Resources

Responsive governance can be evaluated by tracking progress in watershed groups' pursuit of goals and initiatives, and certifying that resources expended are consistent with those goals. Transboundary governance among the governments of Vermont, New York and Quebec to improve water quality and other environmental conditions in the Lake Champlain Basin has operated on a cooperative basis since 1988 with coordination provided by a non-profit organization. Accounting for progress in the Lake Champlain Basin has evolved in recent years from semi-annual narrative progress reports with bar charts to ecosystem indicators and state-of-the-lake reports with illustrated status and trends to an emerging adaptive management strategy and revised basinwide management plan with strategic actions linked to specific organizations on a timeline. This approach to governance answers questions about who is responsible, how they will achieve action, and what the action is for (who, what, what for).

After the Lake Champlain Basin Program released its signature plan *Opportunities for Action*, Lake Champlain's long-term management plan, program participants searched for optimal ways to track progress and accountability. The Lake Champlain Basin Program (LCBP) is a cooperative venture among the U.S. states of Vermont and New York and the Canadian province of Quebec to jointly manage the Lake

Champlain Basin with funding from the federal government—it is a unique and interesting transboundary governance arrangement. The plan contained a "menu" of nearly 100 priority actions, listed possible implementing partners for each action, and roughly projected costs to accomplish each action. A drawback of this presentation is that the list of implementing partners read more like a laundry list of "who's who," and projected costs were hard to quantify and variable.

The LCBP provided the University of Vermont with a grant to develop the *Ecosystem Indicators and Scorecard for the Lake Champlain Basin Program* (Watzin et al., 2005). The goals were to develop ecological indicators that were scientifically defensible and consistent with the goals and objectives of *Opportunities for Action*. Significantly, an embedded requirement was that data must be collected within a framework that allowed information to be used in decision-making. The usefulness and compatibility of data for environmental decision-making is one of the cornerstones of the UNESCO HELP program. This requirement linked what the data were for and how they would be used. The ecosystem indicators report adapted an economic indicator model called "pressure-state-response" for environmental use. The nearly 5-year development process resulted in 65 indicators spanning seven issue areas of phosphorus pollution, fecal coliform bacteria (beach closings), mercury toxicity, sport fish health and abundance, plankton in the pelagic foodweb, water chestnut plant control, and recreation.

The *2008 State of the Lake and Ecosystem Indicators Report* for Lake Champlain (Lake Champlain Basin Program, 2008) incorporated the ecosystem indicators directly into the fabric of the report. The report's purpose was to inform residents about the lake's health and provide a better understanding of problems, solutions and challenges. It focused on public interests in water quality, health and safety, fish and wildlife habitat, and aquatic invasive species. The report was organized as a series of questions that members of the public often asked the LCBP, such as "can I swim in the lake," "can I eat the fish," "are phosphorus levels too high." It featured many complex graphic representations of relevant data—much more complex than the "fish" bar charts of the past. For elected US legislators and federal agencies that have supported the LCBP through tens of millions of dollars worth of appropriations and guidance, the report was a testament to progress in cleaning up the lake (Lake Champlain Basin Program, 2008).

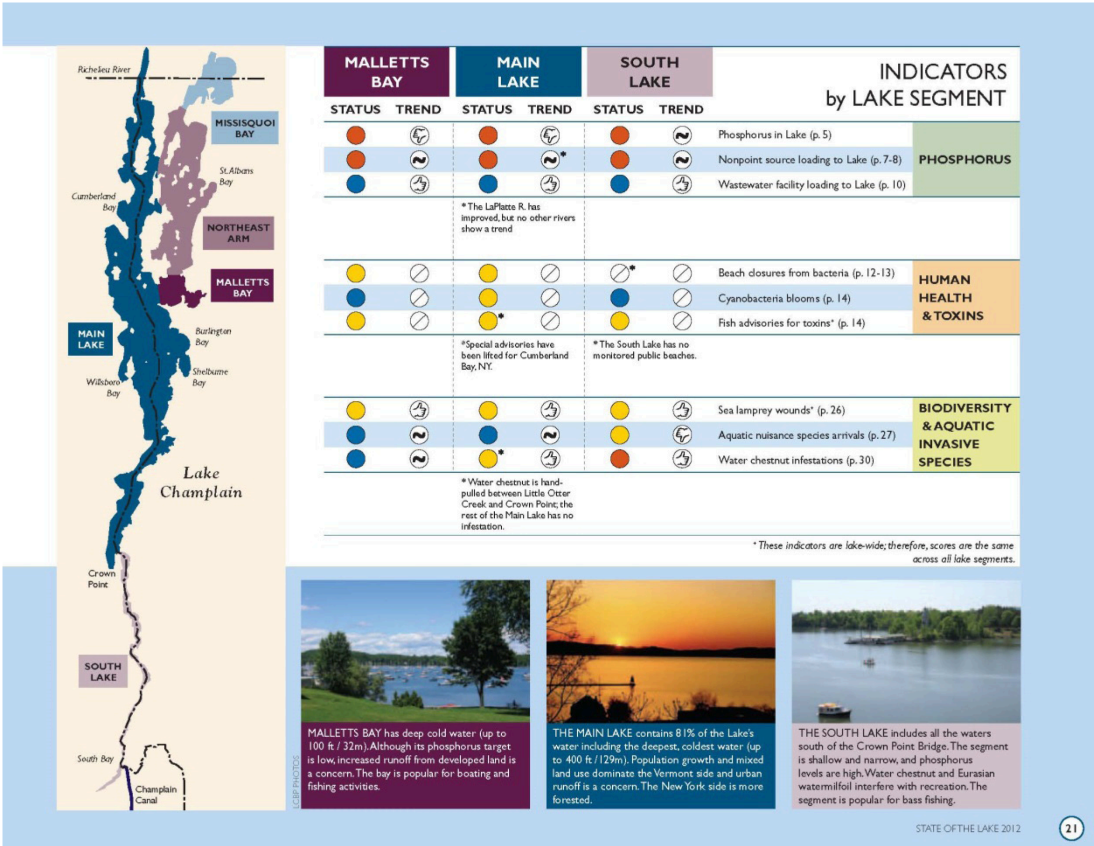

Figure 2-5. *State of the Lake and Ecosystem Indicators Report* for Lake Champlain (Lake Champlain Basin Program, 2012, http://www.lcbp.org/wp-content/uploads/2013/03/SOL2012-web.pdf).

A special feature of the 2008 report was the "centerfold," the first scorecard as recommended in the ecosystem indicators report. Nine indicators were selected covering three general areas of phosphorus and algae: human health and toxins, biodiversity and aquatic invasive species, and their status and long-term trends (positive improvement, negative improvement, no trend detectable). Additionally, climate change made a guest appearance in the report with the disclaimer, "global climate change is expected to have a significant impact on Lake Champlain, however, the full range of potential effects is not well understood… since the last century, the number of days of ice cover on Lake Champlain has decreased significantly." (Here is the first time that a "what if" statement was added to "when," "how," "what," and "what for.") Additionally, "as global pressure mounts to find renewable energy sources, the demand for corn for ethanol has increased. If corn crop is maximized, water quality may suffer from consequences of increasing field cultivation and drainage, decreasing riparian buffers, and increasing fertilizer use" (LCBP, 2008). The *State of the Lake* reports were enthusiastically received by the public, elected state and federal officials, funders, and used as a model in other watersheds nationally and internationally.

In summary, since the early "fish" bar charts of 10 years ago, transboundary partners in the Lake Champlain Basin have developed a sophisticated suite of measures, initiatives and reports to track progress and accountability that are linked in multiple ways. This combination of initiatives gives a comprehensive view of how improvements are evolving to support the lake and its watershed and is an excellent way to gauge governance effectiveness.

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Chapter 3

Knowledge and Information Management for IWRM/AIWM

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A. IWRM and the need for integrated watershed information

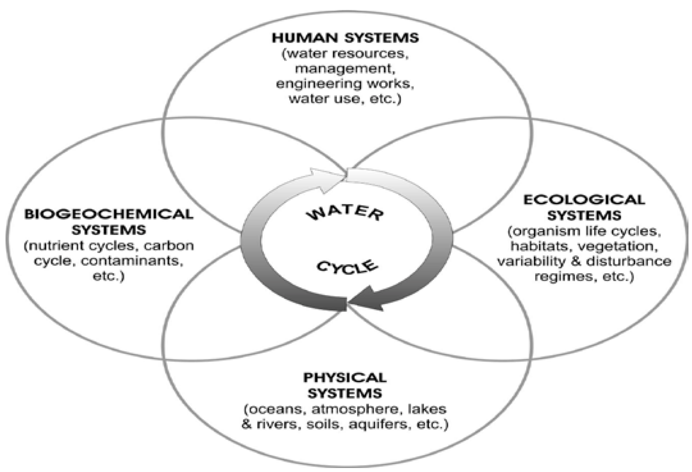


Figure 3-1. Watershed interacting systems.
Source: Muste, 2007.

Transdisciplinary research and application is an emerging trend in hydroscience, environmental engineering, and water resources management. Allied disciplines collaborate to investigate and address the most critical policy and management issues. This integrated approach supports management decision-making by taking into account all water cycle components and interactions within the ecological, biogeochemical and human systems (see Figure 3-1). This trend reflects the conclusion that analysis of water-related processes can no longer be based solely on engineering perspectives and solutions, as has primarily been the case in the past. The major events leading to this change of perspective include:

1. The emergence of continental and global-scale climate changes,
2. The improved understanding of the impact of human intervention on natural systems,
3. The recognition of the need to find a balance between political-economic values, equitable access to water resources, and the requirements of ecosystems.

The global water community realizes that the historic separation between scientific investigation of water issues and water resources management is no longer tenable. Both processes are drivers and sources of perturbation of the natural water systems. Consequently, place-based scientific studies are an effective way to understand and predict interactions between water systems, climate change, land use, the built environment, and ecosystem functions. Never before has science and practice come together with such strong potential to contribute to professional interaction and effective results. The new watershed science and management paradigm uses real-time, integrated cross-disciplinary data and simulation models to analyze watersheds and formulate management policy and practice. These approaches and outcomes will help the worldwide water community ensure the sustainable use of the water resources and the well-being of ecosystems.

Watershed science and watershed management are increasingly converging, based on a common recognition that water problems require a holistic and comprehensive approach. The combination of investigation and practical problem solving supports and improves current approaches to gathering environmental data. Today, in addition to data gathered by scientists, numerous federal, state, and local agencies gather and provide hydrologic data. These data include *in situ* observations, geospatial data sets, and remote sensing products. Typically, the primary focus of these observations is at the local or regional scale where processes can be investigated at the landscape unit (e.g., watershed, river basin or aquifer), and where management decisions can be applied most efficiently. Although the internet has improved access to these disparate data sources, gathering the data required for most hydrologic studies requires visiting multiple sites, each with its own access protocols and data exporting formats. The internet provides a means for individual scientists to publish their data, yet many scientists do not have the expertise or incentives to develop sophisticated interactive data retrieval sites.

Previously, the acquisition of data and the development and application of models had been tasks for expert scientists and engineers. Now, managers are requiring on-line access to decision support systems (DSS). Both scientists and practitioners may want to ask the following questions:

1. What information can scientists deduce from multi-scale data?
2. How can practitioners make best use of that data?
3. What approaches should be used to optimize the monitoring system and performance of the watershed?
4. What is the best way to incorporate reports from stakeholders as part of the monitoring system?

5. What system (integrated with appropriate modeling) will best facilitate adaptation to constraints?
6. What are the best ways to provide data from observations/prediction to watershed stakeholders concerned about extreme events?
7. What are the best ways to provide stakeholders with information on long-term strategies for sustainable management? (Price et al., 1994)

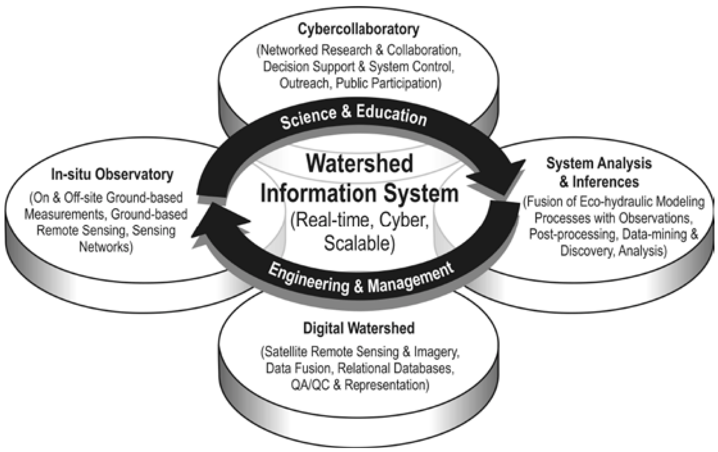


Figure 3-2. Components of the watershed information system.

Source: Muste, 2007.

Decision-makers and scientific investigators may obtain the answers to these questions through an integrated watershed science and management information system. Users can access information about the state of the system, compare the data to expectations, and forecast process evolution based on observations (see Figure 3-2).

The features of the system include:

- Implementation at the natural landscape unit scale (e.g., basin or watershed).
- Consideration of all water cycle fluxes, including vertical (precipitation, surface water, evapotranspiration, groundwater) and horizontal (runoff-stream), and their interactions with ecological and socio-economic aspects.
- Extensive datasets obtained through monitoring, modeling, and post-processing.
- Multilevel (scientist, managers, education, training, outreach, general public) and multi-task (quantitative, qualitative) analysis and visualization.
- Near-real-time operation of the investigative/management platforms (monitoring, interfacing with simulators, process prediction).
- Tools for knowledge discovery (mining, data-driven modeling), dissemination, collaboration/participation.
- Feedback loops for observatory/monitoring operations, quality control, and application of adaptive strategies (decision-making process, systems control).

The watershed information systems integrate tools and methods in one place, allowing seamless conversion of the data using customized workflows (see Figure 3-3). These emerging digital environments uniquely enable production of information and knowledge. The scientific understanding and actionable knowledge of the watershed is readily available for application through engineering and management practice. In other words, the watershed information systems represent the common knowledge-producing technology sought by both watershed science and management to assist them in attaining their independent but closely related objectives; that is, attaining social welfare with sustainable ecosystems.

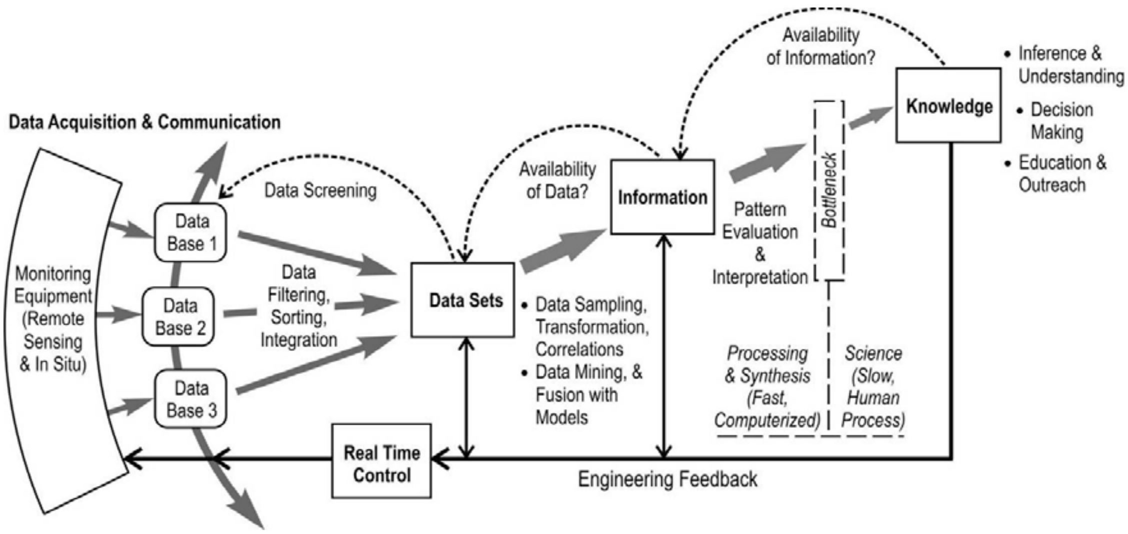


Figure 3-3. The data-to-knowledge transformation process taking place in the information system (adapted from Fletcher and Deletić, 2006).

B. Frameworks for data-to-knowledge transformation

For several decades, the IWRM has made strides in managing water, land, and related resources in ways that achieve an equitable balance between social and economic needs while ensuring the sustainability of ecosystems. The approach that originated in the early 1970s has resurfaced in recent years in the most prominent national (e.g., Environment and Water Resources Institute or EWRI, 2006; American Water Resources Association or AWRA, 2006) and international (e.g., Global Water Partnership or GWP - www.gwpforum.org) water management communities. Implementation of IWRM requires sound enabling technologies that make the conversion of data to knowledge a practical goal. This section summarizes some of these enabling technologies.

C. Informatics and cyberinfrastructure

The traditional pillars of the scientific study of natural systems are observation (plus experiment), theory, and analysis (plus computation). Modern information and communication technology now allows us to address a new class of problems around the organization of data and information, leading to knowledge extraction. The digital revolution affects all facets of society, is changing radically the way we conduct our science, and may now be the fourth pillar of the scientific method. *Informatics* is the science and engineering that occupies the gap between information and communication technology systems and cyberinfrastructure using digital data, information, and related services for research and knowledge generation (Baker and Barton 2008). *Cyberinfrastructure* is a term that has been recently coined by the National Science Foundation (NSF), defining the combination of computer tools, telecommunications, database structures, and distributed computer networks that collectively support advancements in science and engineering through integrated information access and processing (Atkins et al., 2003).

With predecessors in the water sciences, the informatics concept is not new. At the beginning of the 1990s, the rapid process of electronic encapsulation of information and knowledge in hydroscience led to the European concept of hydroinformatics (Abbott, 1991). The term describes a multi-disciplinary investigation approach that "integrates knowledge and understanding of both water quantity and quality with the latest developments in information technology to improve technical and business decision making within the water industry. Hydroinformatics embraces not only methods of data capture, storage, processing, analysis and graphical display, but the use of advanced modeling, simulation, optimization and knowledge-based tools and systems infrastructure" (research.ncl.ac.uk/hydroinformatics). To date, most of the hydroinformatics developments have focused on modeling. Still needed are developments in the areas of data representation, organization, and analysis at the watershed scale. These developments require use of advanced computing and information technology for enabling data accessing, sharing, and model interoperability (both simulation and data models).

The U.S. National Science Foundation began in 2002 to reorganize the manner in which it supports computational infrastructure in science and engineering. NSF introduced for this purpose the general concept of cyberinfrastructure (CI). CI is defined as "… grids of computational centers, some with computing power second to none; comprehensive libraries of digital objects including programs and literature; multidisciplinary, well-curated federated collections of scientific data; thousands of online instruments and vast sensor arrays; convenient software toolkits for resource discovery, modeling, and interactive visualization; and the ability to collaborate with physically distributed teams of people using all of these capabilities" (*www.**nsf**.gov/ci-team* or www.cise.nsf.gov/sci/reports/atkins.pdf).

CI-based Observatories

Current U.S. efforts to improve the infrastructure and methodologies for integrated water-centric studies are being led by two relatively new NSF communities: the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) and the WATer and Environmental Research Systems Network (WATERS Network). CUAHSI and WATERS Network have promoted alliances among U.S. universities to develop and implement cyberinfrastructure-based environmental observatories for watersheds.

Why observatories? The observatory concept is the research community's response to information abundance. The concept currently emerging in the water community is that of designating an open, web-based, distributed research environment for massive and complex data sets. An observation is an event that results in a value describing some phenomenon Oklahoma Geological Survey (OGS, 2006). According to OGS observation, values are not self describing. For this reason, interpretation of a particular set of observations requires contextual information, or metadata. Metadata is the descriptive information about data that explains the measurement attributes, their names, units, precision, accuracy, and data layout, as well as details on how the data was measured, acquired, or computed (Gray et al., 2005). A nation-wide network of observational and experimental facilities for systematic water measurements, data storage and curation, modeling and visualization will enable unprecedented science and engineering research (Schnoor et al., 2007).

The CI-based observatories promoted by CUAHSI and WATERS Network are not unique to the U.S.A or to world scientific communities. A number of similar initiatives have been launched in U.S.A in the past decade. These initiatives focus on distributed data collection, management, and operation of a network of observing stations or interacting scientific activities across time and space. Some of these activities have been explicitly organized as observatories (e.g., NEON, NVO, GEON) while others are focused on core technologies critical to observatories, including high performance computing (e.g., TeraGrid, OptlPuter), data federation (e.g., BIRN), or informatics (e.g., SEEK).

A recent U.S. Interagency Working Group recognized that the digital dimension belongs to all sectors of society (Interagency Working Group on Digital Data, 2009). Government at the federal, state, and local levels, industry, academia, foundations, international organizations, and individuals are all participants in the digital dimension and have important interests in and capabilities for digital information preservation and access. Therefore, the federal government has a responsibility to act as a reliable and transparent partner and as a coordinating entity, enabling all sectors to work together in enhancing the information capabilities of the digital dimension. The continuing exponential increase in the amount of digital scientific information and the ever-expanding needs and expectations of users exceed both the resources and the mission scope of the federal agencies. The digital data challenge cannot be met by the federal government or any one sector acting alone. The government must act to stimulate and facilitate investments by all sectors of society to meet the full scope and scale of the scientific data challenge. Some of the recent U.S. agency initiatives along these lines are showcased in Figure 3-4.

USGS

A National Map for the 21st Century

The U.S. Geological Survey (USGS) is working with federal, state, and local agencies across the country to create a seamless digital base map for the nation. The goal of The National Map (http://nationalmap.gov) is to become the nation's source for trusted, consistent, integrated, and current topographic information available online for a broad range of uses. By integrating data from many federal, state, and local sources on an ongoing basis, the currency and accuracy of the map are enhanced, making it effective for use in a wide variety of applications such as environmental science and land management, natural hazards and emergency response, and resource planning and decision making.

Source: nationalmap.gov

GEOSS and IEOS
A System of Systems

U.S. Integrated Earth Observation System (IEOS): A Contribution to the Global Earth Observation System of Systems (GEOSS)

Earth observations are the data collected about the Earth's land, atmosphere, oceans, biosphere, and near-space environment. These data are collected by means of instruments that sense or measure the physical, chemical and/or biological properties of the Earth. These data provide critical information to assess climate change and its impacts; ensure healthy air quality; manage ocean, water, mineral and other natural resources; monitor land cover and land use change; measure agricultural productivity and trends; and reduce disaster losses.

Figure 3-4. National U.S. efforts toward preserving digital scientific data for maximum use in catalyzing progress in science and society (Interagency Working Group on Digital Data, 2009).

A. Case Studies of Data and Information Management within North America HELP Watersheds

Experiences in the HELP basins, from the Upper Washita River in Oklahoma, the Upper San Pedro Partnership in Arizona, the Williamette River in Oregon, to the Iowa-Cedar River in Iowa indicate that the potential for successful planning and management efforts greatly increases with improved understanding of the impacts of climate variability, land-use changes, and hydrologic processes. This information appears essential for decision-making. All HELP watershed teams are using some type of data information management system to facilitate the complex analyses necessary to support IWRM/AIWM. In this section, we highlight a few examples to illustrate the range of objectives, approaches, and lessons learned in the different teams from using information management systems. These cases range from a research-focused development of STEWARDS (see Table 3-1 below) to integrated groundwater and surface water management, to assessment of floodplain risks and mitigation actions.

Table 3-1. Summary of data-information systems developed in HELP watershed projects to address contrasting objectives.

	1. STEWARDS	**2. TMDL**	**3. Riparian System Health Indicators Matrix**	**4. Floodplain Assessment Decision Support Tool**
Objectives	Provide long-term data from multiple watersheds to support collaborative management and policy-relevant research related to climate change, land use change, and water resource management.	Provide the current level of pollutants that a water body can absorb and still meet water quality standards. Identify priority target areas for improvement in water quality.	Provide decision makers with the technical information they need to assist them in selecting the set of conservation measures that will promote long-term sustainability of the San Pedro system.	Identify floodplain segments and associated watersheds that should be prioritized for project planning and program investments.
Description	Data from a network of long-term ARS research watersheds are made available from a single point of access. Methods and protocols for data collection analysis and quality assurance are clearly documented.	Develop a water quality manage-ment plan based on the TMDLs. Plans document the ways that local landowners, agencies, forest and agricultural land managers (including federal agencies), DEQ and others will implement a specific TMDL and work to improve water quality.	Provide a riparian-health assessment program supported by comprehensive monitoring that includes about 110 data points across the subwatershed. These data are used to evaluate 8 indicators of progress toward sustainable use of groundwater in the Sierra Vista Subwatershed.	Develop a framework to integrate data from multiple sources. Perform objective assessments of floodplain segments with high risks of losses from floods.
Primary users	Researchers	Researchers, managers, environmental groups.	Citizen leaders in watershed, policy makers.	Floodplain managers, communities, agencies.
Modeling applications	SWAT, ANN-AGNPS, APEX	Heat source model, benefit cost analysis for restoring riparian vegetation on floodplains.	Development of a 5-layer groundwater model.	Analysis within spreadsheet and geographic information system framework.
	Climate, hydrology, water quality, land use, conservation practices and management, and various others appropriate to various watersheds.	Climate, water quality, hydrology, soils, land use, land management, vegetation, DEM, geomorphology, wastewater discharge.	Climate, geology, hydrology, land use, monitoring wells, springs.	Topography, hydrology, infrastructure, population, agriculture, sensitive species.

Contact	Through website	Through website	Through website	USDA-NRCS, Des Moines, Iowa martin.adkins@ia.usda.gov gregg.hadish@ia.usda.gov
Web address	www.ars.usda.gov/watersheds/stewards	http://www.deq.state.or.us/wq/willamette/willamette.htm	http://www.usppartnership.com	For internal use only.
Lessons learned	Compilation of metadata and documentation of watershed research methods have created a useful template for other watersheds. Transparent QA/QC procedures have increased the credibility of the data.	Partnership with various regional stakeholders to help develop and implement TMDLs. Vast amount of information has been collected by various agencies. The format and resolution of data are not always consistent. Basin-wide comprehensive water quality management plan is needed (e.g., Temperature trading program).	The wealth of data that has been collected in the watershed has allowed Partnership members with diverse interests and goals to work together to develop strategies for reducing the annual aquifer storage deficit. The indicator data on hydrologic trends have led to the current round of proposed actions to address the groundwater deficit.	Availability of FADST information allows decision makers to move from inundation maps (created through hydraulic/hydrologic modeling) to risk maps in Iowa watersheds. When lands have been identified as having high damage potential from flooding, decision makers can consider several options for reducing that risk.

Case Study 1: Stewards

Larry Wright (Great Plains Resource Conservation and Development), Jean Steiner (USDA), P.H. Moershel (USDA)

The HELP watershed partnership in the Upper Washita River Basin of Oklahoma is led by the U.S. Department of Agriculture (USDA) and the Agricultural Research Service (ARS). This watershed is part of a USDA-ARS network that has conducted research since early in the 20th century in key agro-ecological regions of the United States. Research at these watersheds has supported development of key watershed simulation models and remote sensing technologies that are critical to the success of IWRM. However, data from these watersheds have been managed to address location-specific research needs and disseminated independently by each research team. This is not unexpected, since watershed research has an inherently local focus. On the other hand, lack of a shared ARS watershed data system has reduced accessibility and utility of the data for policy-relevant, multi-site analyses and for multidisciplinary and multi-sectoral activities such as IWRM.

To address these concerns, ARS developed and implemented a web-based geospatial database application called Sustaining the Earth's Watersheds, Agricultural Research Data System (STEWARDS, http://ars.usda.gov/watersheds/stewards), which brings decades of data into an organized, well-documented database (Sadler et al., 2008; Steiner et al., 2008, 2009a, 2009b). STEWARDS accommodates heterogeneous data, including weather, soils, hydrology, water quality, land use, management, and socio-economic data, as well as survey data, spatial GIS layers, metadata, and descriptive text for specific watersheds (Figure 3-5). Many of the watersheds offer the decades of data that are required to understand and address issues of climate variability and global change (Burt, 2003; Slaughter, 2000; Slaughter and Richardson, 2003; Harmel et al., 2007).

The STEWARDS database captures rich descriptive information that is key to understanding the data from complex, dynamic research. The application combines temporal and spatial aspects of data collected from each watershed site. This provides a flexible approach to delivering information to diverse users while retaining local responsibility for the data. The system:

- Allows for centralized management of research-quality data from multiple watersheds
- Interfaces with web-based mapping systems
- Facilitates tabular data visualization and query functions
- Enables downloading of data
- Compiles, manages, and delivers consistent metadata.

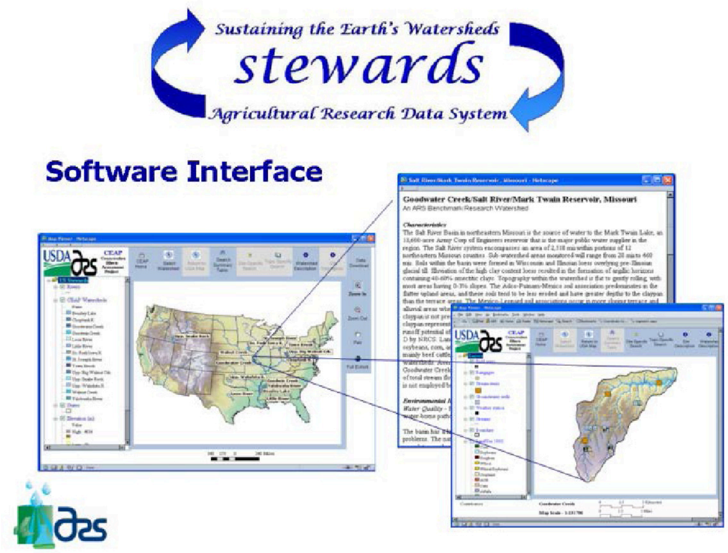


Figure 3-5. Drilling down within STEWARDS to site-specific data and metadata (figure prepared by D. James, USDA, ARS).

Data are retained at the watershed level for quality assurance and initial analysis and publication. There is no requirement to adopt uniform data management procedures by watershed teams for local use, but delivery to STEWARDS requires standardized parameter names, units, and metadata. For the watersheds established earliest, initial upload has included data collected by persons who are no longer employees, requiring considerable effort to document the methods. After initial data upload to STEWARDS, updates are anticipated on approximately an annual basis.

Descriptive information includes watershed and site descriptions. To provide flexibility to accommodate diverse and dynamic data, each data table is paired with a data definition table that defines the content of the data table. A unique SiteID and date/time for each data point are primary keys in the database structure. Each SiteID is linked with geospatial information (Figure 3-6). Methods are identified by code in the data definition table, with the method code being a primary key to an ARS Methods Catalog, which is modeled on the National Environmental Methods Index (http://www.nemi.gov/ assessed 11/09/2010; Keith et al., 2005). Data can be viewed as a time series graph or table, and data can be downloaded into a spreadsheet or text file, along with associated metadata.

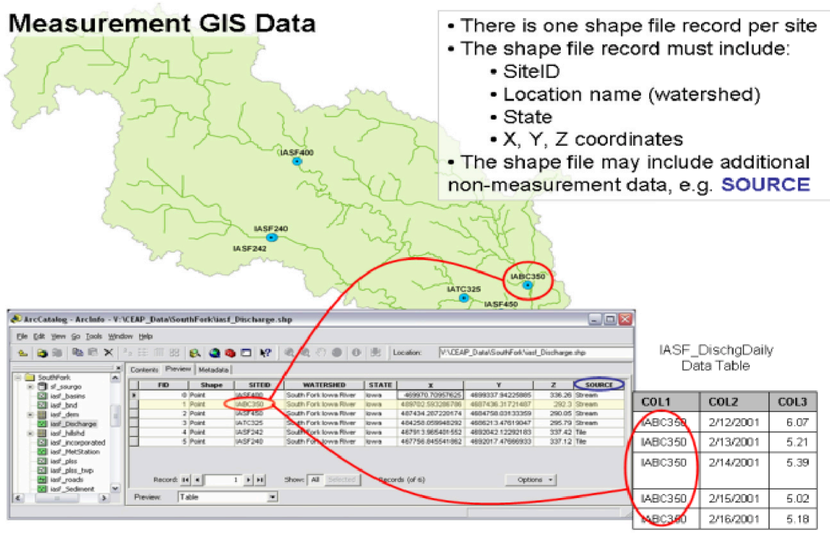


Figure 3-6. Linkage of spatial and measurement data using the SiteID primary key. From Steiner et al., 2009b.

Development of STEWARDS helped foster a change of culture within ARS regarding open data. In contrast to past practice, delivery of data to STEWARDS is a performance requirement for individual scientists. While there is no reason to limit peer recognition of data provision, past culture has not valued these as significant scientific contributions. As critical as high-quality data sets are to IWRM research and management applications, it remains to be seen whether credit from peers will be sufficient to motivate scientists to make the effort to prepare and publish those data sets.

Case Study 2: Oregon's TMDL Program – Willamette Basin Watershed TMDL for Temperature

Eugene Foster (Oregon Department of Environmental Quality) and Heejun Chang (PSU)

Water quality in Oregon rivers and streams is regularly evaluated by the Oregon Department of Environmental Quality (ODEQ). Current and recent historical data are evaluated to identify whether water bodies are meeting water quality standards. Water bodies that are not meeting water quality standards are identified as water quality limited, according to the federal Clean Water Act, Oregon Revised Statutes, and Oregon Administrative Rules (OAR). Loading capacity is the greatest amount of pollutant load that a water body can receive without violating water quality standards. A Total Maximum Daily Load (TMDL) is calculated to meet the loading capacity and is the sum of the allowable load from current sources, load set aside for future sources, and load set aside to account for uncertainty. The TMDL is a method for a cumulative source water-quality-based management of water quality, instead of a point-source by point-source technology based approach. The TMDL process is needed when a water body is identified as water quality limited and the required treatment processes have already been implemented. TMDLs involve science, regulation, and a public process for reducing water pollutant discharge(s) to meet water quality standards.

Allowable loading from point sources is termed Waste Load Allocations. Allowable loading from nonpoint sources is termed Load Allocations. Allowable loading set aside for future sources is termed Reserve Capacity. Allowable loading set aside to account for uncertainty is termed Margin of Safety. Calculation involves selection among implicit and explicit approaches for determining the margin of safety. The implicit approach uses conservative assumptions to calculate the loading capacity, waste load allocations, and loading allocations. The explicit approach states the margin of safety as an added separate allocation in the TMDL calculation. This general TMDL concept is represented by the following equation:

TMDL = Waste Load Allocation + Load Allocation + Reserve Capacity + Margin of Safety

As defined in OAR 340-042-0040, a TMDL contains the following elements:

- Name and location of the water body
- Water Quality Standards and Beneficial Uses that are impaired
- Pollutant identification causing the impairment
- Loading Capacity for the pollutant
- Excess load of the pollutant
- Sources and Source Categories discharging the pollutant
- Waste Load Allocations for point sources
- Load Allocations for nonpoint sources
- Margin of Safety
- Seasonal Variation
- Reserve Capacity
- Water Quality Management Plan for implementation of the TMDL

Many of the TMDLs developed by ODEQ have been developed for entire watersheds. These watershed TMDLs require large and complex datasets and the involvement of many public and private stakeholders. A watershed TMDL for temperature was developed for the Willamette Basin and issued in 2006 (Figure 3-7).

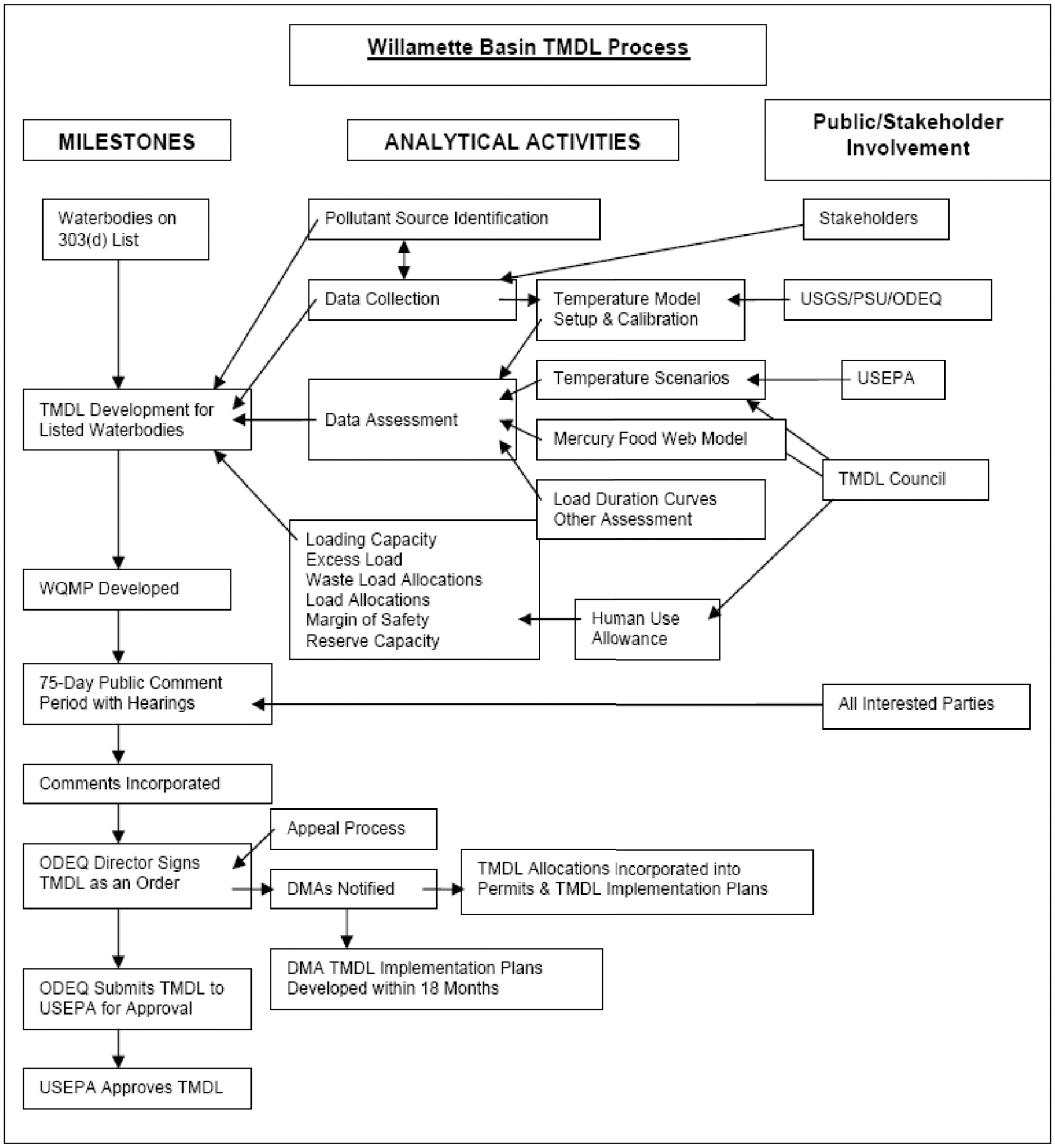


Figure 3-7. Willamette TMDL development process. Source: Oregon Department of Environmental Quality, 2006.

The Willamette River is just less than 190 miles in length. Analyzed in terms of streamflow, the Willamette is the 13th largest river in the 48 states. The tributaries of the mainstem Willamette River roughly correspond to the 12 subbasins that collectively make up the Willamette Basin. Stream temperature data showed that the mainstem Willamette and many of its tributaries were not meeting the water quality standard for temperature and were listed on the 303d list of impaired waters (Figure 3-8).

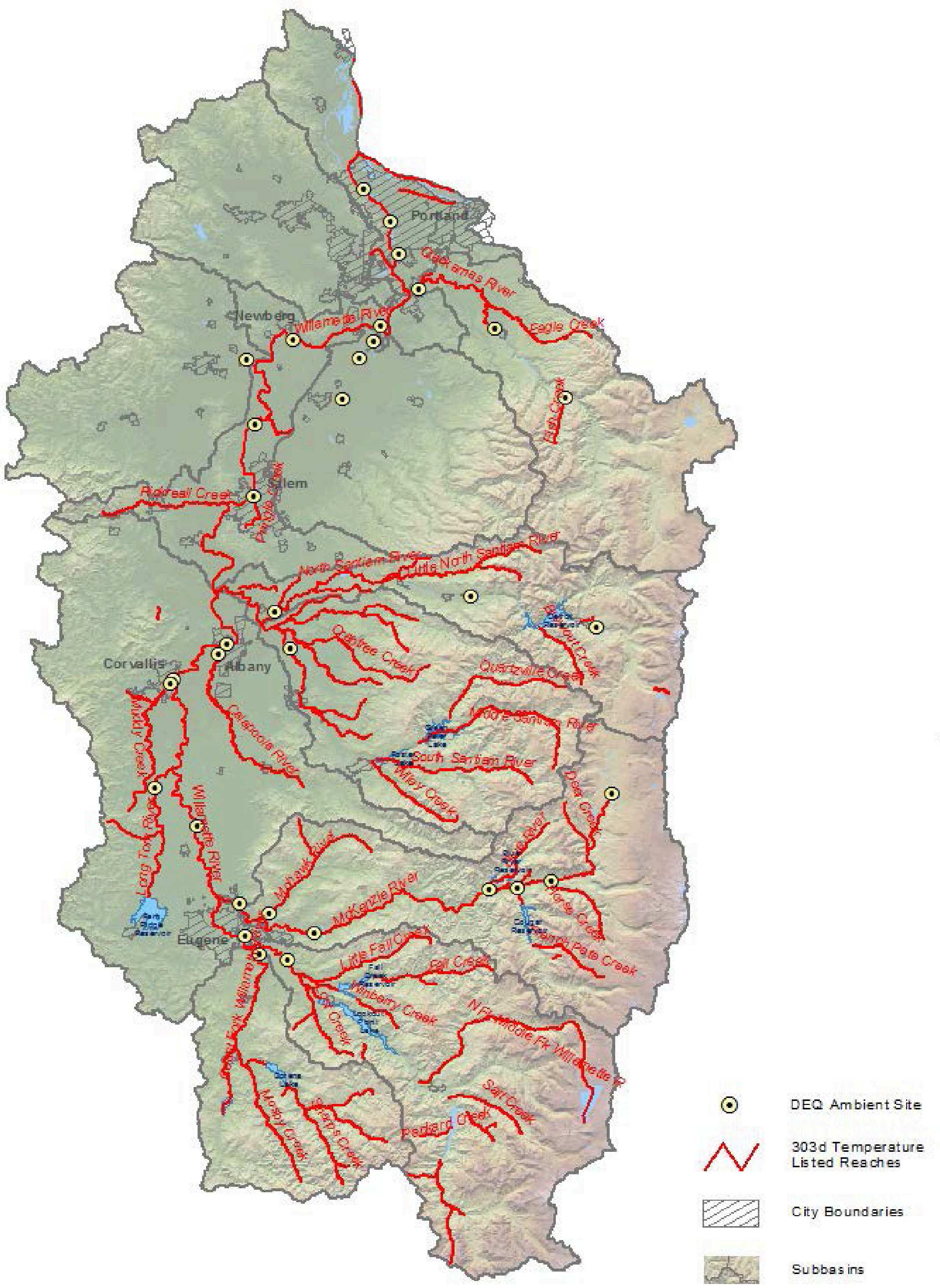


Figure 3-8. Willamette Basin map with temperature standard exceedances. Source: Oregon Department of Environmental Quality, 2006.

Stream temperatures are determined by the interactions of geomorphology, hydrology, vegetation, climate, elevation, aspect, and the degree of anthropogenic disturbance. Water temperature varies over time and space at multiple scales that are affected by the complex interactions of these parameters. Season and elevation are the biggest drivers of precipitation in the Willamette Basin (Figure 3-9). Human-influenced or anthropogenic heat sources may include discharges of heated water to surface waters, reductions in stream shading due to loss of streamside vegetation, changes to stream channel form, and reductions in natural streamflows.

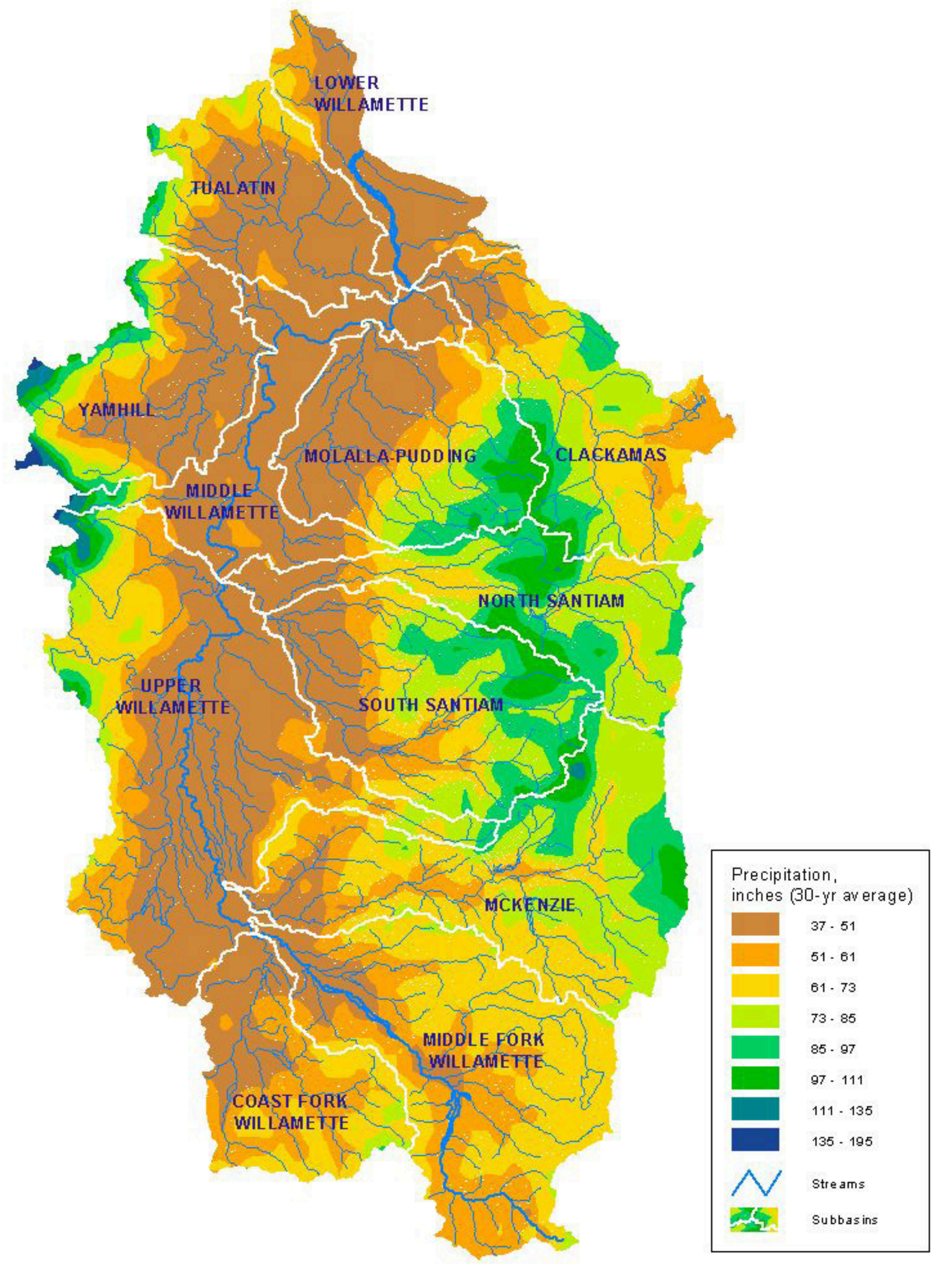


Figure 3-9. Spatial variations of mean annual precipitation in the Willamette Basin.

The Willamette Basin provides habitat for many aquatic species, including both native and non-native fish species. The watershed temperature TMDL was developed to meet the water quality standards for temperature. The temperature water quality standard was developed to protect the most sensitive aquatic species, which in most locations were salmonids. Salmon and trout life cycles are closely tied to the thermal regime of their habitats. The temperature water quality standard was developed to protect the most sensitive salmonid life history stage based on location (Figure 3-10).

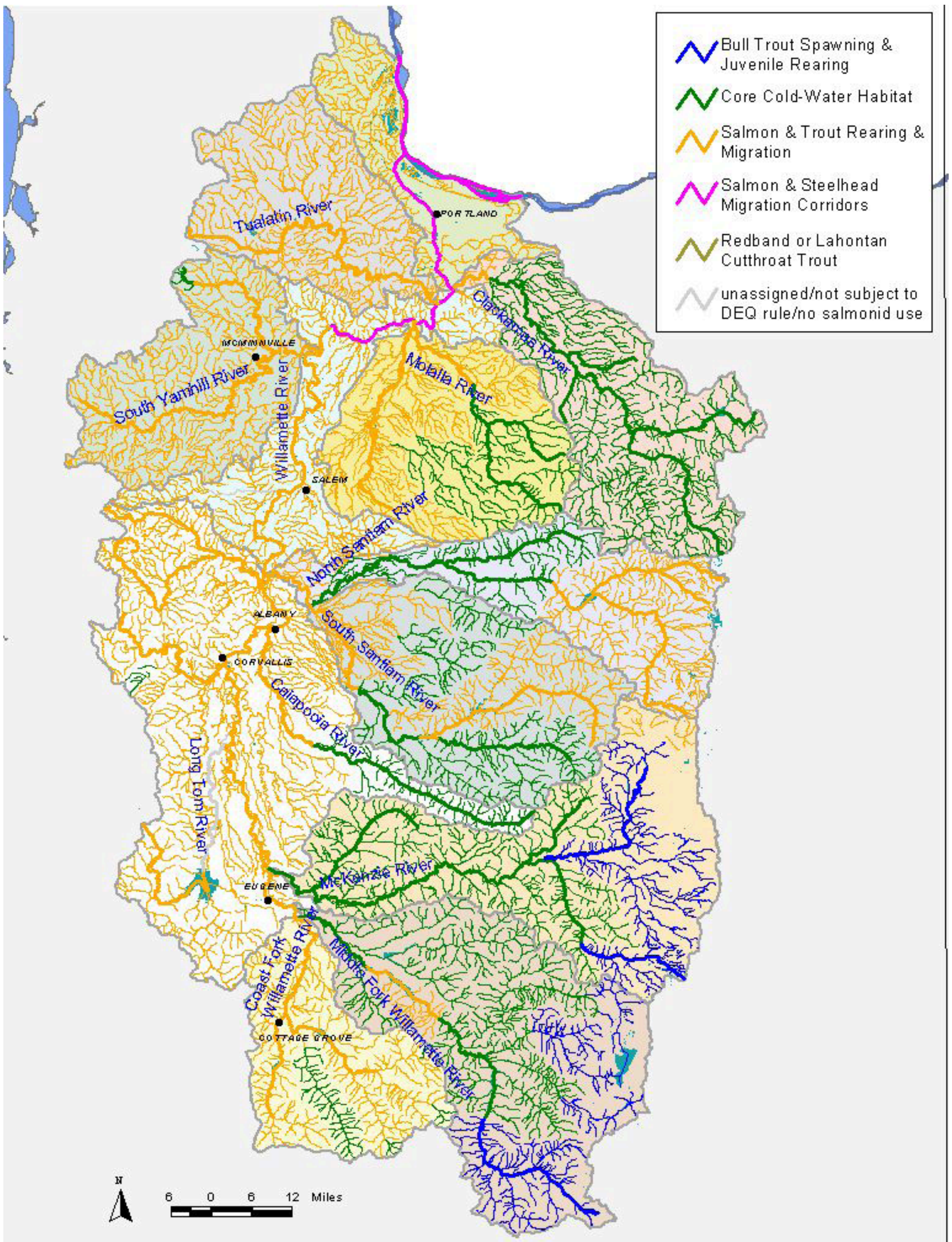


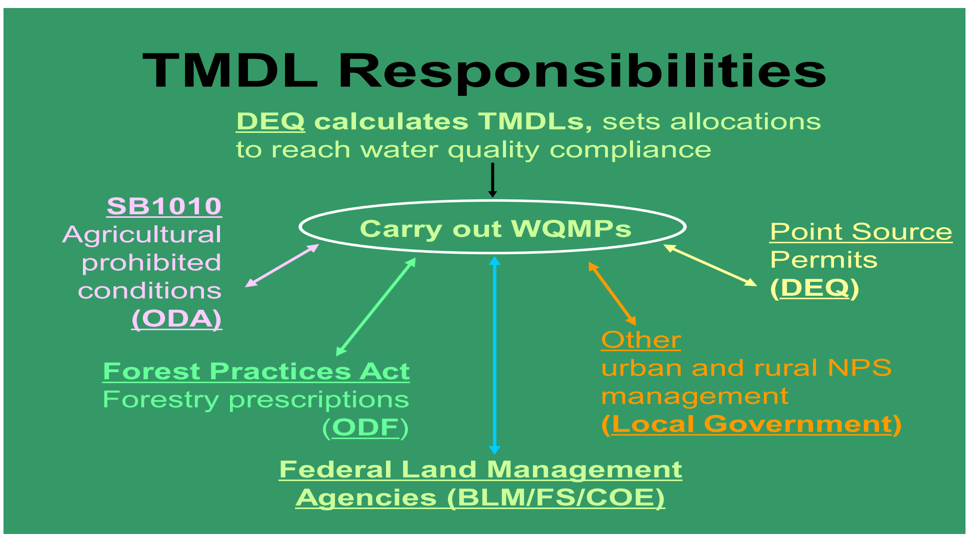
Figure 3-10. Location of salmonids in the Wilamette Basin. Source: Oregon Department of Environmental Quality, 2006.

Salmonid species are particularly sensitive to natural events or human activities that affect the input of thermal energy or the spatial and temporal distribution of that energy. Persistent disturbances may threaten the viability of local populations.

Development of stream temperature TMDLs requires an understanding of the natural and human processes that contribute to stream warming. Temperature is the water quality parameter of concern, but heat, in particular heat from human activities or anthropogenic sources, is the pollutant of concern in this TMDL. Specifically, stream temperature change is an expression of heat energy flux, which is affected by the volume of the water body and thermal input.

Temperature model simulations provided an estimation of the effects of changes in streamside vegetation, solar radiation inputs, and river temperature responses. Heat loads in excess of background rates were attributed to anthropogenic sources as nonpoint source pollution.

Daily thermal loads that met the temperature water quality standard were developed and allocated to point sources, nonpoint sources, margin of safety, and reserve capacity. Meeting these allocations requires the implementation of the TMDL, which requires the involvement of multiple public and private stakeholders (Figure 3-11).



Legend:
SB1010 is the Agriculture Water Quality Management Act implemented by Oregon Department of Agriculture (ODA) for addressing water quality affected by agricultural operations.
ODF is the Oregon Department of Forestry
BLM is the U.S. Bureau of Land Management
FS is the U.S. Forest Service
COE is the U.S. Army Corps of Engineers
NPS is Nonpoint Sources
WQMPs is Water Quality Management Plans

Figure 3-11. TMDL implementation. Source: Oregon Department of Environmental Quality, 2006.

While all inhabitants of the basin share responsibility for preventing water pollution, certain entities are recognized under this TMDL as having specific responsibilities for implementing the TMDL. These parties are required to take the actions necessary to meet their assigned load or wasteload allocations.

The management strategies necessary to meet the TMDL load or wasteload allocations differ based upon the source of pollution and the responsibilities and resources of the responsible party. Some responsible parties are required to implement TMDL through existing regulatory and non-regulatory programs and activities. Other parties are required to develop a TMDL implementation plan that describes the actions they will take to meet their TMDL obligations.

Development and implementation of these community-based water quality management plans require the cooperation and collaboration of multiple public and private stakeholders. The Willamette TMDL Council involved 20 members representing the interests of the environment, industry, fishing, agriculture, forestry, tribes, and municipalities. Several state and federal agencies also participated in the Willamette TMDL stakeholder meetings. At these meetings, the ODEQ communicated TMDL information and solicited stakeholder input and data needed for development of the TMDL Reduction Program. Through this stakeholder process, people with expertise or experience in water quality and watershed science, water quality regulation, implementation, or project funding are brought together to address the water quality problem(s) in the watershed. This approach to stakeholder participation is used in basins throughout Oregon to develop TMDLs.

Case Study 3: The Upper San Pedro Partnership of Southeastern Arizona: Data, Decision-making, and the Reasonable Needs of the Residents and the River

Bruce Gungle, USGS

In the Upper San Pedro, access to data and effective decision-making tools have been regularly named as critical to building institutional capacity, but management decisions must reflect the attitudes, meanings, and values attached to water and land use as well. The HELP agenda promotes the integration of climate data and models to help explore management strategies of water stakeholders and managers. Inputs from other HELP basins that describe and assess data platforms and models, case studies of technology transfer, and information-sharing between basins shorten the preparation for decision-making.

Groundwater is the primary source of water for the residents of the Sierra Vista Subwatershed (Subwatershed) in Cochise County, Arizona (Figure 3-12). Groundwater is also the essential component among the water sources that sustain the base flow of the San Pedro River and its associated riparian ecosystem. This area is formally protected through an act of Congress as the San Pedro Riparian National Conservation Area. Water outflow from the Sierra Vista Subwatershed, including water withdrawn by pumping, exceeds natural inflow to the regional aquifer within the Subwatershed. As a result, groundwater levels in parts of the Subwatershed are declining and groundwater storage is being depleted. In the absence of more effective management measures, continued decline of water levels and associated depletion of storage will diminish groundwater flow to the San Pedro River and endanger the Conservation Area.

The Defense Authorization Act of 2004 (Public Law 108-136, Section 321 (Section 321) set goals and an end date of 2011 for achieving, by various means, a sustainable level of groundwater use from the Subwatershed. In addition, Section 321 alters the way the Endangered Species Act applies to Fort Huachuca and specifies the Upper San Pedro Partnership (Partnership) as the regional cooperative organization responsible for recommending policies and projects to mitigate water-use impacts in the Subwatershed.

The Partnership is a consortium of 21 federal and state agencies, local jurisdictions, and non-governmental organizations. Partnership members include owners or managers of land, entities capable of implementing water-management measures, and science and resource agencies. The collective goal of the Partnership is to ensure an adequate supply of water to meet the reasonable needs of Subwatershed residents while protecting the resources of the San Pedro River. In pursuit of this goal, the Partnership has:

1. Invested in a comprehensive monitoring program that includes about 110 data points across the Subwatershed (Figure 3-13).
2. Initiated and (or) funded studies to better understand recharge processes, the riparian system, and the regional hydrologic system.
3. Developed a 5-layer USGS groundwater model.
4. Systematically identified, evaluated, and documented management measures that can be used to attain sustainable yield from the regional aquifer.

Annual Section 321 reporting began in calendar year 2002 when the annual Subwatershed groundwater storage deficit is estimated to have been 9,700 acre-ft. Despite an increase in annual groundwater pumping of about 500 acre-ft, a variety of water management measures and conservation programs reduced the annual deficit in 2008 to about 6,100 acre-ft, a reduction of 3,600 acre-ft since 2002. This was accomplished through recharge of treated effluent, construction of stormwater infiltration basins, turf removal, and rebates on low-flow water fixtures. Partnership-sponsored research has made it possible to refine the values found in the groundwater budget over the past 6 years. These improvements are now included in the annual deficit values cited above. Despite the reduction in the annual deficit from 2002 to 2008, it is unlikely that the Partnership will be able to attain its congressionally-mandated goal to eliminate the annual Subwatershed aquifer storage deficit by 2011. In addition, a 6,100 acre-ft annual deficit in 2008 means that another 6,100 acre-ft has been withdrawn from storage and that the cumulative deficit, currently in the hundreds of thousands of acre-ft, has increased by another 6,100 acre-ft.

Because the annual Subwatershed groundwater deficit provides but a single lens through which to view the hydrologic health of a physically complex and variable system, in 2008 the Partnership decided to consider a broader suite of hydrologic indicators that takes advantage of the wealth of monitoring data accumulated over the previous decade and beyond. In addition to the annual aquifer storage deficit, the indicators of progress toward sustainable yield of groundwater use now include:

1. Regional aquifer water levels
2. Alluvial (near-stream) aquifer water levels
3. Near-stream vertical water level gradients
4. Discharge from springs
5. Stream discharge
6. Streamflow permanence
7. Aquifer storage change (measured using microgravity techniques).

While many of the indicators showed improvement over the previous 12 months, the trends since the beginning of Section 321 reporting in 2002 were mostly unchanged, with a few improving and a few degrading. The long-term indicator trends (beginning with the earliest available data) were mostly degrading. Long-term data exist for 14 (less than half) of the indicator monitoring locations across the Subwatershed. Given this rather bleak picture of long-term progress, the Partnership is pursuing three courses of action to ensure a sustainable yield of groundwater in the Subwatershed.

The first strategy utilizes spatial water management—specifically, the USGS groundwater model—to locate the best near-river sites for artificial recharge of available water (reclaimed effluent, storm runoff, imported extrabasin supplies). By this means, it may be possible to forestall significant impacts to the San Pedro River and its riparian system. The second course of action would enhance infiltration of available stormwater as a means to increase recharge to the regional and (or) alluvial aquifer. The third strategy would bring water from outside the Subwatershed to augment existing supplies. Note that the first action would provide information about how best to utilize any additional water obtained via the second and third actions.

The wealth of data that has been collected in the Subwatershed has allowed Partnership members—who often have different individual goals—to nevertheless work together in developing strategies to reduce the annual aquifer storage deficit. In addition, the hydrologic indicator data trends allow for annual evaluation of project effectiveness, and have led to the current round of proposed actions to address the deficit. Eventually, the effects of groundwater withdrawals in the alluvial aquifer will be quantified. In the meantime, the fact that the alluvial aquifer appears unimpacted at this time provides hope that if more is done now to mitigate the impacts of groundwater withdrawals, an adequate supply of water may yet be retained for the San Pedro River, its riparian area, and for the residents of the Sierra Vista Subwatershed.

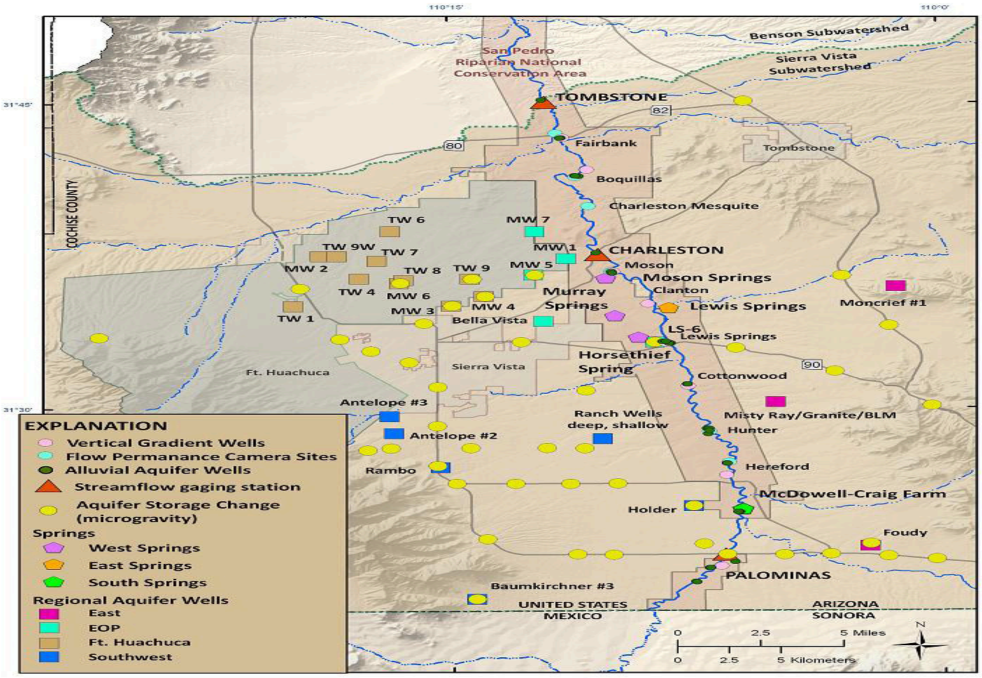


Figure 3-13. Monitoring locations in the Sierra Vista Subwatershed, Upper San Pedro basin, southeastern Arizona. The indicators of Subwatershed sustainability are evaluated annually using the data collected at these locations to assess progress toward system health and sustainable groundwater use in the Subwatershed.

Source: U.S. Geological Survey, 2009 (Appendix A: Progress Toward Achieving and Maintaining Sustainable Yield of the Regional Aquifer of the Sierra Vista Subwatershed, Arizona).

Case Study 4: Floodplain Assessment and Decision Support Tool in Iowa

Daniel Moriasi (USDA), Charles Siptzak (USACE-Rock Island) – Iowa-Cedar Basin, Jason Smith (USACE-Rock Island)

The Iowa-Cedar Rivers Basin is the most recent (2009) addition in the worldwide network of HELP basins. Since 2009, driven by the pressure of flood threats, an impressive series of actions have been undertaken by a network of federal and local management agencies and research institutes, and communities have emerged in response. The Iowa-Cedar River Basin Interagency Watershed Coordination Team was created in the fall of 2009 (http://iowacedarbasin.org). This entity is led by the U.S. Army Corps of Engineers and the Iowa Department of Natural Resources for the purpose of addressing water resource problems and opportunities in the Basin. The Coordination Team goals are to increase social and economic value of water, protect ecological integrity, and manage flood risk.

The current action priority for the Interagency group is flood mitigation, using IWRM concepts. In the spring of 2010, a new grass-root body, the Cedar River Watershed coalition, formed to focus specifically on floods. This community-driven group organizes and advocates for practices and policies (federal, state, and local) that will reduce future flood damage and improve water quality. The role of the Iowa HELP basin is to bridge the gap between management, community, and science and build a collaborative and contemporary decision support system that is based on the latest area research.

Currently, the Iowa water-concerned groups are inventorying the infrastructure and expertise of each individual partner and determining how to integrate those resources in a common web-portal. This web-portal will showcase each partner's efforts and share this information with the general public. A useful resource made available to the public is the Floodplain Assessment & Decision Support Tool (FADST). This resource was developed as a joint effort between the USDA Natural Resources Conservation Service (NRCS) in Iowa and the Iowa Department of Natural Resources (IDNR), the Nature Conservancy, the U.S. Army Corps of Engineers (USACE), and the Iowa Homeland Security and Emergency Management Division, with input from several other organizations.

The FADST was developed to perform multi-criteria, objective assessments of floodplain segments. The assessments help identify floodplain segments and associated watersheds that should be prioritized for project planning and program investments. It works by quantifying activities, infrastructure, and populations within polygons defined by floodplain soils and Hydrologic Unit Code (HUC) boundaries. A HUC areal identifier was introduced by the USGS to provide a unique hierarchical system for classification of the nation's watersheds from the region to subwatershed level. Quantified values for each data layer in FADST are then normalized to values ranging from 0 to 100. The normalized values may then be weighted and combined and displayed as desired in a geographic information system (GIS) in order to address specific questions or interests.

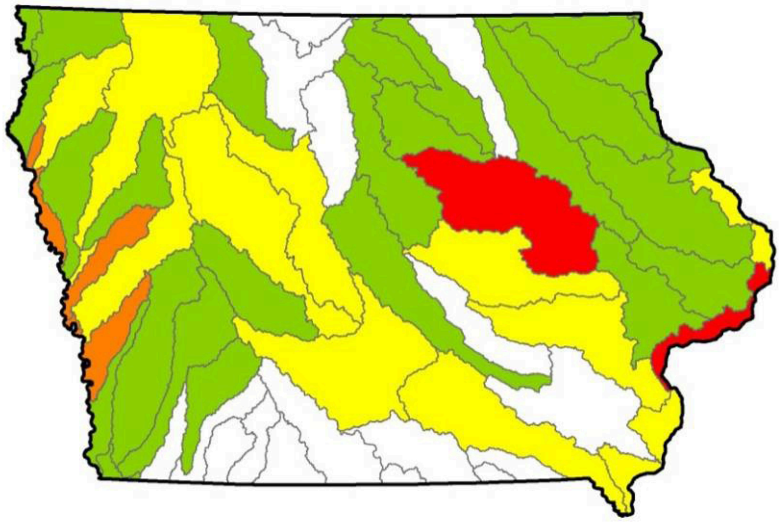


Figure 3-14. Iowa statewide comparison of 8-digit hydrologic unit areas sorted for density of critical infrastructure in floodplains.

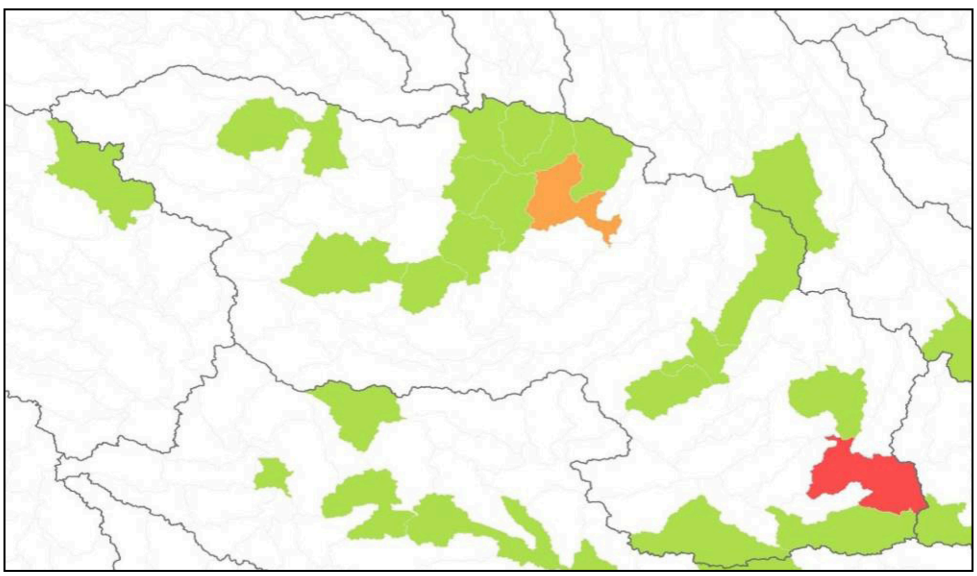


Figure 3-15. Critical infrastructure in floodplain at a 12-digit hydrologic unit code level within the Middle Cedar Watershed (the large watershed shown in red in east-central Iowa).

Table 3-2. FADST data sets and sources.

Layer	Iowa Floodplain Assessment Map Layers	Primary Source
1	Animal Feeding Operations - Livestock	Iowa DNR - GSB
2	Confinement Feeding Operations	Iowa DNR - GSB
3	Critical Infrastructure	Iowa Homeland Security
4	Crop - Corn Suitability Rating weighted average	NRCS
5	Cultural Resources	Iowa Office State Archaeologist
6	EWP Damage Sites 1998-2008	NRCS
7	EWP-FPE Applications 2008	NRCS
8	FEMA Acquired Properties	FEMA
9	Households - 2000 Census	US Census
10	Housing Units - 2000 Census	US Census
11	Land cover/Land Use	Iowa DNR - GSB
12	Leaking Underground Storage Tanks	Iowa DNR
13	NRCS Wetland Conservation Easements	NRCS
14	Pipeline - miles	Iowa DOT
15	Population - 2000 Census	US Census
16	Publically Owned Lands	Iowa DNR - GSB
17	Railroad miles	Iowa DOT
18	Rainfall averages	ISU - Mesonet
19	Repetitive Loss sites	FEMA
20	Roads - miles	Iowa DOT
21	Source Water Assessment and Protection Wells	Iowa DNR
22	Threatened and Endangered Species Data	Iowa DNR - GSB
23	Underground Storage Tanks	Iowa DNR
24	Unsewered Communities	Iowa DNR
25	Wastewater Treatment Plants	Iowa DNR - GSB
26	Wells - Private Well Tracking System	Iowa DNR - GSB
27	Iowa Aquatic Priority Areas	TNC

Availability of FADST information allows decision makers to move from inundation maps (created through hydraulic/hydrologic modeling) to risk maps in Iowa watersheds. To reduce risks of damage on lands that have been identified as having high flood damage potential, several development options exist. One avenue for reducing risk potential is to prevent development in the areas through programs like the NRCS conservation easement program. Not only do the easements prevent damages by halting further development in these areas, but the conserved wetlands also provide more carrying capacity for floodwaters. By conserving those lands that can hold, filter, and infiltrate floodwaters, the flood risks are reduced both upstream and downstream. A second option involves converting high flood-risk lands into public property like parks, trails, and preserves. When developed areas are hit by severe flooding, governments at the local, state, or federal level may purchase that land, remove development, and convert the land into green space that can be enjoyed by the public at large. When the next flood event occurs, these properties may be inundated with water, but will suffer only minor damages involving relatively inexpensive repairs.

The FADST has been used to help prioritize 8- and 12-digit HUC watersheds for further analysis and for possible project development as part of the Iowa-Cedar Interagency Watershed Coordination Team. This effort is coordinated by the USACE and

IDNR with participation from many other federal, state, university, and non-governmental organizations. The FADST will also be used by the NRCS to help prioritize future investments in USDA conservation easement programs. Questions regarding the FADST may be directed to Martin Adkins, Assistant State Conservationist for Water Resources (martin.adkins@ia.usda.gov) or Gregg Hadish, Geographic Information Systems Specialist (gregg.hadish@ia.usda.gov) with USDA-NRCS in Des Moines, Iowa.

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Conclusions

In this monograph, we compared the science and practices of IWRM in seven North and Central American river basins. While each basin faces unique challenges to different stressors of social and environmental changes (e.g., climate change) and possesses different kinds of different adaptive capacities, we found that some common lessons can be drawn from these comparative case studies.

1. Climate change is already occurring and basin water-resource managers are beginning to incorporate climate information into adaptive water-resource management. Smart land-use planning through best land management practices in agricultural and urban lands is now reducing pollutant loading, outdoor water consumption, and flood risks. Once implemented successfully in a spatially explicit way, it can further reduce the potential negative consequences of climate change and thus increase basin resilience. Working closely with regional and local land stakeholders is recognized as a key strategy in implementing smart land- and water-use planning.

2. Effective integrated water-resource management requires a social and scientific learning process in order to form an effective governance of hydrological regimes. Successful water governance under climate uncertainty relies on equitable stakeholder representation and a capacity for building trust and confidence that the stakeholder group can achieve its mission and goals. It also requires outreach and education to build a common understanding among stakeholders and an accepted means for measuring accountability. Frequently the social learning process emerges as a catalyst for action and collaboration/partnership during times of potential crisis.

3. Access to basin-wide information is an essential feature of IWRM, and synchronization of data in a user- (namely, water stakeholder) friendly format is urgently needed. While there has been much progress in hydroinformatics with the help of new technology such as interactive GIS, web-based environment, hydro data are often measured at different spatial and temporal scales by different agencies, so the harmonization of data is long overdue. Identifying and filling in hydro information gaps is another key for the successful implementation of IWRM.

4. In implementing IWRM, continuous dialogues between scientists and stakeholders, including water resource policy makers and practitioners, are essential. Through multiple interactions, quantitative and qualitative basin information can be transferred back and forth between the two communities in a transparent and mutually beneficial way. By doing so, the scientific community can deliver useful information to stakeholders while decision-makers can bring in the economic and social issues of water governance, all of which can be discussed through the social learning process. In the basins featured in this Monograph, stakeholders, managers, and other decision-makers recognize that the concept of good governance as central to successful IWRM, largely because the social

learning process provides HELP basins with a means of integrating multiple social, scientific, and economic values and uses of water in basin visioning, planning and adaptation.

5. Exchange of basin information and progress on the science and practice of IWRM in each basin has resulted in invaluable lessons to basin scientists and practitioners. As each basin has strengths in certain water resource areas (either science or practice), other basins can learn their experiences to better plan for their own IWRM in a changing environment. This is the keystone of UNESCO's HELP Program and an IWRM perspective which other watersheds can learn from. We offer this Monograph as an example of how to adapt IWRM to the new challenges of climate change and stress, complex information management, and multi-stakeholder governance. As a process, we have learned that the HELP approach to these challenges must be applied again and again in recognition that change is inevitable and that we must be ready to adapt to it. In this way, HELP can transform potential water conflicts into collaboration.