A CONCEPTUAL FRAMEWORK FOR DEVELOPING AND IMPLEMENTING INTEGRATED WATER RESOURCES MANAGEMENT (IWRM) PROGRAMS IN THE UNITED STATES

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AUTHORIZATION TO SUBMIT DISSERTATION

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ABSTRACT

The United States (U.S.) is a resource-rich nation and the development of our water and water-related resources has created great socioeconomic stability and allowed Americans to prosper for more than 200 years. However, development of these resources has not been without its attendant costs. Global change has impacted virtually every river basin in the U.S., often degrading the quality and availability of water and water-related resources.

The concept of Integrated Water Resources Management (IWRM) has evolved over approximately the past 50 years and it was formally accepted internationally as part of Agenda 21 in 1992. IWRM provides a holistic, systematic, and integrated framework that promotes the sustainable development and management of water and water-related resources in order to maximize the economic and social welfare of humans without compromising the sustainability of the environment. IWRM was designed for world-wide applicability and has been largely embraced by the international water resources community, but not by the U.S. water resources community. However, a growing number of U.S. organizations now believe that IWRM can significantly improve water resources management in the U.S. (AWRA 2011, AwwaRF 1998, and USACE 2010a). As demands for and conflicts over water and water-related resources continue to increase, it may be time for the U.S. water community to develop more holistic, systematic, and integrated policies, laws, methods, and tools to meet those growing demands and changing needs. IWRM may be the most appropriate next step for managing water and water-related resource needs in the U.S.

A few others have discussed conceptual models for implementing IWRM in the U.S. (Shabman and Scodari 2012). However, most IWRM-related research in the U.S. is focused on the implementation of project-level or watershed-level programs. This research focuses on developing a scientifically-based policy and legal framework to assist state, tribal, and federal natural resource and environmental policy- and decision-makers refocus and/or modify their existing policies and laws with respect to implementing IWRM, where they deem it is appropriate and desirable to do so within their jurisdiction.

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DEDICATION

I dedicate this dissertation to the wonderful women in my life: Lisa, Mackenzie, Madison, and Zoe Sehlke. You have always fully supported and encouraged me during my long academic journey, and you gave me more love, friendship, inspiration, and support than any one man deserves. I have been truly blessed to be able to share the path that life has laid out for us as a family and as individuals, as each of us has grown and pursued our life's joys, ambitions and academic pursuits. I love you and I am so proud of each of you for who you are and for all of your accomplishments!

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CHAPTER 1: INTRODUCTION

The United States (U.S.) is a resource-rich nation with regionally sufficient and reliable supplies of water, energy, building/manufacturing materials (e.g., timber and stone), and fertile soils for agriculture. Like much of the developed world, development of these resources has brought socioeconomic stability and prosperity to the U.S. The development of these natural resources has provided many Americans with the basic food, shelter, and commodities needed to survive and surpluses of these commodities have allowed Americans to prosper.

Water resources development has been occurring for more than 200 years in the U.S. and many have prospered because of it. However, there have been large environmental costs associated with that development. Anthropogenic modification of the environment, mass consumption of natural resources, large-scale diversion and use of water, and the widespread discharge of pollutants to the land, water, and air have drastically impacted the quality and availability of water and water-related resources. For example, the most recent national summary of surface water quality in the U.S. indicates that although only about 30% of the nation's waters have been assessed recently for water quality. Approximately 54% of those waters were threatened or impaired (EPA 2015). In addition, many water-related (e.g., aquatic, riparian, and hyporheic) ecosystems and species populations in the U.S. are no longer sustainable. For example, 164 species of fish, 37 species of reptiles, and 35 species of amphibians in the U.S. are currently listed under the Endangered Species Act (ESA) as "threatened" or "endangered" (USF&WS 2015).

If this is the condition we are in now, with approximately 325 million people in the U.S. (WPC 2015) and 7.3 billion on Earth (UNDESA 2015), we must ask ourselves: how will we adapt to future conditions as the U.S. population increases to 438 million (Ortman and Guarneri 2008) and the world population climbs to 9.7 billion (UNDESA 2015) in 2050? How will we address the needs of such a large population when humans are already over-utilizing so many of the critical renewable and non-renewable resources we depend on, including water resources? Within the U.S., we must also ask ourselves: how can we continue to meet the water, food, and energy needs of our expanding population and maintain the quality of life we are accustomed to living? This is especially true in light of the fact that we have expanded to fill the physical length and breadth of our national territory (at least in the continental U.S.). In addition, we have already extracted many of our easily and economically available natural resources and we have already harnessed most of our readily available water resources. A question oft asked to fill idle times is now becoming imperative to answer: how do we find a sustainable balance between socioeconomic development and the protection of the natural resources that sustain us?

While land and water resource development in the U.S. has undoubtedly helped extend human longevity, health, and prosperity, it has also significantly altered the quality of most freshwater resources (e.g., surface water and groundwater) and the vast majority of ecosystems (e.g., forests, prairies, freshwater bodies, and oceans) in the U.S. and most of the world (Georgakakos et al. 2014). Virtually every river basin in the U.S. has been impacted to some extent; either directly (e.g., modification of natural water storage and flows and land-use changes due to dams and diversions, and agriculture) or indirectly (e.g., atmospheric deposition of pollutants and climate change impacts on precipitation patterns and snowpack levels) (Bates et al. 2008, Georgakakos et al. 2014, Glennon 2009, and Reisner 1993). Cumulatively, these wide-spread, large-scale changes are part of what is known as "global change" (Steffen et al. 2004):

> *Global change encompasses change in a wide range of global scale phenomena: population; the economy, including magnitude and distribution; resource use, especially for production of energy; transport and communication; land use and land cover; urbanization; globalization; coastal ecosystems; atmospheric composition; riverine flow; the nitrogen cycle; the carbon cycle; the physical climate; marine food chains; and biological diversity.*

Combined, these phenomena directly or indirectly impact the quantity and quality of freshwater resources, thereby impacting the overall health and well-being of both humans and the environment in the U.S. Of these phenomena, climate change arguably has the greatest potential to broadly impact both humans and the environment worldwide (Georgakakos et al. 2014 and Steffen et al. 2003). Based on recent projections, it's likely climate change will increasingly impact future water resources in many parts of the U.S. and throughout the world. Bates et al. (2008) states:

> *Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems.*

Whether global change will cause irreparable harm to water resources sustainability within a given basin and, if so, which phenomenon or set of phenomena will prove to be the critical tipping point (e.g., cause water resources development to become unsustainable), will be highly dependent on the specific basin. However, as each basin or watershed approaches its critical tipping point, one can assume that the number and intensity of conflicts will increase. Historically, there are and have been many social, legal, and political conflicts over water resources in the U.S. and it is anticipated that there will be many more conflicts (e.g., lawsuits) as more people compete for the remaining available water supplies, as water managers try to allocate new or reallocate existing water rights, and as water quality and ecosystems continue to be degraded by anthropogenic water use (Gleick 2013, Greenberg 2009, Hunton and Williams 2009, and Wines 2014).

Viessman and Feather (EWRI 2006) evaluated the status and evolution of water resources planning and management in the U.S. They show that as times, conditions, and priorities have changed in the U.S., the water community has evolved its activities, funding, and approaches to water management (e.g., from simple water management to multi-purpose to multi-objective management of water resources). Because of the cumulative impacts of global change are currently degrading so many waters in the U.S., some researchers/organizations are starting to call on U.S. water managers to develop more holistic, systematic, and integrated planning and management approaches to address future challenges (ASCE 2001, ASCE 1998a, ASCE 1998b, ASCE 1997, EWRI 2007, Grigg 1998 and 2008, Mitchell 1990, Melillo et al. 2014, NRC 1999, NWC 1973, and WWPRAC 1988). Some water organizations have suggested that Integrated Water Resources Management (IWRM) may be the best management approach for responding to the various global change impacts and management challenges in the U.S. (AWRA 2011, USACE 2010, and USACE 2013).

However, in order to evaluate whether IWRM can provide a better framework for implementing cost-effective improvements to water resources management in the U.S, we must first understand what IWRM is, what potential benefits it offers over traditional U.S. water management approaches, and what potential costs and/or other potential drawbacks may be associated with this approach. Then, we must decide as a water community whether the net benefits can provide a significantly better approach to water management in the U.S.

If the goal of the U.S. water community is to provide a robust and sustainable supply of water to meet society's socioeconomic needs and to also maintain a healthy environment, then I would contend that we must learn to be better stewards of the water resources available to us. We need to adapt more effective and robust water practices and technologies to improve the management and use of water resources to meet socioeconomic needs in the U.S. In addition, we need to restore the water resource systems that we have already highly modified, simplified, and degraded. In addition, we need to protect and conserve sufficient quantities of sufficient quality water to ensure the survival and success of water-related ecosystems and species in the U.S.

In this dissertation, I contend that the U.S. needs to develop a more holistic, systematic, and integrated approach to managing water and water-related resources in the U.S.; whether that approach meets the contemporary definition of IWRM (UNCED 1992) or it is IWRM-like (e.g., adopts selected aspects of contemporary IWRM). Therefore, this dissertation adopts a “normative” approach to analyzing how an IWRM or IWRM-like approach could be designed and implemented in the U.S., rather than conducting a strict, “positive” policy analysis of the relative merits of IWRM as defined by Agenda 21 (UNCED 1992).

Overview of Integrated Water Resources Management

IWRM, as it is known today, was first formally defined in Chapter 18 of Agenda 21, “Protection of the Quality and Supply of Freshwater Resources: Application of Integrated Approaches to the Development, Management and Use of Water Resources,” (UNCED 1992). Within this chapter, IWRM is discussed in Sections 18.6–18.22. These sections provide the original basis for action (18.6), objectives (18.7–18.11), activities (18.12), and means of implementation (18.13–18.22) for developing IWRM programs.

The most broadly accepted definition of IWRM is (GWP 2000):

> *A process, which promotes the coordinated development and 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.*

Based on this definition and its associated discussions (GWP 2000 and GWP 2009), IWRM is intended to be a framework that promotes the sustainable development and management of water and water-related resources in order to maximize the economic and social welfare of humans without compromising the sustainability of the environment. IWRM is designed to be a comprehensive, interdisciplinary, stakeholder-driven approach to developing and implementing efficient, equitable, and sustainable solutions to water and water-related development challenges.

IWRM promotes the objectives of sustainable freshwater management, which include: “…to make certain that adequate supplies of water of good quality are maintained…while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature and combating vectors of water-related diseases,” (UNCED 1992). IWRM advocates the need for understanding and managing all water resources within a sub-basin or watershed as a unitary source from a hydrologic cycle perspective; including consideration of both water quantity and quality. In addition, IWRM advocates for the consideration of the multi-sectoral nature of water resources development (e.g., water supply for domestic, commercial, municipal, industrial, sanitation, agricultural, power generation, freshwater fisheries, transportation, and recreation), the implementation of water conservation and waste minimization measures, flood prevention and control measures, and sedimentation control, where it is needed.

In summary, IWRM is intended to be a framework that promotes the sustainable development and management of water and water-related resources in order to maximize the economic and social welfare of humans without compromising the sustainability of the environment (GWP 2000 and UNCED 1992). IWRM is designed to be a comprehensive, interdisciplinary, stakeholder-driven approach for developing and implementing efficient, equitable, and sustainable solutions to water and water-related development challenges. While IWRM challenges stakeholders to try to achieve the "sustainability trifecta" (i.e., balancing social and economic development and environmental protection), it leaves it up to the stakeholders within each sub-basin/watershed to collectively determine the appropriate balance between these three broad goals.

Review of U.S. IWRM Literature

The vast majority of research relative to IWRM has been conducted internationally, largely through the United Nations (UN). Therefore, majority of IWRM-related papers, guidelines, and other documents have been written by international researchers and organizations that promote and/or implement IWRM internationally. Two of the most prominent sources of IWRM literature are the Global Water Partnership (GWP) (GWP 2015) and the UN Department of Economic and Social Affairs (UNDESA 2015). The GWP is the lead organization for the UN relative to promoting and developing IWRM internationally. UNDESA is the parent organization for the UN-Water (2008) Program. Both organizations maintain a large number of IWRM-related guidance documents, case studies, and reviews of IWRM international projects and programs.

In addition, the UN Development Programme (UNDP 2015) manages a number of IWRM related programs, including the Transboundary Waters Programme, UNDP Water Governance Facility at Stockholm International Water Institute, Cap-Net, Mainstreaming Human Rights and Gender Equality, Small Island Developing States IWRM Programme, and Promoting IWRM in Central Asia. Much information can be found on its website and related resources (UNDP 2015).

However, these documents and the information are primarily focused on international topics, generally regarding the third world. Essentially, none of these documents focus on IWRM in the U.S. or other aspects of water resources management in the U.S. These and other international sources of

IWRM information provide some very good, fundamental information that could be very useful to many U.S. researchers, depending on their focus. However, because the focus of this dissertation is the development of a U.S. IWRM conceptual model based on U.S. polices, laws, and conditions, the information is of limited value for this research. Information that is of value to this research is discussed in detail in Chapter 2; therefore, this introductory review focuses on a select number of programs in the U.S.

The U.S. Army Corps of Engineers (Corps) is one of the primary federal water agencies in the U.S. that advocates for the development and implementation of IWRM, both domestically and internationally (USACE 2013). The Corps conducted an extensive two-year assessment and numerous interactive stakeholder sessions to assess federal and state water management programs and to identify common nationwide water resources needs and issues, and potential solutions to address those needs and issues. In its final report on this initiative, *Building Strong Collaborative Relationships for a Sustainable Water Resources Future* (USACE 2010), the Corps stated that one of its major goals is to "Make integrated water resources management more understandable and a preferred way to plan and manage public water and related land resources as a system." The report states:

> *Integrated water resources management (IWRM) is an ideal towards which to strive in order to manage multiple stakeholders intent on multiple water uses through multiple objectives for more balanced benefits. Robust concepts and models for IWRM hold the promise to manage the true complexities and interdependencies that exist for water managed at watershed scale. Integration can bring economy of effort and save resources to enable government at all levels to do more with fewer resources.*

Furthermore, the report provides some specific recommendations that IWRM programs and plans should consider, including:

- Conjunctively managing and using surface water and groundwater resources
- Integrating water quantity and quality management planning and programs
- Assessing rivers, watersheds, and inland and coastal waters together as a whole
- Designing and implementing water resource projects in the context of a large geographic regions
- Understanding and balancing multiple stakeholder interests and priorities.

Furthermore, the report states that key IWRM concepts need to include the concepts of holism, systems, watersheds, participation, balance and sustainability (USACE 2010). Finally, it suggests that it is important that state watershed-based plans reflect an appropriate balance between economic and human uses and ecological and environmental benefits in a manner that meets their various needs and roles.

Shabman and Scodari (2012) assessed the Corps existing water and related land resources planning processes and requirements relative to the National Research Council's (NRC's) recommendation that the Corps "refocus attention in planning studies to multiple objectives and tradeoffs, better account for uncertainty, and accommodate the concepts of adaptive management, stakeholder collaboration, and systems analysis for watershed scale planning and evaluation." This research provides a good overview of IWRM and IWRM-like concepts and processes that could be implemented through existing Corps planning processes. The research is focused on Level C (project-specific) planning, as described by the Water Resources Planning Act of 1965; however, at the watershed level. This includes incorporating the National Environmental Quality and National Economic Efficiency effects, public safety effects, "other environmental quality effects, and the effect of planning on low-income, tribal, and minority communities into the planning process. In addition, it addresses the various aspects of ecosystem services.

This framework (Shabman and Scodari 2012) emphasizes a number of challenges relative to integrating IWRM into the Corps' planning processes, including:

- Accommodating Corps' mission and policy needs that are not amendable to IWRM
- Acknowledging and communicating necessary uncertainties inherent in the analyses that support decision-making
- Clearly defining the Corps' roles in ecosystem restoration and flood risk management relative to other agencies
- Recognizing that multiple decision criteria measured in non-commensurate terms cannot be determined by simply applying analytical algorithms that compute the "best" plan
- Realizing the enhancement of collaborative planning and shared decision-making by incorporating different agency responsibilities into planning, increasing the transparency of the logic and computations used in analyses, and assuring that multi-criteria evaluation and analytical tools help reconcile disparate view and lead to more expeditious decision making.

The White House's Council on Environmental Quality (CEQ) recently began advocating for more integrated and sustainable water resources water resources development. The "Principles and

Requirements for Federal Investments in Water Resources," (Principles and Requirements) (CEQ 2013) states that:

> *The Federal Objective, as set forth in the Water Resources Development Act of 2007, specifies that Federal water resources investments shall reflect national priorities, encourage economic development, and protect the environment by:*
>
> *(1) seeking to maximize sustainable economic development;*
>
> *(2) seeking to avoid the unwise use of floodplains and flood-prone areas and minimizing adverse impacts and vulnerabilities in any case in which a floodplain or flood-prone area must be used; and*
>
> *(3) protecting and restoring the functions of natural systems and mitigating any unavoidable damage to natural systems.*

The Principles and Requirements (CEQ 2013) expanded the number of federal agencies that are required to utilize the Principals and Requirements as part of their planning process, by including various water-related agencies. It specifically addresses six principles that should be considered in water and water-resources related planning: healthy and resilient ecosystems, sustainable economic development, floodplains, public safety, environmental justice, and a watershed approach. In addition, it established 11 requirements that must be considered in the planning process for all major water and water-related projects.

In general, the Principles and Requirements provide some significant improvements by expanding the scope to the other water-related federal agencies and by trying to reinstitute the balance between socioeconomic and environmental costs and benefits. For example, the draft version of the Principles and Requirements (CEQ 2009) specifically called out the use of IWRM, stating that:

> *Water resources planning shall use contemporary water resources paradigms such as integrated water resources management and adaptive management, and consider the effects of climate change.*

Unfortunately, the final version of the Principles and Requirements (CEQ 2013) and their related interagency guidelines (CEQ 2014) do not mention IWRM as either a principle or a requirement. This was largely due to CEQ's decision to "step up" to a higher policy level in order to ensure that the Principles and Requirements can address the needs of the broader array of agencies now covered under the Principles and Requirements without encumbering the agencies with current terms and scientific approaches that may go out of vogue in the not too distant future, and such that they can "…be applied to a broad range of federal investments that by purpose, either directly or indirectly, affect water quality or water quantity, including ecosystem restoration or land management activities."

The U.S. Environmental Protection Agency (EPA) has long promoted a holistic watershed-based approach to protect surface water resources (EPA 2008 and NRC 1999), an independent aquifer-wide based approach to protecting groundwater resources (e.g., sole-source aquifer protection and well head protection programs) and a combined surface water/groundwater approach for selected programs (e.g., Safe Drinking Water Act [SDWA] source water protection programs). However, it has not been successful to date in integrating surface water and groundwater protection programs generally throughout the U.S. largely because of "pushback" from states and water users who apparently fear that a holistic approach to managing water quality issues will infringe on their water rights and their ability to dispose of pollutants easily and cheaply.

Recently, largely based on the recommendations of the National Drinking Water Advisory Council (NDWAC 2010), EPA explicitly embraced IWRM concepts relative to implementing climate change adaptation in the water utility sector. EPA's "Climate Ready Water Utilities (CRWU)" initiative (EPA 2013 and EPA 2012):

> *…provides resources for the water sector to adapt to climate change by promoting a clear understanding of climate science and adaptation options and by promoting consideration of integrated water resources management (IWRM) planning in the water sector.*

EPA's National Water Program 2012 Strategy includes a direct goal to "support IWRM in the water utility sector to sustainably manage water" and it establishes three strategic objectives (EPA 2012):

1. *Understand and promote IWRM through technical assistance through the use of water supply management strategies;*
2. *Evaluate, and provide technical assistance on the use of water demand management strategies; and*
3. *Increase cross-sector knowledge of water supply climate challenges and develop watershed specific information to inform decision making.*

The American Water Resources Association (AWRA) has long supported the concept of developing and implementing IWRM in the U.S. by providing leadership, facilitating discussions, and highlighting IWRM at conferences, including at the second and fourth National Water Policy Dialogs (AWRA 2005 and 2008). In addition, it helped frame and lead the discussions on IWRM at the 6th World Water Forum in 2012.

In 2011, the AWRA Board of Directors formalized its support by publishing a board policy on IWRM (AWRA 2011):

> *The American Water Resources Association recommends that water management goals, policies, programs, and plans be organized around the concept of Integrated Water Resources Management (IWRM), the coordinated planning, development, protection, and management of water, land and related resources in a manner that fosters sustainable economic activity, improves or sustains environmental quality, ensures public health and safety, and provides for the sustainability of communities and ecosystems. The American Water Resources Association calls on policy makers, planners and managers at national, tribal, interstate, state and local levels to encourage collaborations, policies, programs and plans that embrace Integrated Water Resources Management.*

The policy paper also indicates this effort will take a national commitment to: clean water as a basic human right and as an economic and ecological necessity, planning for long term sustainability, participatory decision making, management based on sound science and hydrologic units, realistic measurement of outcomes, and continuous improvement of institutional capacity at all levels.

Recently, AWRA published a review of the history of IWRM and provided seven case studies relative to the development and implementation of statewide (e.g., California and Oregon), large river basin (e.g., Delaware River and Minnesota River Basins) and smaller river basin (e.g., Rio Grande River, St. Johns, and Yakama River Basins) IWRM, and IWRM-like programs (AWRA 2012). This assessment used GWP's three "Areas to Facilitate Change for IWRM Implementation" framework for evaluating the programs. This framework includes "an enabling environment" (e.g., policies, legislative framework, and financing and incentive structures), "institutional roles" (e.g., creating an organizational framework and institutional capacity building), and "management instruments" (e.g., water resources assessment, plans for IWRM, demand management, social change instruments, conflict resolution, regulatory instruments, economic instruments, and information management and exchange).

AWRA's (2012) review indicates there are a relatively limited number of documented U.S. IWRM case studies are available. The scales and approaches employed by these IWRM projects varied widely, but there are a number of common issues and approaches between the various projects.

It should be noted that the Western Governors' Association (WGA 2008) has advocated for the development of an IWRM-like program at the federal level, although few states have actually developed and/or implemented their own IWRM programs. According to the WGA (2008):

The Western States Water Council (WSWC) should urge Congress to require federal water resource agencies to include "Integrated Water Resources Planning and Assistance" as one of their primary missions, with the goal of:

(a) changing the way water planning is conducted by encouraging more comprehensive plans developed under state leadership with federal assistance; and

(b) reducing inefficiencies caused by the present mode of project-specific responses to competing demands, contradictory actions by multiple state, local and federal water agencies, and hastily conceived reactions to the latest real or perceived crisis.

Both the WGA and WSWC have indicated that they endorse the development of IWRM-like programs for the management of federal projects by federal agencies and the development of a national IWRM framework. However, both the WGA and WSWC have been very clear that they would be very resistant to the development of a federal IWRM program that dictates to the states how to manage waters under the state's purview. Although few states have developed or indicated they are developing IWRM-based programs, several states, most notably California (CADWR 2013), Nebraska (Nebraska Revised Statue 46-715) and Oregon (OWRD 2012), have developed state water plans that explicitly develop statewide or local/regional IWRM or IWRM-like strategies and plans.

The American Water Works Association (AWWA) advocates the practice of "Total Water Management," defined as (AwwaRF 1996):

Stewardship of water resources for the greatest good of society and the environment.

Grigg (2008) states that total water management, conceptually and in practice, is very similar to IWRM in that it is a holistic approach to solving water problems. One of the basic principles of total water management is that "water supplies are renewable; however, they are limited, and therefore, they should be managed on a sustainable use basis" (Grigg 1998). Furthermore, he states:

Taking into consideration local and regional variations, Total Water Management:

- *Encourages planning and management on a natural water systems basis through a dynamic process that adapts to changing conditions;*
- *Balances competing uses of water through efficient allocation that addresses social values, cost effectiveness, and environmental benefits and costs;*
- *Requires the participation of all units of government and stakeholders in decision-making through a process of coordination and conflict resolution;*
- *Promotes water conservation, reuse, source protection, and supply development to enhance water quality and quantity; and*
- *Fosters public health, safety, and community good will.*

The Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE) has been developing IWRM-related policies, guidelines and standards for a number of years. In 1990, the EWRI began an extensive assessment of existing state water policies and laws throughout the U.S. to develop guidelines for model state water codes for the U.S. While not explicitly stated, these model water codes were designed and developed largely based on the concept of IWRM (Dellapenna 2014).

Two model codes were designed to provide an integrated framework to inform state policymakers regarding how they can better manage water resources within their jurisdictions in a more integrated manner. The *Regulated Riparian Model Water Code* (ASCE 1997) provides a model for the eastern U.S. and the *Prior Appropriation Model Water Code* (EWRI 2007) provides a model for the western U.S. A third model code, *Guideline for Development of Effective Water Sharing Agreements* (ASCE 2013) was developed for managing transboundary waters, based on a mix of eastern and western U.S. and international water laws. Combined, these model codes could provide a holistic body of water policy and law for the integrated and sustainable administration of water resources throughout the U.S.

In part, these policies confirm the state's ownership and responsibilities for managing water allocation and use within their jurisdiction; they encourage states to develop integrated water policies and management approaches based on the physical laws which "govern the occurrence, movement, and storage of water," including systematically linking the management of all hydrologic compartments (i.e., atmospheric, surface, vadose, and ground waters); and they encourage the integration of water quantity and water quality management into a single process to help achieve water resources sustainability.

Viessman and Feather (EWRI 2006) conducted one of the only nation-wide reviews of state water plans in the U.S. They observed that the majority of the states have developed formal water resources plans and that state water plans are often fashioned after federal water plans. They also observed that the nature and scope of state water resources planning has evolved from single-purpose, to multiple-purpose, to multiple-objective, and now towards more integrated planning and management. In addition, they observed that state water plans vary considerably between their scope, content, and level of detail (EWRI 2006). This assessment evaluated 28 key components that the authors consider to be important for state water planning, which provides a nice baseline for assessing the "state of the states" relative to their potential for developing and implementing holistic, integrated water management plans and programs.

Of specific interest, 17 states utilize what the authors classify as "integrated planning" processes. The authors don't specifically define what they mean by integrated planning, but they state it is a process that "recognizes the true spatial, ecosystem, and institutional dimensions of the planning problemshed and their interactions" (EWRI 2006). In addition, they state in the future they believe that "Integrated water planning and management will be more widely accepted as a state goal. The true dimensions of the water problemshed and the linkages among its physical, spatial, environmental, social, and institutional dimensions will be addressed."

Finally, it should be noted that several significant interagency efforts have been initiated to increase cooperation between federal agencies relative to coordinating the collection, analysis, and distribution of water resources related data and information. For example, the "Collaborative Science, Services and Tools to Support Integrated and Adaptive Water Resources Management" Memorandum of Understanding between the Corps, National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS) is intended to help address national water information needs by creating high-resolution water resources forecasts and integrating water information to provide one-stop shopping through a common database portal (USACE 2011).

Research Goal and Objectives

The overall goal of this dissertation is to evaluate if IWRM could be a useful approach for improving the management of water resources in the U.S. and, if it is a useful approach, to provide a conceptual framework, recommendations, and examples concerning an IWRM approach to water management the U.S. This dissertation evaluates the basic principles and concepts of IWRM, as provided in Agenda 21 (UNCED 1992), versus a comprehensive conceptual hydrologic model and existing U.S. water and water-related policies and laws. This evaluation is intended to determine if an IWRM framework can provide a more holistic, systematic, and integrated national framework for developing and managing water and water-related resources in the U.S. in a more sustainable manner to meet the U.S.' increasingly demanding water resources challenges. The objectives of this dissertation are to:

- Review the evolution and implementation of IWRM since its conception in1992
- Provide a conceptual model of what IWRM should look like in the U.S. from a physically-based policy and law perspective
- Evaluate whether IWRM is a useful approach that can be potentially applied to the U.S.
- Provide selected recommendations for implementing IWRM in the U.S.

The U.S. already has well established governance, institutional, and other structures and programs that have historically served the U.S. well. Therefore, while this evaluation is intended to offer suggestions that can help improve the water resources management in the U.S., it is intended to do so in a manner that respects the established rights, responsibilities, and authorities of federal, state, tribal and local governments, and the private sector.

Content, Form, and Style

In order to evaluate IWRM relative to the U.S., this dissertation reviews the history, evolution, and basis of IWRM to better understand why IWRM was developed, what it actually means, and its potential applicability to the U.S. (Chapter 2: The Genesis and Evolution of Integrated Water Resources Management). It then provides an integrated conceptual model and discussion on the physical/hydrological aspects of the natural storage and flow of water and the movement of contaminants in a basin, sub-basin, or watershed and how such an integrated framework applies to IWRM (Chapter 3: A Conceptual Hydrological Model of IWRM Objectives in the U.S.). Finally, this dissertation evaluates selected U.S. water and water-related policies and laws that could be modified and integrated to provide a more holistic, systematic, and integrated policy and legal framework for managing water resources in the U.S., whether or not the U.S. water community decides to formally adopt IWRM as a practice in the U.S. (Chapter 4: Water Policies and Laws Potentially Applicable to the Development and Implementation of Integrated Water Resources Management in the U.S.).

This dissertation was developed using the well-accepted format of writing three technical papers designed to be submitted for publication in professional peer-reviewed journals. As such, each of the chapters was designed to be self-contained, such that Chapters 2, 3, and 4 could be submitted for publication "as is" with only minor formatting and editing. Therefore, there is inherently some overlap and duplication between these chapters. Chapters 1 and 5 provide introductory materials and a summary, observations and recommendations, respectively, in order to integrate the three main papers into a completed document.

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CHAPTER 2: THE GENESIS AND EVOLUTION OF INTEGRATED WATER RESOURCES MANAGEMENT

Introduction

Integrated Water Resources Management (IWRM) is a systematic and integrated approach to water resources management that has been largely embraced by the international water resources community (GWP 2005, GWP 2000, UNCED 1992b, and UNEP 2012). IWRM offers a range of approaches and tools that many in the international water community believe can help significantly increase the adaptive capacity and the sustainability of water resources (GWP 2013, GWP 2010 and GWP 2009; Mitchell 1990 and 2004). The concept of IWRM was primarily developed through the United Nations (UN) and it was formally accepted internationally as part of Agenda 21 in 1992 (UNCED 1992a). According to the UN's 2012 review of IWRM (UNDESA 2012):

> *Agenda 21 recognised that freshwater resources are needed for all aspects of life; it recognised the interconnected nature of water across sectors and geopolitical boundaries and that to protect them effectively would need management strategies that were far-reaching and dynamic.* ***Primarily the intention was to shift the common approach from the supply-oriented mindset to a more holistic catchment conscious approach, integrating all stakeholders, users, polluters and regulators to inform governance processes and develop compatible monitoring systems to inform those processes.*** *Although there have been significant developments in integrated management, technologies, and water quality in some regions, the state of global freshwater resources is more precarious today than ever before. [Bolding added]*

Whether IWRM can be or has ever been successfully implemented anywhere has been questioned by some researchers (Biswas 2001, 2004, and 2008), and whether IWRM is significantly different or any better than how well-established and well-run water resources management programs are currently managed in the United States (U.S.) has also been debated (AWRA 2005). However, a growing number of organizations believe that IWRM can be successfully implemented and can provide a significant improvement to water resources management in the U.S. (AWRA 2011, AwwaRF 1998, and USACE 2010a).

IWRM was approved as a concept and framework for potential world-wide implementation (UNCED 1992a). However, it was primarily intended to aid less developed countries that lack sufficient water-related knowledge and/or governance, institutional, financial, and other capacities necessary to develop sustainable water programs, which balance human development needs with the needs of nature. Unlike these countries, the U.S. and other more developed countries usually have more extensive and robust capacities to manage water resources, including well-developed governance, institutional, financial, and scientific capacities. In addition, they generally have relatively high-quality water resources personnel and extensive data and information collection, management, analysis programs, and sufficient tools and infrastructure to manage their water resources. Therefore, it is legitimate to ask: why should the U.S. embrace IWRM over or in addition to its existing water and water-related management traditions and programs?

While in many aspects water resources management in the U.S. is very advanced, in general, the "mindset" of the U.S. water community is also primarily supply-oriented rather than a holistic basin or sub-basin conscious orientation and approach. In addition, water and water-resources related policies, laws, programs, and agencies in the U.S. are highly decentralized and fragmented. Land management, water allocation, water quality, habitat and species protection, and general environmental protection policies and laws are typically written separately, and they may or may not be well coordinated, if at all. Responsibilities for land, water, and environmental management in the U.S. are divided between federal, state, tribal, territorial and local levels, and the private sector. The responsibilities are typically subdivided between numerous agencies at each level of government. In some cases, agency authorities, roles, and responsibilities are clearly delineated and coordinated within a level of government (e.g., between federal agencies) and in some cases between the various levels of government (e.g., between federal, state, tribal, and local governments). However, in many cases they are not well delineated or coordinated on a day-to-day basis at all.

Listening to general conversations and professional discussions and reading the popular press and both professional and non-professional technical publications, there are many diverse, sometimes uninformed and often incongruent concepts of what constitutes IWRM, where the concepts were developed, and the potential costs and benefits of developing IWRM programs.

For example, among the federal agencies and professional societies, the scope of IWRM is typically focused on a watershed or sub-basin level; however, the Corps includes assessing "rivers, watersheds, and inland and coastal waters together as a whole" (USACE 2010a). Over the years, there have been a number of publications, primarily in the grey literature that argues IWRM is a U.N. plot to take control over U.S. property and water rights (Posel 2013 and Wile 2012).

As the U.S. water community begins to seriously evaluate whether an IWRM approach could be a beneficial and appropriate approach for managing water resources in the U.S., it is worthwhile to develop a common overview of the purpose, objectives, concepts, and terminology associated with IWRM. This research provides an overview of these factors and of the evolution of IWRM in the attempt to provide a common understanding and basis of IWRM as we begin our assessment of IWRM's potential to improve water resources management in the U.S.

International Water Resources Programs

Genesis of IWRM Strategies and Goals

The initial concepts of IWRM are based on the works of many organizations. For example, an early UN report, "Integrated River Basin Development" (UN 1958) advocated for the "orderly development of rivers" and the need to address supporting services along with the necessary infrastructure engineering. The early sustainable development philosophies of the Harvard Water Program helped establish an interdisciplinary approach to the development of water resources and the Brundtland Commission's Report "Our Common Future" provided the basic context for sustainability (WCED 1987). The conference report for the International Water Conference in Mar del Platta (1977) advocated for coordination between the various water-related sectors (Snellen and Schhrevel 2004).

The final IWRM concepts came together at the 1992 International Conference on Water and the Environment in Dublin. According to Snellen and Schhrevel (2004), papers presented in Dublin by Koudstaal, Rijsberman, and Savanije (1991), which brought to bear the concept of environmental sustainability, and by Falkenmark and Lundqvist (1992), which pointed out the importance of land management relative to water quality and quantity, were critical pieces for developing IWRM. All of these concepts were brought together through the "Dublin Guiding Principles" (ACC/ISGWR 1992), which lead to the development of the final principles and objectives adopted by the UN Conference on Environment and Development (the Earth Summit), in Rio de Janeiro in 1992.

The final principles and objectives were agreed upon and documented in Chapter 18, "Protection of the Quality and Supply of Freshwater Resources," of the UN's Agenda 21 (UNCED 1992b). Program Area A of this chapter establishes the basis for action, objectives, activities, and means of implementation for developing IWRM programs.

Section 18.2 (18.2) states that for freshwater management:

> *The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature and combating vectors of water-related diseases.*

The overarching objective for IWRM programs is to "…satisfy the freshwater needs of water users for their sustainable development" (18.7). Other key objectives are provided in parts18.8–18.11

(Table 1) and various recommended activities (18.12) and means of implementation (18.13–18.22) are also discussed in this program area. Later, the "Report of the World Summit on Sustainable Development" (UN 2002) called for the development of national/regional IWRM and water efficiency plans by 2005. This call was renewed by the attendees of Earth Summit 2012 (UN 2012).

The Global Water Partnership (GWP) was one of the earliest and most active proponents of IWRM internationally. GWP's (2010) definition of IWRM is currently the most broadly accepted definition internationally. It defines IWRM as;

> *A process, which promotes the coordinated development and 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.*

GWP (2009) also advocates "IWRM principles" which recognize water as:

> *…a public good with both social and economic values, and that good water resources management requires both a broad holistic perspective and the appropriate involvement of users at different levels.*

These principles include the development of infrastructure, the allocation of water resources, and the implementation of incentives for its efficient use, its protection, as well as the financing of all of these activities (GWP 2009). The GWP also recognizes the importance of the "soft management" (non-infrastructure) processes that regulate water resources and addresses conflicts between various users.

Finally, according to the GWP, IWRM includes addressing the concepts of economic efficiency, social equity and environmental sustainability, and the need for understanding and managing the physical resource as a unitary source from a hydrologic cycle perspective (GWP 2009).

Implementation of International IWRM Programs

Kennedy et al. (2009) conducted a review of approximately 70 international case studies that they believe "…represent a majority of the published practice descriptions pertinent to recent work in IWRM and [Integrated River Basin Management]." The key findings of this study indicate a relatively limited number of documented case studies, the scales of the IWRM projects varied widely, and that there are a number of common general concerns and considerations. Kennedy et al. (2009) summarized what they considered to be the important themes, conclusions, and recommendations from their assessment as:

- Sharing and access to knowledge and understanding good science

Table 1. Agenda 21 management objectives and attributes that should be considered for integration into U.S. IWRM programs (Adapted from Chapter 18, UNCED 1992b).

Freshwater Management Objectives

- Ensure that adequate supplies of water of good quality are maintained while preserving the hydrological, biological, and chemical functions of ecosystems (18.2)
- Adapt human activities within the capacity limits of nature (18.2)
- Combat vectors of water-related diseases (18.2)
- Develop and utilize innovative technologies, including the improvement of indigenous technologies, to fully utilize limited water resources and to safeguard water resources against pollution (18.2)
- Understand and manage all interrelated freshwater bodies including both surface water and groundwater considering both water quantity and quality aspects (18.3)
- Recognize the multi-sectoral nature of water resources development in the context of socio-economic development (18.3)
- Recognize the multi-interest utilization of water resources for water supply and sanitation, agriculture, industry, urban development, hydropower generation, inland fisheries, transportation, recreation, low and flat lands management, and other activities (18.3)
- Concurrently develop water conservation and waste minimization measures (18.3)
- Develop flood prevention, flood control, and sedimentation control measures (18.3).

Integrated Water Resources Management Objectives

- The overall objective is to satisfy the freshwater needs of the U.S. for their sustainable development (18.7)
- Protect water resources taking into account the functioning of aquatic ecosystems and the perenniality of the resource (18.8)
- Satisfy basic human needs while safeguarding ecosystems (18.8)
- Charge water users appropriately (18.8)
- Integrate land- and water-related aspects at the level of the basin, sub-basin, or watershed (18.9)
- Promote a dynamic, interactive, iterative, and multi-sectoral approach to water resources management, including the identification and protection of potential sources of freshwater supply that integrate technological, socio-economic, environmental, and human health considerations (18.9)
- Plan for the sustainable and rational utilization, protection, conservation, and management of water resources based on community needs and priorities within the framework of the appropriate state, tribal, and/or national economic development policy (18.9)
- Design, implement, and evaluate projects and programs that are both economically efficient and socially appropriate within clearly defined strategies, based on an approach of full public participation, including that of women, youth, indigenous people, and local communities in water management policy-making and decision-making (18.9)
- Identify, strengthen, or develop the appropriate institutional, legal, and financial mechanisms to ensure that water policy and its implementation are a catalyst for sustainable social progress and economic growth (18.9)
- In the case of transboundary water resources, there is a need for riparian states [countries, states, and tribes] to formulate water resources strategies, prepare water resources action programs, and consider, where appropriate, the harmonization of those strategies and action programs (18.10).

- Support for, and building of, institutions (from local to national scales)
- Stakeholder engagement
- The necessity of dispute resolution
- The political will
- The necessity of capacity development, as a complement to planning and action
- The importance of understanding economics and financing
- Timing, in terms of length and opportunities
- The role of partnerships and informal groups
- Organizations should be self-financing
- All water uses and implementation alternatives should be evaluated
- A key or focal issue (e.g., crisis, conflict, and natural disaster) is commonly a starting point
- Use of existing methods can facilitate the process
- Cooperation can be linked to economics
- Conservation and protected areas are important for biodiversity
- Intermediaries can play a potentially important role in the process
- Local (community) engagement is a critical aspect
- Drawing from research and studies helps to provide legitimacy and stakeholder access
- Protection is a more beneficial approach than remediation
- Biodiversity may have to take a “back seat.”

While this list of attributes is neither totally comprehensive nor applicable to all situations, it provides a good starting point for others to consider when developing an IWRM program.

Hassing et al. (2009) provides a summary of 42 countries that have adopted IWRM programs at the national level. They argue that successfully implementing IWRM requires “getting ‘three pillars’ right:”

- Moving towards an enabling environment of appropriate policies, strategies, and legislation for sustainable water resources development and management
- Putting in place the institutional framework through which the policies, strategies, and legislation can be implemented
- Setting up the management instruments required by these institutions to do their job.

They go on to say that IWRM has proven to be a flexible approach to water management that can adapt to diverse local and national contexts.

The Agenda 21 target goals established for national and sub-national IWRM programs are that member states would, by 2000:

- Design and initiate targeted national action program
- Implement appropriate institutional structures and legal instruments for water management
- Establish an efficient water-use program to attain sustainable resource use patterns
- Achieve sub-sectoral targets of all freshwater programs by 2025 (UNDESA 2012).

In 2008, UN-Water conducted a survey of national IWRM programs being developed and/or implemented around the world as part of the Agenda 21 process (UN-Water 2008). The survey included 104 countries, 77 developing or in transition countries, and 27 developed countries (OECD and EU member states) (note the U.S. did not participate in this survey). The survey indicates that many countries are attempting to develop IWRM programs. However, in its 2012 "Review of Implementation of Agenda 21 and the Rio Principles" (UNDESA 2012), the UN states that:

> *Survey results indicate that some countries are moving towards implementing the Agenda 21 IWRM goals; however, 'there is much room for further improvement.' Many countries have tacitly met the deadlines for developing IWRM plans following the Johannesburg World Summit on Sustainable Development in 2005. Some have also embodied the tenets of the concept into their legal instruments, but the actual implementation of the various aspects of it to support the day-to-day water management in most countries is a long way off.*

Critique of International IWRM Programs

While many people and organizations are proponents of IWRM, others have been rather skeptical about the practicality of implementing IWRM (Biswas 2001, 2004, and 2008; and Rahaman and Varis 2005). Biswas (2008, 2004, and 2001) is one of the most vocal skeptics to provide technically-based critiques. Biswas (2008) summarizes the situation as:

> *Integrated water resources management is not a new concept: it has been around for some two generations. In the early 1990s it was 'rediscovered' by some water professionals, and then subsequently heavily promoted by several donors and international institutions. In spite of the fact that its promoters have spent hundreds of millions of dollars in recent years, the facts remain that the definition of this concept remains amorphous, and the results of its application in a real world to improve water policy, programme and projects at macro- and meso-scales have left much to be desired.*

One of his major criticisms is that IWRM concepts are overly broad and the most commonly used definition of IWRM (GWP 2000) is so vague that it has "…little practical resonance on the present, or on the future [of] water management practices" (Biswas 2004 and 2008). To demonstrate his point, he decomposes GWP's (2000) definition of IWRM and then asks a number of pointed questions such as: Who promotes this concept, why should it be promoted, and through what processes? What is meant by "related resources"? Does it include energy, minerals, fish, other aquatic resources, forests, environment, etc.? What specific parameters are to be maximized and what process should be used to select these parameters properly. Who will select these parameters?

He points out that because there isn't an agreement on what IWRM actually means or what it entails, there are at least 41 different major objectives defined in the literature as being important for developing IWRM programs and that many of these objectives may conflict with each other (Biswas 2008). Biswas (2004) also questions whether water-related issues are too heterogeneous (e.g., physically, socioeconomically, institutionally, and governance-wise) and complex (e.g., the impacts and interdependence of various water-related sectors) to be integrated throughout the world under a single IWRM paradigm or framework. For example, he states:

> *Unfortunately, in a complex world, issues like water, energy, agriculture, or the environment are becoming increasingly interrelated and interdependent, and thus integrated management of any one of these resources is not possible because of accelerating overlaps and inter-linkages with the other resources.*

While Biswas (2008, 2004, and 2001) is skeptical about the implementation of IWRM, being skeptical doesn't mean he's wrong. For example, in general, the definition of IWRM is rather amorphous, making it difficult to determine what such a program should include and how it can be implemented on the ground. IWRM is also a more expensive and complex approach to implement relative to most existing water management programs in the U.S. and presumably in others parts of the world (e.g., the increased costs of implementing participative management, more fully characterizing resources, developing and constructing the infrastructure and monitoring/management programs necessary to conjunctively manage surface water and groundwater resources and to integrate water use with water quality management). The integration of many resources and uses in multiple hydrologic compartments (e.g., groundwater and surface water), especially over larger scales, will inherently increase the complexity in understanding and managing water resources.

In addition, by integrating water users into a sub-basin or watershed scale management schema, many water users may perceive a loss of local independence/rights relative to their historical practices, and it is likely that programs such as conjunctive management will cause the reshuffling of some established priorities/rights (e.g., if groundwater and surface water rights are allocated under a unified system). Each of these factors are compounded by IWRM's stated goal of "users pay/polluters pay" principles that potentially shift many costs from a general tax base or other funding sources directly to the user/polluter.

These aspects, alone or in combination, may increase the likelihood of existing water managers and water users resisting the implementation of IWRM. Therefore, although Biswas' analyses are from an international perspective, his questions are conceptual and strategic in nature. Therefore, they should be considered prior to the potential development and implementation of IWRM in the U.S.

That said, researchers have found numerous examples where the implementation of an IWRM process was beneficial to a given country or basin. For example, Hassing et al. (2009) describes IWRM programs in 40 countries that found an IWRM framework to be useful and recent case studies by AWRA found IWRM or IWRM-like approaches being used in major water resources programs in the U.S. (AWRA 2012). Clearly, IWRM is not a panacea, but it appears that it can be a useful approach/tool for better managing water resources.

Water Resources Management Programs in the U.S.

The concept of integrating social, economic, and environmental issues and needs on a basin or catchment (watershed) scale through an effective governance model is not a new idea in the U.S. For example, the National Research Council's "New Strategies for America's Watersheds," (NRC 1999) states:

> *National goals of vibrant economic development with simultaneous progress in environmental restoration and preservation emphasize the need to bring together the public, decision makers, and scientists in effective strategies. The attainment of these goals is not mutually exclusive, but can be assured only with the integration of ecological, social and economic approaches to environmental management problems. At the same time, the reinvention of the federal government, with continuing devolution of authority to state and local authorities, demands a more effective integration of administrative levels. Watershed management is one method for addressing these needs for integration.*

The need to effectively integrate economic, environmental, ecological, physical, and social impacts into natural resources management are echoed by scientists, water managers, decision makers and others in many publications (ASCE 1998a, ASCE 1998b, Naiman 1992, NEPA 1969, NRC 1999, and NWC 1973). However, attempts to actually develop and implement integrated, physically-based approaches at the appropriate scales (e.g., at the watershed, basin, or landscape scale) have been a fairly difficult and elusive process in the U.S. like in much of the world. Much progress has been made towards being more comprehensive in the U.S. However, much more progress is necessary to develop a sustainable balance between human development goals and protecting the environment; that is, achieve sustainable development of water resources throughout the U.S.

Early Attempts at Comprehensive Water Resources Development

The U.S. government has long espoused comprehensive and coordinated water resources planning and development. For example, in the early 1800s the "Gallatin Report" provided the first comprehensive assessment and proposals for constructing canals, river navigation, harbors, and other water related projects in the U.S. (Gallatin 1808). In addition, John Wesley Powell's western lands and irrigation surveys in the 1880s provided recommendations for orderly land and water resources development in the western U.S. (Powell 1909 and Stegner 1992). In addition, the U.S. Army Corps of Engineers (Corps) developed several hundred comprehensive river basin planning reports under the authority of Section 308 of the River and Harbor Act of 1927 (USACE 2010a). While many of these and other assessments were large, comprehensive studies, many of the resulting projects were implemented rather narrowly. While considered comprehensive or multipurpose, many projects were actually focused on maximizing water resource development for a relatively narrow band of water-related sectors (e.g., navigation, hydropower or irrigation), while deemphasizing the larger social, economic, and environmental issues or balancing the full spectrum of stakeholder's needs or desires within the basin or watershed of interest.

In addition, there have been numerous attempts over the years to develop water commissions to coordinate water resources management in the U.S. (Neuman 2010). Probably the most successful, albeit a short-lived effort, was the National Water Commission (the Commission).

The Commission conducted a comprehensive review of water issues, activities, and programs in the U.S. in the late 1960s and early 1970s. The Commission's final report (NWC 1973) provided 232 recommendations framed under seven basic theme areas for address existing and anticipated water resources development related issues (Cody and Carter 2009). Many of those recommendations have been enacted; however, many still remain unfulfilled (Cody and Carter 2009).

Each of the themes and many of the specific recommendations are as valid today as they were in 1973 and many of them are directly applicable to potentially developing and implementing IWRM in the U.S. For example, the report discussing improving water pollution control, reducing flood losses, improving erosion and sediment control, improving fish and wildlife programs, making better use of existing supplies, integrating social values, and developing/improving water resources permitting in states implementing riparian water rights policies and laws (NWC 1973). Significantly, from an IWRM perspective, the Commission recommended conjunctively managing surface water and groundwater supplies and integrating water quality planning with other water resource related planning (e.g., land management plans).

Although the Commission was defunded during the Reagan Administration in 1983, its impact has been long-lived by the development several river basin commissions (e.g., in the Delaware, Susquehanna, Potomac River Basins) and the development and implementation of the *Principles and Standards for Planning Water and Related Land Resources* (Principles and Standards, WRC 1973). The Principles and Standards established the basis and process for assessing the beneficial and adverse effects associated with federal water resources development projects in the U.S.

The Principles and Standards (WRC 1973) stated that:

> *The overall purpose of water and land resource planning is to promote the quality of life, by reflecting society's preferences for attainment of the objectives defined below:*
>
> *A. To enhance national economic development by increasing the value of the Nation's output of goods and services and improving national efficiency*.
>
> *B. To enhance the quality the environment by the management, conservation; preservation, creation, restoration, or improvement of the quality of certain natural and cultural resources and ecological systems.*
>
> *For each alternative plan there will be a complete display or accounting of relevant beneficial and adverse effects on these two objectives.*

The Principles and Standards (WRC 1973) were succeeded by the *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (Principles and Guidelines, WRC 1983) and most recently the Principles and Requirements for Federal Investments in Water Resources (Principles and Requirements, CEQ 2013). All three "Principles" required water resources planning to be conducted in a holistic, systematic, and transparent manner. The Principles and Standards and the Principles and Requirements required the agencies to utilize a relatively balanced approach towards obtaining national economic and environmental goals. However, the Principles and Guidelines were heavily biased towards achieving economic goals.

Recent Attempts to Develop an IWRM Framework in the U.S.

Prima facie, IWRM seems like the most holistic, equitable, and appropriate way of managing complex water resources and other water-related issues in a holistic, systematic, integrated manner. Is it? Even if IWRM is superior relative to current U.S. water resource management approaches and processes, are U.S. policy makers and water users willing to accept implementing IWRM? For example, will water users in eastern "common law" (reasonable use) riparian states that do not have a tradition of managing water through a formal permitting program be willing to submit to formal, relatively complex, and potentially more costly IWRM programs? Will western water users who have a long tradition of strict, formal permitting programs, but who insist that water rights are individual rather than collective rights and who traditionally manage atmospheric-, surface-, and ground-water separately be willing to integrate all water rights in hydrologically-interconnected waters into a single, unified water allocation system? Can IWRM be successfully implemented as a single, all-encompassing paradigm or framework in such a large, physically, economically, socially, culturally, and legally diverse country as the U.S.? These are only a few of the questions that need to be considered relative to developing and implementing IWRM programs within the U.S.

Despite the number of open questions and many uncertainties, a number of organizations have recently discussed and advocated for the development and implementation of IWRM in the U.S. (AWRA 2011, AwwRF 1986, and USACE 2010a). In addition, a small number of federal, state, interstate, and local organizations have already begun developing and implementing IWRM or IWRM-like activities on the local, state, or regional scale (AWRA 2012). A brief overview of selected IWRM-related programs and activities is provided below.

Examples of Federal Agency Approaches to IWRM in the U.S.

In a comprehensive review of western water policies and programs, the Western Water Policy Review Advisory Commission (WWPRAC 1988) recommended integrating river basin and watershed governance:

> *Perhaps the most useful and durable recommendation that the Commission can make is to promote mechanisms that help integrate the management of river basins and watersheds across agencies, political jurisdictions, functional programs, and time. This integrated governance will help improve our process of problem solving and resources management in many areas.*

The commission was explicit that various approaches must be tried because each basin is different in its history, governing institutions, legal structures, and resource problems. However, the commission provided a general set of objectives/recommendations for integrating and improving water resources governance, including developing:

- New governance approaches based on hydrologic systems, which link basin and watershed based financial support, improve collaboration, and cooperation between federal, tribal, state and local agencies, watershed council leaders, and other stakeholders to develop jointly supported solutions
- An Executive Order or memorandum/directive requiring regional and/or watershed level coordination of federal agency budget requests, including mandatory reviews of agency budget requests pertaining to water resource management and development to ensure interagency programmatic coordination and consistency

- Joint basin-level objectives that are measurable and comply with federal, tribal, state, and local laws
- Joint basin-level accounts/trust funds to integrate federal, state, tribal, and local funds with money or in-kind contributions from nongovernmental sources to fund activities that support basin objectives
- Links between federal agency and watershed council plans and projects to accomplish unique local needs consistent with the objectives established in basin plans to develop and utilize integrated federal, state, tribal, etc. databases, as well as to gather new information to establish baseline conditions and resources and to educate stakeholders
- Greater consistency of proposed projects with federal, state, and local laws and regulations
- Greater reliance on adaptive management.

The National Research Council (NRC 1999) reviewed water resources programs in the U.S. and developed numerous recommendations relative to watershed management that essentially look and feel like IWRM. This review provides 15 major recommendations relative to developing a guiding philosophy, management processes, research, and support functions (Table 2). Many of these guiding philosophies are still relevant today relative to improving the management of water resources in the U.S.

The U.S. Army Corps of Engineers (Corps) is one of the primary federal water agencies in the U.S. researching (Cardwell et al. 2006) and advocating for the development and implementation of IWRM, both domestically and internationally (USACE 2013). The Corps conducted an extensive two-year assessment and numerous interactive stakeholder sessions to assess federal and state water management programs and to identify common nationwide water resources needs and issues and potential solutions to address those needs and issues. In its final report, “Building Strong Collaborative Relationships for a Sustainable Water Resources Future” (USACE 2010a), the Corps identifies a number of key freshwater management issues that need to be addressed, including the need for developing an IWRM approach to water management in the U.S.

In addition, it provides some specific recommendations that IWRM programs and plans should consider, including:

- Conjunctively managing and using surface water and groundwater resources

Table 2. Summary of guiding philosophies for watershed management in the U.S. (NRC 1999).

1) Watersheds are optimal organizing units for dealing with the management of water and closely related resources, but the natural boundaries of watersheds rarely coincide with political jurisdictions and thus they are less useful for political, institutional, and funding purposes.
2) Specific watershed problems must be approached in distinctive ways and determining the appropriate scale for the resolution of any problem is an essential first step.
3) Risk and uncertainty are parts of the natural as well as institutional settings for watershed management; we need to develop practical procedures for considering risk and uncertainty in real world decision making and educate the public relative to these uncertainties.
4) Watershed management plans should be viewed as the starting point and not the end product of a management cycle.
5) Scientific and technical peer review of watershed improvement activities conducted by qualified independent professionals can provide objective evaluations of their impact.
6) USACE, Bureau of Reclamation, USDA, and EPA should examine the watershed-wide implications of their policies, programs, rules, and permitting processes to take into account the regional and downstream ecological, social, and economic consequences of their actions.
7) Regionally based analysis (e.g., the Western Water Policy Review Advisory Commission) provides a comprehensive evaluation of the current management of American watersheds and guidance for the future and should be duplicated for other regions.
8) The President and Congress should consider establishing some stable mechanism to fund the federal contribution to watershed management partnerships.
9) Watershed management decisions must be based on the best possible science.
10) Need to improve the U.S.'s fundamental understanding of how physical, biological, economic, and social processes operate together within watersheds.
11) Process-orientated research addresses structure, function, and the how and why of the processes operating within a watershed and can lead to enhanced predictive capabilities, better understanding of cause-effect relationships, and a firmer foundation for planning and management.
12) A solid scientific foundation of basic and applied research is needed to provide the data, information, and tools necessary for effective implementation of watershed management activities.
13) The Federal Geographic Data Committee should assume a leadership role in establishing a capability for collecting spatial data on watersheds by creating national data standards, designating a central clearinghouse, and maintain a single national watershed database.
14) Data collection efforts provide baseline information for increased scientific understanding of watershed processes, for analyses and interpretation of problems and causes, for assessing the status of watershed resources and detecting and predicting trends, and for decision making in watershed management.
15) Effective watershed management requires integration of theory, data, simulation models, and expert judgment to solve practical problems and provide a scientific basis for decision making at the watershed scale.

- Integrating water quantity and quality management planning and programs
- Assessing rivers, watersheds, and inland and coastal waters together as a whole
- Designing and implementing water resource projects in the context of a large geographic regions
- Understanding and balancing multiple stakeholder interests and priorities
- Being respectful of the authorities, perspectives, roles and responsibilities of diverse government levels
- Designing and implementing programs to provide sustainable outcomes through a collaborative process
- Using a systems perspective within an appropriate geographic context to achieve a balance between multiple objectives needed and/or desired by the various stakeholders.

The Corps states that it intends to help promote sustainable water resources management by promoting holistic and integrated management of water resources in the U.S. and its commonwealths, districts, protectorates, and territories. Furthermore, the report states that key IWRM concepts need to include the concepts of holism, systems, watersheds, participation, balance, and sustainability (USACE 2010a). Finally, it suggests that it is important that state watershed-based plans reflect an appropriate balance between economic and human uses and ecological and environmental benefits in a manner that meets their various needs and roles.

The Corps' approach for sustainable water resources planning and management is outlined in Engineering Circular EC 1105-2-411 (USACE 2010b). This circular describes watershed planning as a more comprehensive, strategic, and integrated watershed-based approach that crosses diverse political, geographic, physical, institutional, technical, and stakeholder considerations to address the identified water resources needs from any source in the watershed and provide a joint vision of a desired end state. It further describes watershed planning as an approach for managing water resources within specified drainage areas or watersheds and addresses problems in a holistic manner that reflects the interdependency of water uses, competing demands, and the desires of a wide range of stakeholders in order to address watershed problems and opportunities. Finally, it states that watershed planning facilitates the collaborative evaluation of a more complete range of potential solutions and is more likely to identify the most technically sound, environmentally sustainable, and economically efficient means to achieve multiple goals in the entire watershed over the long term (i.e., IWRM).

The White House Council on Environmental Quality (CEQ) has advocated for a more sustainable and integrated approach to water resources development. For example, in its "Principles and Requirements for Federal Investments in Water Resources" (Principles and Requirements) (CEQ 2013) CEQ expanded the number of agencies that are required to implement Principles and Requirements. This includes not only the previously covered water resources agencies (the Corps, Bureau of Reclamation, Tennessee Valley Authority, and Natural Resources Conservation Service), but to also other water-related agencies (i.e., the Environmental Protection Agency and the Departments of Commerce and Homeland Security [Federal Emergency Management Agency]), and land-management agencies (i.e., the Departments of Interior and Agriculture).

These additional inclusions are a very important because now, when these agencies conduct water-resources related planning or expend water related funding, they too will be bound by the Principles and Requirements, which are specifically designed to provide planning and assessments that seek to balance socioeconomic and environmental issues and concerns. CEQ's intent is, in part, to apply the Principles and Requirements over a broader range of federal investments that can either directly or indirectly, affect water quality or water quantity, including ecosystem restoration and land management activities (CEQ 2013). The scope of the Principles and Requirements includes the above agency's grant programs, funding programs, studies, or investigations leading to construction of infrastructure, including new facilities or modernization of existing facilities, dam safety or operational modifications, ecosystem protection and restoration projects, and proposals and plans that affect the management of federal assets including National Wildlife Refuges, National Parks, National Forests, and National Grasslands (CEQ 2013).

The Principles and Requirements state that the federal objectives (CEQ 2013):

> *…shall reflect national priorities, encourage economic development, and protect the environment by: (1) seeking to maximize sustainable economic development; (2) seeking to avoid the unwise use of floodplains and flood-prone areas and minimizing adverse impacts and vulnerabilities in any case in which a floodplain or flood-prone area must be used; and (3) protecting and restoring the functions of natural systems and mitigating any unavoidable damage to natural systems.*

In addition, the federal objectives establish six principles, which are abstracted and summarized below:

1. Healthy and Resilient Ecosystems – Federal investments in water resources should protect and restore the functions of ecosystems and mitigate any unavoidable damage to these natural systems.
2. Sustainable Economic Development – Federal investments in water resources should encourage sustainable economic development.
3. Floodplains – Federal investments in water resources should avoid the unwise use of floodplains and flood-prone areas and minimize adverse impacts and vulnerabilities in any case in which a floodplain or flood-prone area must be used.
4. Public Safety – Threats to people, including both loss of life and injury, from natural events should be assessed in the determination of existing and future conditions, and ultimately, in the decision making process.
5. Environmental Justice – Agencies should ensure that federal actions identify any disproportionately high and adverse public safety, human health, or environmental burdens of projects on minority, tribal, and low-income populations. In implementing the Principles, Requirements, and Guidelines, agencies should seek solutions that would eliminate or avoid disproportionate adverse effects on these communities.
6. Watershed Approach – Watershed assessments should encompass a geographic area large enough to ensure that plans address cause and effect relationships among affected resources and activities that are pertinent to realizing public benefits. The scope and degree of evaluations across a watershed should reflect the nature of these relationships. It is imperative that assessments evaluate the interaction of a potential federal investment with other water resources projects and programs within a region or watershed.

In addition, they establish 10 requirements that all federal investments in water resources are required to incorporate into their project analyses. These requirements are abstracted and summarized below:

1. Evaluation Framework – It is important that potential federal investments be evaluated for their performance with respect to the federal objectives using a common framework. In addition, the evaluation methods should be designed to ensure that potential federal investments in water resources are justified by public benefits, particularly in comparison to costs associated with those investments.
2. Best Available Science and Commensurate Level of Detail – Analyses to support federal investments in water resources should utilize the best available science, data, analytical techniques, procedures, models, and tools in hydrology, engineering, economics, biology, ecology, risk and uncertainty, and other fields to the extent that sufficient funding is available

The level of detail, scope, and complexity of analyses should be commensurate with the scale, impacts, costs, scientific complexities, uncertainties, risks, and other sensitivities (e.g., public concerns) involved in potential decisions.

3. Collaboration – Federal agencies should collaborate fully on water resources related activities with other affected federal agencies and with tribal, regional, state, local, and non-governmental entities, as well as community groups, academia, and private land owners (stakeholders) to realize more comprehensive problem resolution and better informed decision making, Specific efforts should be made to provide opportunities for effective participation by minority, tribal, and low-income communities in the federal planning and decision making processes.
4. Risk and Uncertainty – When analyzing potential investments in water resources, areas of risk and uncertainty should be identified, described, and considered. Risks and uncertainties should be identified and described in a manner that is clear and understandable to the public and decision makers. The Principles identify three specific areas of risk and uncertainty should be evaluated: climate change, future land use, and adaptive management.
5. Water Use – It is critical to consider water availability and promote water efficiency with all federal investments in water resources. The efficient use of water and the consideration of multiple uses and competing demands on water resources should be taken into account when designing solutions to water resources problems. Alternative actions or plans, where applicable, should first consider opportunities to improve water efficiency with respect to existing water infrastructure and supplies. When efficiency alone will not suffice, the reuse and reclamation of water should be promoted. The effect of federal investments on water quality should also be considered and evaluated for all alternative plans or actions.
6. Nonstructural Approaches – Full consideration and reporting on nonstructural alternative actions or plans should be an integral part in the evaluation of federal investments in water resources.
7. International Concerns – Federal water resources investments must consider treaty and other international obligations and develop alternatives that are consistent with meeting such obligations. Analyses should identify any way in which an international obligation constrains choices or precludes selection of a better plan to meet the federal objective. In all cases, timely consultations with relevant foreign governments should be undertaken when a federal action is likely to have a significant impact on any land or water resources within its territorial boundaries or on the high seas.
8. Design of Alternatives – Alternative plans, strategies, or actions are to be formulated in a systematic manner to ensure that a range of reasonable alternatives are evaluated. Each

alternative plan, strategy or action is to be formulated to consider the following four criteria: completeness, effectiveness, efficiency, and acceptability.

9. Transparency in Decision Making – Both qualitative and quantitative information should be considered and displayed, including monetized and non-monetized effects, when alternatives are compared and evaluated.
10. Plan Selection – Any recommendation for federal investments in water resources to address identified water resources needs must be justified by the public benefits when compared to costs. The basis for selection of the recommended plan should be fully reported and documented, including the criteria and considerations used in the selection of the recommended course of action by the federal government.

In general, many of the Principles and Requirements have been practiced, formally or informally, to one extent or another for many years. However, they do provide some significant improvements by expanding the scope to the other water-related federal agencies, explicitly documenting the specific principles and requirements that must be considered and implemented and by trying to reinstitute the balance between socioeconomic and environmental costs and benefits that was lost in the 1983 "Principles and Guidelines" (WRC 1983), which contained a clear bias towards economic development.

The most unfortunate aspect of the Principles and Requirements is that it does not mention IWRM as either a principle or a requirement. IWRM was listed as a requirement in the draft version of the Principles and Requirements (CEQ 2009); however, there is no mention of IWRM in the final version of the document. The draft document specifically called out the use of IWRM, stating that (CEQ 2009):

> *Water resources planning shall use contemporary water resources paradigms such as integrated water resources management and adaptive management, and consider the effects of climate change.*

That omission is important in that IWRM could have been one of the powerful policy catalysts for driving water and water-related federal agencies to conduct more holistic, systematic, and integrated assessments of the potential true costs and benefits of future federal investments in water resources development. In December 2014, CEQ released the final Interagency Guidelines (CEQ 2014) which provides additional information and guidance for implementing the Principles and Requirements. However, it did not mention IWRM either.

The U.S. Environmental Protection Agency (EPA) has long promoted a holistic watershed-based approach to protect surface water resources (EPA 1993, EPA 2008, and NRC 1999), and aquifer-wide based approaches to protecting groundwater resources (e.g., SDWA sole-source aquifer protection program; EPA 2012a) and a combined surface water/groundwater approach for selected programs (e.g., SDWA source water assessment program) (EPA 2012b). However, it has not been successful to date in integrating surface water and groundwater protection programs generally in the U.S. because of its failure to regulate groundwater under the Clean Water Act and, apparently, largely due to "pushback" from water users who fear that water quality issues and requirements will infringe on their water rights.

Recently, largely based on the recommendations of the National Drinking Water Advisory Council (NDWAC 2010), EPA explicitly embraced IWRM concepts relative to implementing climate change adaptation in the water utility sector. EPA's "Climate Ready Water Utilities (CRWU)" initiative (EPA 2013 and EPA 2012c):

> *…provides resources for the water sector to adapt to climate change by promoting a clear understanding of climate science and adaptation options and by promoting consideration of integrated water resources management (IWRM) planning in the water sector.*

EPA's National Water Program 2012 Strategy (EPA 2012c) also includes a direct goal to "support IWRM in the water utility sector to sustainably manage water" and it establishes three strategic objectives:

- Understand and promote IWRM through technical assistance through the use of water supply management strategies
- Evaluate, and provide technical assistance on the use of water demand management strategies
- Increase cross-sector knowledge of water supply climate challenges and develop watershed specific information to inform decision making.

Examples of Professional Society and Non-Governmental Organization Approaches to IWRM

The American Water Resources Association (AWRA) has long supported the concept of developing and implementing IWRM in the U.S. by providing leadership, facilitating discussions, and highlighting IWRM at conferences, including at the second and fourth National Water Policy Dialogs (AWRA 2005 and AWRA 2008). In addition, it helped frame and lead the discussions on IWRM at the 6th World Water Forum in 2012.

In 2011, the AWRA Board of Directors formalized its support for IWRM by publishing a board policy on IWRM (AWRA 2011):

> *The American Water Resources Association recommends that water management goals, policies, programs, and plans be organized around the concept of Integrated Water Resources Management (IWRM), the coordinated planning, development, protection, and management of water, land and related resources in a manner that fosters sustainable economic activity, improves or sustains environmental quality, ensures public health and safety, and provides for the sustainability of communities and ecosystems. The American Water Resources Association calls on policy makers, planners and managers at national, tribal, interstate, state and local levels to encourage collaborations, policies, programs and plans that embrace Integrated Water Resources Management.*

The policy paper also points out that this effort will take a national commitment to: provide clean water as a basic human right and as an economic and ecological necessity, planning for long term sustainability, participatory decision making, management based on sound science and hydrologic units, realistic measurement of outcomes, and continuous improvement of institutional capacity at all levels.

Recently, AWRA published a review of the history of IWRM and provided seven case studies relative to the development and implementation of statewide (e.g., California and Oregon), large river basin (e.g., Delaware River and Minnesota River Basins) and smaller river basin (e.g., Rio Grande River, St. Johns, and Yakama River Basins) IWRM programs (AWRA 2012). This assessment used GWP's three "Areas to Facilitate Change for IWRM Implementation" framework for evaluating the programs. This framework includes "an enabling environment" (e.g., policies, legislative framework and financing and incentive structures), "institutional roles" (e.g., creating an organizational framework and institutional capacity building), and "management instruments" (e.g., water resources assessment, plans for IWRM, demand management, social change instruments, conflict resolution, regulatory instruments, economic instruments, and information management and exchange).

Similar to Kennedy et al.'s (2009) assessment of international IWRM programs, AWRA's (2012) review indicates there are a relatively limited number of documented IWRM case studies available for the U.S., that the scales and approaches employed by these IWRM projects varied widely and that there are a number of common issues and approaches between the various projects (Table 3).

In addition, four key themes emerged from the case studies (AWRA 2012). These include each organization's commitment to sustainability, adaptive management, collaboration, information collection and sharing, and providing adequate funding. The study states that a strong commitment to

Table 3. Summary of selected organizations implementing IWRM in the U.S. (AWRA 2012).

	California Regional	Delaware River Basin	Oregon State	Middle Rio Grande Basin	Minnesota River Basin	St. Johns River Basin	Yakima River Basin
Policies and legislative framework	State legislation	Interstate compact	State legislation	State policy	Federal legislation	State legislation	Federal funding
Financing and incentive structures	Federal, state and local[1]	Federal, state and local	Federal, state and local[1]	Federal, state and local[1]	Federal, state and local	Federal, state and local	Federal, state and local
Organizational framework	Broad stakeholder group	Established interstate/ federal	Broad stakeholder group	Local and non-governmental organizations	Federal, state, tribal and local	Established by state authority	Broad stakeholder group
Institutional capacity building	Broad institutional capacity building		Place-based capacity building	Capacity building tools	Capacity building tools	Capacity building tools	
Water resources assessment	Surface water supply	Surface water supply	Surface water supply	Surface water & groundwater assessments	Surface water supply	Surface water, groundwater & ecosystems assessments	Surface water supply
IWRM plans	Developed IWRM plans	Developed IWRM plans	Developed IWRM plans	Developed IWRM plans	Modeling assessment	Modeling assessment	Developed IWRM plans
Demand management	Conservation/ efficiency programs	Conservation/ efficiency programs	Conservation/ efficiency programs	Conservation/ efficiency programs	Demand management	Conservation/ efficiency programs	Conservation/ efficiency programs
Social change instruments	Includes social change	Includes social change	Includes social change	Includes social change	Includes social change	Includes social change	Includes social change
Conflict resolution	Via regional plans	By institutional design	Guiding principal	Via regional plans		By institutional design	In development
Regulatory instruments		Water quality & groundwater protection	Ballast water management[4]	Domestic well controls	Agriculture drainage[5]		
Economic instruments	Water pricing & grants		Stream restoration credits	Conservation rate structures			Tools developed
Information management and exchange	Information storage protocols	Modeling tools[6]	Information and data management tools[4]	Modeling tools	Decision support system	Withdrawal & ecological impact trade-offs	Modeling tools
Holistic management	Holistic & integrated[7]	Holistic & integrated[7]	Holistic & integrated[7]	Holistic & integrated[7]	Holistic & integrated[7]	Holistic & integrated[7]	Holistic & integrated[7]

	California Regional	Delaware River Basin	Oregon State	Middle Rio Grande Basin	Minnesota River Basin	St. Johns River Basin	Yakima River Basin
Economic, social & ecological purposes	Balanced ecosystem & economics/ social justice	Balanced ecosystem& economics	Balanced ecosystem& economics	Balanced ecosystem& economics	Balanced ecosystem& economics	Balanced ecosystem& economics	Balanced ecosystem& economics
Iterative process	[8]	[8]	[8]	[8]	[8]	[8]	[8]
Public and stakeholder engagement	Solicited public input	Solicited public input	Solicited public input	Solicited public input	Solicited public input	Solicited public input	Solicited public input
Government coordination	State framed local lead, consults at all levels	Commission lead, consults at all levels	State lead consults, at all levels	State framed local lead, consults at all levels	Federal lead state partner consults at all levels	District lead consults at all levels	State lead, federal partner consults at all levels

1. Includes additional local funds and local in-kind survives
2. Includes education programs and professional training
3. Includes education programs
4. Recommended
5. Studies conducted to inform potential future regulations
6. Separate tools are being developed to model landscape change, water supply needs, ecological flow needs, water quality and influences on ecological systems, and range of intensities of floods and droughts
7. Addressed water quality, water quantity, balance consumptive use, and environmental needs; groundwater considered coastal, where appropriate
8. "Most" in the initial stages of iterative IWRM spiral.

sustainability is key to implementing IWRM. This includes a commitment to "balancing economic, environmental, and social equity needs for current and future generations, and holistic management of the entire water resource at the watershed or basin level." It also indicates that adaptive management is essential to facilitating progress towards meeting water management goals in the face of complexity and finite resources. Finally, it found that collaboration and coordination are necessary to meet the information demands of IWRM programs, because IWRM programs are data and information intensive. In fact, the study found that a lack of resources, information, data, and decision-support tools were the greatest obstacles faced by the projects reviewed.

It should be noted that the Western Governors' Association (WGA 2008) has advocated for the development of an IWRM at the federal level, although few states have actually developed and/or implemented their own IWRM programs. According to the WGA (2008):

> *The Western States Water Council (WSWC) should urge Congress to require federal water resource agencies to include "Integrated Water Resources Planning and Assistance" as one of their primary missions, with the goal of:*
>
> *(a) changing the way water planning is conducted by encouraging more comprehensive plans developed under state leadership with federal assistance; and*
>
> *(b) reducing inefficiencies caused by the present mode of project-specific responses to competing demands, contradictory actions by multiple state, local and federal water agencies, and hastily conceived reactions to the latest real or perceived crisis.*

Both the WGA and the WSWC have indicated that they endorse the development of IWRM-like programs for the management of federal projects by federal agencies and the development of a national IWRM framework. However, both WGA and WSWC have indicated that they would be very resistant to the development of a federal IWRM program that dictates to the states how to manage waters under the state's purview. Although few state have developed or indicated that they are developing IWRM-based programs, several states, most notably California (CADWR 2013), Nebraska (Nebraska Revised Statue 46-715) and Oregon (OWRD 2012), have developed state water plans that explicitly develop statewide or local/regional IWRM or IWRM-like strategies and plans.

The American Water Works Association (AWWA) advocates the practice of "Total Water Management" which it defines as (AwwaRF 1996):

> *Stewardship of water resources for the greatest good of society and the environment.*

Grigg (2008) states that total water management, conceptually and in practice is very similar to IWRM in that it is a holistic approach to solving water problems. One of the basic principles of total water management is that "water supplies are renewable; however, they are limited, and therefore, they should be managed on a sustainable use basis" (Grigg 1998). Furthermore, he states:

Taking into consideration local and regional variations, Total Water Management:

- *Encourages planning and management on a natural water systems basis through a dynamic process that adapts to changing conditions;*
- *Balances competing uses of water through efficient allocation that addresses social values, cost effectiveness, and environmental benefits and costs;*
- *Requires the participation of all units of government and stakeholders in decision-making through a process of coordination and conflict resolution;*
- *Promotes water conservation, reuse, source protection, and supply development to enhance water quality and quantity; and*
- *Fosters public health, safety, and community good will.*

The Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE) has been developing IWRM-related policies, guidelines, and standards for a number of years (ASCE 2001, 1998a, 1998b, 1997, and EWRI 2007). In 1990, the EWRI began an extensive assessment of existing state water policies and laws throughout the U.S. to develop model state water codes for the U.S. While not explicitly stated, these model water codes were designed and developed largely based on the concept of integrated water resources management.

Two model codes were designed to provide an integrated policy and law framework to inform state policy makers how they can better manage water resources within their jurisdictions in a more integrated manner. The "Regulated Riparian Model Water Code" (ASCE 1997) provides a model for the eastern U.S. and the "Prior Appropriation Model Water Code" (EWRI 2007) provides a model for the western U.S. A third model code, "Guideline for Development of Effective Water Sharing Agreements" (EWRI 2013) was developed for managing transboundary waters. It is based on a mix of eastern and western U.S. and international water laws. Combined, these model codes could provide a holistic body of water policy and law for the integrated and sustainable administration of water resources throughout the U.S.

While these model water codes provide many policies and provisions for all aspects of regulating state waters in the U.S., five policies are particularly critical relative to helping develop a model IWRM framework for in the U.S. (ASCE 1997 and EWRI 2007):

1. Protecting the Public Interest in the Waters of the State (§ 1A-1-01 and §1R-1-01)
2. Conformity to the Policies of the Code and to Physical Laws (§ 1A-1-04 and 1R-1-03)

3. Atmospheric Water Management (§ 1A-1-16 and § 1R-1-15)
4. Coordination of Water Allocation and Water Quality Regulation (§ 1A-1-10 and § 1R-1-09)
5. Sustainable Development (§ 2A-2-31 and § 2R-2-24).

In totality, these policies confirm the state's ownership and responsibilities for managing water allocation and use within their jurisdiction; they encourage states to develop integrated water policies and management approaches based on the physical laws which "govern the occurrence, movement, and storage of water," including systematically linking the management of all hydrologic compartments (i.e., atmospheric, surface, vadose, and ground waters); and they encourage the integration of water quantity and water quality management into a single process to help achieve water resources sustainability.

Viessman and Feather (EWRI 2006) conducted one of the only nation-wide reviews of state water plans in the U.S. They observed that the majority of the states have developed formal water resources plans and that state water plans are often fashioned after federal water plans. They also observed that the nature and scope of state water resources planning has evolved from single-purpose, to multiple-purpose, to multiple-objective, and now towards more integrated planning and management (i.e., addressing the true spatial, temporal, environmental, and institutional dimensions of the water management problem). In addition, they observed that state water plans vary considerably between their scope, content, and level of detail (EWRI 2006).This assessment evaluated 28 key components that the authors consider to be important for state water planning (Table 4), which provides a nice baseline for assessing the "state of the states" relative to their potential for developing and implementing holistic, integrated water management plans and programs.

Viessman's and Feather's (EWRI 2006) results show that approximately 60% of the states have formal published water plans. However, some states use other methods or processes for planning and documenting their state water programs (e.g., state budget funding documents). Almost all states include stakeholders in their planning processes; however, they vary relative to who they formally include in their stakeholder process and the collaborative processes and tools they employ in their planning process. The planning scope also varies between the states (e.g., integrated planning, comprehensive planning, compartmentalized planning, or water-supply only planning processes).

Table 4. State water resources planning framework.[1]

Function	Components Assessed by EWRI (2005)	Number of States
State water plan	Published state water plan	31
	Goal, mission, and vision statement	48
	Plan implementation strategy	38
	Plan revision timetable	28
Stakeholder involvement	Direct stakeholder involvement	49
	Federal agency involvement	32
	Local government involvement	42
	Non-governmental organization involvement	45
	Coordination/collaboration strategy	38
	Use of shared vision planning	8
Planning scope	Integrated planning process	17
	Comprehensive planning process	21
	Compartmentalized planning	26
	Water supply planning only	5
	Drought management component	26
	Flood damage reduction component	22
	Climate change considered	4
	Sustainability considered	15
	Adaptive management considered	7
Resource characterization	Regional, river basin or watershed component	49
	Surface water component	40
	Groundwater component	31
	Water quantity component	41
	Water quality component	40
Monitoring and assessment	Monitoring strategy	41
	Continuing assessment and appraisal	34
Research	Research component	9
Education	Education component	24

1. Adapted from an unpublished review table developed by EWRI (2005).

Of specific interest, 17 states utilize what the authors classify as “integrated planning” processes. The authors don’t specifically define the details of “integrated planning,” but they state that it is a process that “recognizes the true spatial, ecosystem, and institutional dimensions of the planning problemshed and their interactions” (EWRI 2006). In addition, they state that in the future they believe that integrated water planning and management will be more widely accepted as a state goal” and that “the true dimensions of the water problemshed, and the linkages among its physical, spatial, environmental, social, and institutional dimensions will be addressed.”

The geographic scale for planning also varies between states. Some states develop statewide plans, other states conduct planning in selected geographical areas, and some states implement more than one planning approach within their state.

Table 4 also shows that about half of the state water plans include flood (44%) and drought (52%) planning. However, only a few of the state plans address climate change (8%), sustainability (30%), or adaptive management (14%) strategies. In addition, the analysis shows that most state water planning is conducted on a regional, river basin, or watershed basis (49%); about 80% of the plans assess surface water; about 60% assess groundwater; about 80% assess water quality; and about 80% assess water availability. Approximately 80% of the plans include water monitoring programs and almost 70% include a continuing assessment and appraisal process for evaluating monitoring results. Very few states include a research component (18%) within their planning process; however, almost half of the states include an education component (48%).

These numbers indicate that many of the states are already implementing many of aspects of an IWRM program. However, it appears that there is much room for improvement if the goal is to develop a more holistic, systematic, and integrated approach to water resources management in the U.S.

Barriers to Implementing IWRM in the U.S.

Extensive discussions were held on the challenges and opportunities associated with implementing IWRM at the Second National Water Policy Dialog. A key finding was (AWRA 2005):

> *There is a need to address the nation's water issues in an integrated manner dealing with watershed-level problems. Obstacles to integrated approaches include: a) the absence of clear policy promoting integrated water resources management; b) the presence of multiple, often conflicting, agency mandates and priorities; c) the lack of coordinating mechanisms and forums for dealing with differences among agencies and among stakeholders; and d) the lack of adequate scientific data to permit basic understanding of complex physical and biological issues and to facilitate good decisions.*

The Corps' recent report points out similar findings (USACE 2010a). That is, there has been some progress toward developing and implementing IWRM in the U.S.; however, other efforts have been hindered by a number of factors including:

- A lack of common definitions of terms, approaches, and decision frameworks
- Governance issues
- Data and model needs

- Economic and political factors
- Disjointed and uncoordinated planning across state boundaries and agencies
- Fragmented and conflicting authorities
- Unclear, conflicting, or overlapping agency responsibilities.

Some of these barriers likely could be solved relatively quickly and easily if the appropriate parties choose to do so. However, some governance, social, political, and economic factors are deep seated issues that historically have been and will likely continue to be significant impediments to implementing IWRM in the near future.

For example, issues such as developing common definitions, approaches and decision frameworks, and selecting and developing the most appropriate data and models could be largely conceptualized and developed through academic, professional society, state, and/or federal working committees. Determining the most common and appropriate terms usually can be agreed upon relatively quickly and easily, if the parties are willing to work together. In addition, determining the best models available and the data needed to drive them is typically a technical evaluation based on the best models currently available to do the job and the amount of funding available for developing/maintaining models and collecting the data necessary to populate those models. These issues can generally be addressed relatively quickly via technical committees in coordination with the appropriate managers and/or policy-makers who control the budget.

Economic factors are generally more difficult to determine relative to how much funding is available and agreeing upon the economic priorities within a given area/jurisdiction. Even more difficult is determining and agreeing upon the real and/or perceived economic benefits from developing and managing water resources and deciding who should receive those benefits. Addressing economic issues will likely take longer to address than the technical issues above.

It is popular in natural resources debates to talk about “win-win” solutions. However, in the distribution and use of a finite resource (most water resources are seasonally finite), there are generally winners and losers. Those individuals or groups that get adequate amounts of water, of adequate quality, when and where they need it on a regular basis are “winners,” those that do not are “losers.” Winners and losers typically fight, politically or otherwise, to maintain their winnings or to become winners. It is this ongoing competition between the winners and losers that shape many governance and political debates that occur in state capitals and in Congress on a regular basis, and this competition will likely continue *ad infinitum*.

Disjointed and uncoordinated planning across state boundaries and between transboundary agencies is the general rule early in the development of transboundary sub-basins and watersheds and it generally remains such until an important/critical resource becomes stressed. Once a resource becomes overstressed, coordination and planning generally will be worked out between adjoining states; either though cooperation and coordination, through the courts or, occasionally, through congressional action.

Finally, fragmented and conflicting agency authorities and unclear, conflicting, or overlapping agency responsibilities probably reflect the battles between the winners and losers discussed above more so that a given state, tribal, or federal bureaucracy's inability to implement rational and coordinated policies and laws. These issues may be due to the historical development of agencies that were initially not well thought out or properly focused, or the *ad hoc* development of agencies whose roles were not well thought out relative to the roles of other agencies, and the political/bureaucratic inertia that maintain them. However, at times, it is likely that fragmented and conflicting authorities and responsibilities are intentionally designed and maintained in order to achieve a desired result(s) such as providing a favorite user group or agency the opportunity to gain additional control over an issue or an advantage over a competitor. Since important advantages may be gained or lost, it is often very difficult to implement reforms to reduce fragmentation, conflicts, and overlapping agency responsibilities in these cases once they have been established.

Summary of IWRM Objectives Relative to U.S. Water Policy and Law

IWRM has developed and evolved over the past 50 or so years primarily in the international realm; however, recently there has been interest in the potential of implementing IWRM in the U.S. The formal concept of IWRM was developed through the international water community and formally approved by the UN at the Earth Summit in 1992 (UNCED 1992b). A growing number of organizations believe that IWRM can provide a much more holistic and systematic approach to water resources planning and management that can greatly improve our current fragmented and often narrowly focused planning, management, and/or operations paradigms in the U.S.

Using the most universally accepted definition (GWP 2000), IWRM is defined as:

> *A process, which promotes the coordinated development and 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.*

Although this definition has been criticized as being overly broad and vague (Biswas 2008 and 2004), it appears to be appropriate in that IWRM must be adaptable to many different locations and under many different physical, socioeconomic, and environmental conditions that exist in the U.S. That said, there must be some core goals and activities that establish the basis for determining what constitutes an IWRM program and what may be considered IWRM-like or not IWRM-like *per se*.

Agenda 21 provides nine objectives for managing freshwater resources in general and nine objectives for IWRM (Table 1). These objectives can be broken down in seven general categories. Each of these categories should be considered relative to implementing IWRM in the U.S. although they should be considered in light of U.S.-based conditions, needs, policies and laws, and customs and traditions.

The first category is related to balancing human and environmental needs. According to Agenda 21, the overall objective for IWRM is to satisfy the freshwater needs of water users for their sustainable development (18.7). Sustainability includes satisfying basic human needs while safeguarding ecosystems (18.8) by ensuring that adequate supplies of water of good quality are maintained for human use while preserving the hydrological, biological, and chemical functions of ecosystems (18.2). Protecting water resources includes taking into account the functioning of aquatic ecosystems and the perenniality of the water resources (18.8). This includes developing and utilizing innovative technologies including the improvement of indigenous technologies to fully utilize limited water resources and to safeguard water resources against pollution (18.2).

Sustainable development is defined as “The development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987). It directly infers balancing long-term social, economic, and environmental needs such that both humans and the environment can survive and prosper. Water resources sustainability includes developing long-term water supplies of sufficient quantity and high quality in the right place at the right time to meet human needs without significantly impacting the environment.

Satisfying basic human needs has been the primary focus of federal and state land, water, and other natural resources policies and laws for over 200 years. Protecting human health has been another area of focus for 100 years or so (e.g., the Rivers and Harbors Act of 1899). Protecting natural resources has also been discussed for many years. For example, although the term would not be coined for another 80 years, in a 1907 speech to Congress, President Theodore Roosevelt sounded very much like an advocate for sustainable development when he stated (Billington, Jackson, and Melosi 2005):

> *...there must be the look ahead, there must be a realization of the fact that to waste, to destroy, our natural resources, to skin and exhaust the land instead of using it so as to increase its usefulness, will result in undermining in the days of our children the very prosperity which we ought by right to hand down to them amplified and developed.*

Such concepts as "safeguarding ecosystems by preserving the hydrological, biological and chemical functions of ecosystems," "protecting water resources by taking into account the functioning of aquatic ecosystems and the perenniality of the water resources," and "developing and utilizing innovative technologies to fully utilize limited water resources and to safeguard water resources against pollution" are relatively new. Although they are called out specifically in Agenda 21 in 1992, they have been to a large extent, hallmarks of U.S. environmental laws since the 1960s and early 1970s (e.g., Clean Water Act, Safe Drinking Water Act, and Endangered Species Act). Finding a sustainable balance between the human needs and environmental protection has been a goal of many water resources organizations and professionals in the U.S. (ASCE 1997, Cardwell et al. 2006, CEQ 2013, EPA 2012c, EWRI 2007, NRC 1999, and USACE 2014 and 2010). Without such regulations and efforts by various organizations to balance economic development and environmental protection, the U.S. risks the potential of returning to the "good ole days" of denuded landscapes, large fish kills, polluted drinking water, and burning rivers.

The second category includes understanding and administering water resources based on the physical laws and properties that control the storage and flow of water and integrating the management of the lands that impact the storage, flow, and quality of water resources in a holistic manner. IWRM calls for the understanding and management of all interrelated freshwater bodies, including both surface water and groundwater considering both water quantity and quality aspects (18.3) and the integration of land- and water-related planning and management at the level of the basin, sub-basin, or watershed (18.9). According to Evans (2006), conjunctively managing surface water and groundwater systems can:

> *…protect water quality, maintain ecological and riparian needs, improve security of supplies, lessen problems associated with droughts, and eliminate costly and environmentally damaging surface water distribution systems.*

However, in a decision concerning the Klamath Indian tribes in Oregon, the Ninth Circuit Court of Appeals pointed out (Paschal 1995):

> *Scientists have long delighted in pointing out to lawyers that all waters are interrelated in one continuous hydrological cycle. As a result, it has become fashionable to argue that an effective legal regime should govern all forms and uses of water in a consistent and uniform manner. The law is otherwise.*

This statement reflects the disconnection between many water and water-related policies and laws in the U.S. and the physical laws that govern the storage and flow of water. It is well understood scientifically that all interrelated freshwater bodies within a given hydrologic unit, including both surface water and groundwater, are hydrologically interconnected and that the quantity and quality aspects of water within that hydrologic unit are inextricably linked (Winter et al. 1998). Therefore, all hydrologically interconnected surface water and groundwater resources should be managed in an integrated manner. In addition, it is well understood scientifically that land management and use affects the quantity, quality, and timing of water flowing to surface waters and aquifers. Therefore, it is also important that the interaction between land and water resources be understood and lands be managed to help protect the surface water and groundwater resources within a given hydrologic unit.

The disconnection between man's laws and physical laws may reflect a failure on the part of state and federal policy- and decision-makers to develop a full understanding of the physical laws and processes that govern the storage and flow of water and the implications of the impacts of human development and use on water resources. However, in many cases, it is more likely that many policy- and decision-makers understand this connection, but are unwilling to make the hard choices to make man-made laws comport with the physical laws of nature, much to the detriment of both water users and the environment. In order to address the U.S.' water related challenges in an effective and robust manner in the future, federal, state, and tribal policy- and decision-makers need to develop more physically-based, systematic, and integrated policies and laws.

The third category is related to understanding and addressing the needs of the various sectors and interests within a given hydrologic unit. IWRM calls for the recognition that water resource development is multi-sectoral in nature, water resources must be developed in the context of socio-economic development (18.3), and there are many diverse interests in the development and utilization of water resources (18.3). IWRM calls for promoting a dynamic, interactive, iterative, and multi-sectoral approach to water resources management. This includes the identification and protection of potential sources of fresh water supply that integrate technological, socio-economic, environmental, and human health considerations (18.9). It also includes planning for the sustainable and rational utilization, protection, conservation, and management of water resources based on community needs and priorities within the framework of the appropriate state, tribal, and/or national economic development policy (18.9). Finally, IWRM calls for designing, implementing, and evaluating projects and programs that are both economically efficient and socially appropriate within clearly defined strategies, based on an approach of full public participation, including that of women, youth, indigenous people, and local communities in water management policy-making and decision-making (18.9).

There are many people that live in any given hydrologic unit that use or otherwise have specific interests and needs associated with the management of water-related resources. IWRM advocates meeting the interests and needs of those stakeholders (often represented by sector or interest groups); however, doing so within the context of national plans and programs that provide the socio-economic context and framework for water resources development. Because of the water governance structure in the U.S., such an approach would have to account for the socio-economic goals and constraints associated with federal, state, and tribal governments. In addition, IWRM calls for water resource planning and decision-making to be based on full public participation by those who are interested in or affected by the policy decisions being made. This means that stakeholders not only need to be allowed to participate, but that policy- and decision-makers actually need to understand what the public needs/desires and factor those needs/desires into their policy decisions, as appropriate.

Each of these aspects has been well integrated into U.S. federal law since the passage of NEPA in 1969. NEPA requires all federal agencies evaluate and give proper consideration to the potential impacts of their actions on the environment, including water resources, prior to initiating a major federal action that could significantly affect the environment. It also requires those agencies to inform the public, gather input from all concerned individuals and organizations, and consider their input (both positive and negative) prior to initiating those actions. Such requirements also permeate the various versions of the Principles and Guidelines for water resources development (CEQ 2013) and federal environmental justice policies (EPA 2012d).

The fourth category is related to two potentially contentious aspects of water resource management. These include adapting human activities within the capacity limits of nature (18.2) and charging water users appropriately (18.8).

Based on the American concept of individual freedom, U.S. citizens can generally live and work wherever they desire and most states and municipalities actively promote moving to their state or municipality. Most people migrating to new towns and cities presume that whatever basic resources (e.g., water) they need and/or desire will be made available to them relatively cheaply. This presumption is based on historical state and federal government policies subsidizing or directly developing many of the basic resources.

For example, the federal government provided cheap land in the arid west and it developed many of the water resources necessary for protecting/sustaining human life and for promoting economic development throughout the U.S. homesteading era (1862–1934) (e.g., via the Reclamation Act of

1902 and the various Rivers and Harbors Acts) (Adams 1993). Therefore, rather than people naturally moving to where water and other natural resources could sustain them, the federal government (with encouragement of state governments and delegations) developed and moved water (e.g., via the development of the Colorado, Columbia and Snake Rivers, central Utah and central Arizona projects, Central Valley project in California, Missouri River, Platte River, Rio Grande, and the Arkansas River projects) and it encouraged and subsidized transportation (e.g., via construction of dams and navigation infrastructure) for the movement of goods and resources to the places where it wanted people to settle.

Many, if not most of the federal (and private sector) water projects in the arid west fully utilized the hydrologic capacity of the original project area and then needed additional funding and resources (subsidies) to improve, maintain, and/or expand their capacity. This has often meant government funded infrastructure improvement projects and importing water from other hydrologic units at ever increasing distances (e.g., historically, the central Utah and central Arizona projects, and currently the Southern Nevada Water Authority's scheme to import water from Snake River Valley in Utah and Nevada). At times, this has meant fully extinguishing the available water resources locally and/or regionally (e.g., Los Angles depleting the Owens Valley and the Colorado River Compact States and Mexico extinguishing the Colorado River prior to reaching the Gulf of California).

In very few cases did/do the direct beneficiaries of federal projects pay the full cost of development and few pay the full cost of operating and maintaining those projects. However, in today's climate of reducing taxes and with reducing the functions and roles of state and federal government, direct beneficiaries will not be able to rely as much on federal technical and funding support; hence, they will likely have to rely on smaller, self-funded projects where beneficiaries pay a larger percentage, if not the full cost of developing, operating, and maintaining their water systems.

The fifth category is related to combating vectors of water-related diseases (18.2); developing water conservation and waste minimization measures (18.3); and developing flood prevention, flood control, and sedimentation control measures (18.3).

These are generally standard activities that occur in the U.S., often via federal-state and/or public-private partnerships. For example, many states authorize quasi-governmental mosquito control districts (e.g., Massachusetts [MA 2015] and Washington [MRSC 2015]) and monitor and address water-borne diseases through state and local public health districts (Georgia 2015 and Idaho 2015). Flood prevention/control measures are often standard practices for all water projects, including construction activities near water bodies (FEMA 2011). In addition, conservation/waste minimization and sedimentation control are often promoted, where necessary or beneficial, or are required by state law (Title 30 Texas Administrative Code, Chapter 295.9.; the California Water Conservation Act of 2009, SB X7-7 2009) and federal laws or programs (EPA 2015; Soil and Water Resources Conservation Act of 1977, 16 U.S.C. 2001-2009; Flood Control Act of 1944, P.L. 78-534; and the Watershed Protection and Flood Prevention Act of 1954, P.L. 83-566).

The sixth category is associated with having and/or developing the appropriate institutional and legal frameworks and providing sufficient financial support for understanding and managing water resources. IWRM calls for identifying, strengthening, or developing the appropriate institutional, legal, and financial mechanisms to ensure water policy and its implementation are a catalyst for sustainable social progress and economic growth (18.9).

The federal government (e.g., Reclamation Act of 1902 and the various Rivers, various Harbors Acts, Soil and Water Resources Conservation Act of 1977, and Flood Control Act of 1944) and each state (EWRI 2006) have established policies, laws, and (in most cases) management plans that are intended to provide the framework and catalyst for sustainable social progress and economic growth. How comprehensive, how inclusive, and how well each of these policies, laws, and plans meet the needs and expectations of those who implement or are governed by them is largely dependent on who is assessing them, when, and in what context.

It is clear the interactions between federal, state, and tribal government policies, laws, and plans are complex and often disjointed and contentious. This is largely due to numerous factors associated with managing common water resources under separate but interdependent authorities and responsibilities, and differing needs and desires for using and/or preserving those resources at the various geographic and political scales (Figure 1). For example, the federal government has constitutional authority over the states and Indian tribes in the U.S. for water quality, as provided under the U.S. Constitution. However, the ownership and authority to manage water resources (e.g., water allocation) was largely given to the states and, from a practical standpoint, in a more limited measure, to Indian tribes as "sovereign dependents" of the federal government. That said, the federal government has retained authority over such aspects as navigation and water quality, which are inextricably linked to water development and use and both can impact multiple states and Indian reservations within a single body of water; hence, often leading to multijurisdictional conflicts.

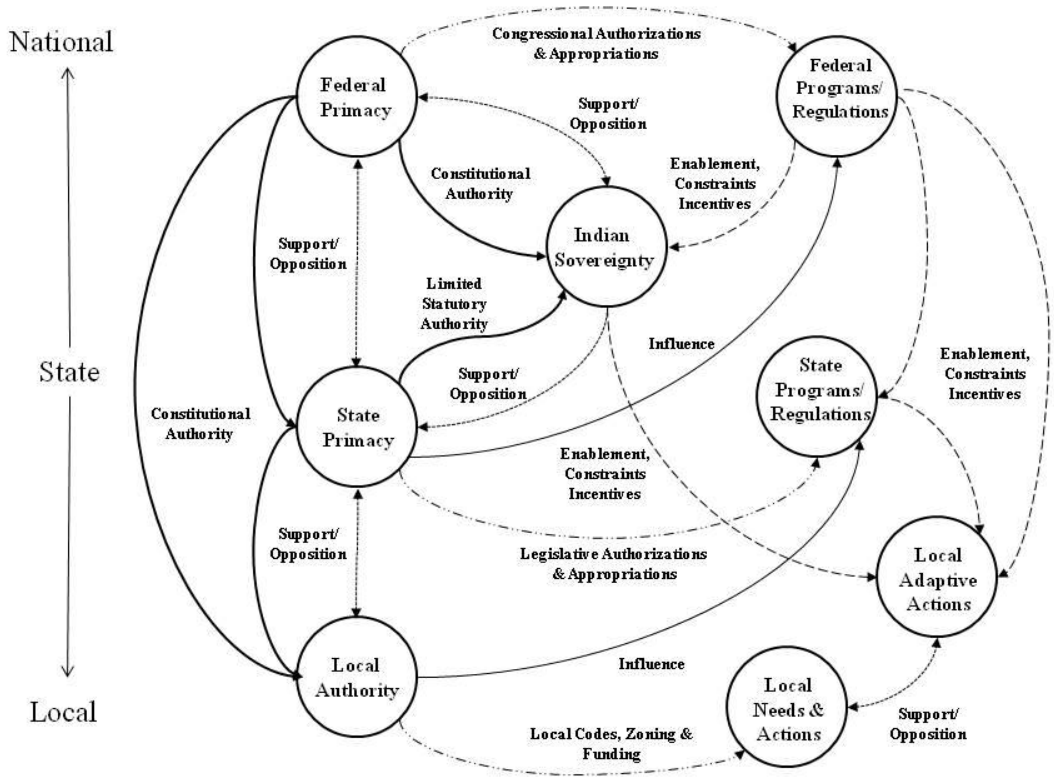

Figure 1. Interactions and feedback between various levels of government (after Wilbanks 2007).

The seventh and final category is related to transboundary water resources. IWRM calls for riparian "states" (countries, states, and tribes) to formulate water resources strategies, prepare water resources action programs and consider, where appropriate, the harmonization of those strategies and action programs (18.10). Under the Supremacy Clause of the U.S. Constitution, transboundary water resources, whether international (i.e., between the U.S. and either Canada or Mexico), interstate (i.e., between two or more U.S. states), or between an Indian tribe and either a state or federal government, are under the purview of the federal government. However, any policies or laws (e.g., treaty, compact, or agreement) developed or implemented on transboundary water resources impact each "state" that is riparian to the body of water in question. The U.S. has long held water-related treaties with its international neighbors, including the Boundary Water Treaty of 1909 and the Columbia River Treaty of 1961 (NWPCC 2013a) with Canada (IJC 2012), the Conventions of 1906, 1933, and 1963, and the Treaty of 1944 with Mexico (IBWC 2013a). In addition, there have been at least 45 water-related interstate compacts and/or commissions in the U.S. (USF&WS 2010). Finally, there have been an increasing number of settlements and agreements between Indian tribes and states through adjudications and agreements. However, almost all of these treaties and most compacts, settlements, and agreements are focused on surface water management and few (e.g., the Delaware River Basin Compact) are holistic, governing water quantity, quality, and other water-related resources such as land management. None of the treaties, compacts, settlements, or agreements reviewed fully addressed water resource management in a holistic and integrated manner as advocated by IWRM.

Therefore, although some have argued that IWRM is an international approach to water resource management that does not have any bearing on the water management in the U.S., it is clear that most of the objectives espoused by IWRM actually do fit many U.S. water management needs and objectives. In fact, many of these objectives are already being practiced in the U.S. The primary disconnections appear to be in three categories. The first category is managing common water resources under separate but interdependent authorities and responsibilities. The second category is the extent to which U.S. water and water-related laws do not necessarily recognize or at least do not emphasize the physically-based laws of nature that govern the storage and flow of water in the hydrosphere. The third category is the U.S.'s unwillingness to limit growth within watersheds/sub-basins based on the hydrologic capacity or charge water users appropriately. These are the three categories that would likely provide the most benefits from implementing an IWRM approach.

Summary and Conclusions

The concept of IWRM began developing in the 1950s based on the efforts and consensus of many individuals and organizations (Falkenmark and Lundqvist 1992, Koudstaal, Rijsberman and Savanije 1991, Snellen and Schhrevel 2004, UN 1958, and WCED 1987). The final principles and objectives were adapted at the Earth Summit in Rio de Janeiro in 1992 and they were documented in Chapter 18, "Protection of the Quality and Supply of Freshwater Resources," of the UN's Agenda 21 (UNCED 1992b). The most commonly accepted definition of IWRM is (GWP 2010);

> *A process, which promotes the coordinated development and 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.*

Program Area A of this chapter establishes the basis for action, objectives, activities, and means of implementation for developing IWRM programs. Overall, IWRM provides an overarching policy framework for managing water and-water related resources in a holistic, systematic, and integrated manner.

Although the concept of IWRM was largely fostered by the international water community, many individuals and organizations in the U.S. were critical participants in its development (e.g., the Harvard Water Program). Currently, most IWRM programs are being developed and implemented internationally (Kennedy et al. 2009 and UN-Water 2008). Overall, the results are mixed (Hassing et al. 2009, Kennedy et al. 2009, and UN-Water 2008) and "there is much room for further improvement" (UNDESA 2012).

In fact, some authors have been rather skeptical about the practicality of implementing IWRM because the concept may be too vaguely defined and because water-related issues may be too heterogeneous (e.g., physically, socioeconomically, institutionally, and governance-wise) and complex (e.g., the impacts and interdependence of various water-related sectors) to be integrated throughout the world under a single IWRM paradigm or framework (Biswas 2008, 2004, and 2001). However, other authors have found examples where the implementation of IWRM and IWRM-like programs has been successful (Hassing et al. 2009). Therefore, it appears that it can be a useful approach/tool for better managing water resources given the right circumstances; however, it may be difficult to implement.

The difficulties associated with implementing IWRM are not very clear in the literature. However, it is presumed that Biswas' (2008, 2004, and 2001) observations are correct in many cases. IWRM is a complex approach to managing water resources. Most countries assuredly have the capacity to understand the concepts and the benefits of an IWRM approach. However, it is likely that many underdeveloped countries do not have the governance, institutional, scientific, management, and infrastructural capacity to implement such a complex process. Therefore, it is likely not the lack of understanding and desire; it is likely the lack of capacity necessary to implement the IWRM process that has impeded many countries from implementing IWRM. That is not the case for the U.S.

The U.S. water community has continually adjusted its water policies, laws, and the management of water resources over time to meet new needs and growing demands for water and addressing new and growing water-related environmental challenges (NEPA 1969). Viessman and Feather (EWRI 2006) observed the nature and scope of water resources planning in the U.S. has evolved from single-purpose, to multiple-purpose, to multiple-objective, and now towards more integrated planning and management. For example, many water resources professionals and organizations in the U.S. have advocated for better integration of economic, environmental, ecological, physical, and social impacts into natural resources management (ASCE 2010a, ASCE 1998a, ASCE 1998b, AWRA 2012, AWRA 2011, AwwRF 1986, CEQ 2013, EPA 2013, Grigg 2008, Naiman 1992, NDWAC 2010, NEPA 1969,

NRC 1999, NWC 1973, WRC 1973, WRC 1983, and WWPRAC 1988). However, attempts to actually develop and implement more physically-based holistic, systematic, and integrated approaches at the appropriate scales (e.g., at the watershed or sub-basin scale), have been mixed in the U.S. due to a number of barriers (AWRA 2005 and USACE 2010a).

Most of the barriers in the U.S. are associated with governance and institutional fragmentation. The U.S. has sufficient scientific, management, and infrastructure capacity to manage water and water related resources in an integrated manner. In addition, it has an abundance of water and water-related policies and laws, and agencies and organizations to manage these resources. However, many of these policies and laws, and the roles and responsibilities of the agencies and organizations are fragmented, disjointed and in many cases at odds with each other. Much of this is due to the fragmented authorities and the divergent needs, goals, and desires associated with the multi-tiered (e.g., federal, state, tribal, and private sector) structure/approach to water management in the U.S. Further fragmentation occurs longitudinally when multiple authorities have jurisdiction over a single resource (e.g., rivers and aquifers that occur/flow through multiple states and/or reservations). Especially in the western U.S., the institutionalization of water rights as “private property” establishes an often adversarial relationship between government agencies and the private sector.

While IWRM has been evolving and becoming more accepted throughout the world over the past 50–60 years, it is not clear whether this approach will fully succeed internationally or whether the U.S. water community is ready and/or willing to embrace the implementation of the formal IWRM process, as described in Agenda 21 (UNCED 1992). However, it is clear that water and water-related resources in both the U.S. and internationally are becoming over-stressed by over-allocation, pollution, significant modification of water bodies, and the degradation of water and water-related ecosystems. In order to meet the water and water-related needs of present and future populations in the U.S. in a more effective and robust manner, the U.S. water community must manage those resources in a more holistic, systematic, and integrated manner.

A famous quote often attributed to Winston Churchill is “You can always count on Americans to do the right thing - after they’ve tried everything else.” As more and more stresses are placed on water and water-related resources in the U.S., it will become imperative that the U.S. water community embrace more advanced science and technologies and more holistic, systematic, and integrated approaches to governance and institutions. When/how will the U.S. water community choose to do so is another question? Will it choose to develop and implement such policies and practices in a thoughtful and deliberate manner, *a priori* to potentially impending crises? Or will it wait until it is in a crisis, such as the current drought emergencies being experienced in California?

In either case, whenever the U.S. water community chooses to move forward with the development and implementation of a more holistic, systematic, and integrated approach to water management, in part or whole, its success or failure will largely rest on the strength of policies and laws that either require or at least support an IWRM or IWRM-like approach. Therefore, it is critical to understand the primary objectives of IWRM and decide whether they meet the needs and objectives of the U.S. water community. To the extent that the objectives do meet the U.S. water community's needs and objectives, it is recommended that the community evaluate existing U.S. water and water-related policies and laws, institutional structures, and management practices against the IWRM framework to determine if they can be used to effectively and robustly support those objectives, if they need to be modified for implementation, or if new ones need to be developed to implement an IWRM or IWRM-like framework in the U.S.

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CHAPTER 3: A CONCEPTUAL HYDROLOGICAL MODEL FOR DEVELOPING AND IMPLEMENTING INTEGRATED WATER RESOURCES MANAGEMENT OBJECTIVES IN THE U.S.

Introduction

Throughout much of its history, the United States (U.S.) has developed its natural water resources to increase the quantity and the certainty of water supplies available for beneficial use by humans and to protect human populations and infrastructure from extreme events and water borne diseases (Adams 1993 and Reuss 1991). Federal, state, and local agencies and the private sector have invested enormous amounts of funding and resources to develop and implement both structural and non-structural approaches to improve the delivery of water supplies, balance the needs of various water users and water sectors, mitigate the impacts of extreme floods and droughts, and protect human health. More recently, they have also invested large sums to reduce the impacts of water development and use on the environment.

Yet, many watersheds and aquifers in the U.S. are fully- or over-allocated (Konikow 2013). The U.S.' critical water and water-related infrastructure are in poor health. For example, the most recent Report Card for America's Infrastructure (ASCE 2013) ranked the condition of U.S. dams, drinking water systems, and waste water systems as D, and its levees and inland water ways as D- (on a scale of A to F, with F being the lowest grade). Human developments (e.g., farm fields) and infrastructure (e.g., homes, offices, and factories) are increasingly in harm's way from extreme hydrologic events which are causing increasingly higher monetary damages (Smith and Katz 2013). In addition, from an environmental perspective, water quality is degraded (EPA 2013), environmental flows are greatly reduced or extinguished (Arthington et al. 2006, Poff et al. 2009, Poff et al. 1997, and USGS 2013a), ecosystems are degraded (Belsky, Matzke, and Uselman 1999; and Kauffman 1997), and many aquatic and riparian species are becoming listed as threatened or endangered throughout the U.S. (USFWS 2011).

Adding to these dilemmas, climate change is projected to increase the uncertainty associated with future availability of water supplies and further impact water quality in many basins in the U.S. (Bates et al. 2008 and Shi et al. 2013). The question is whether we can find a more effective and robust approaches to sustainably manage our water resources and to balance the needs of both humans and the environment.

In a decision concerning the Klamath Indian tribes in Oregon, the Ninth Circuit Court of Appeals pointed out (Paschal 1995):

> *Scientist have long delighted in pointing out to lawyers that all waters are interrelated in one continuous hydrological cycle. As a result, it has become fashionable to argue that an effective legal regime should govern all forms and uses of water in a consistent and uniform manner. The law is otherwise.*

From many hydrologists' perspective, such a statement is an anathema. However, from a legal perspective, it is probably a true statement that simply reflects the disconnection between many water and water-related policies and laws in the U.S. and the physical laws which govern the storage and flow of water. Unfortunately, this disconnection likely reflects a failure on the part of state and federal policy- and decision-makers to develop a full understanding the physical laws and processes that govern the storage and flow of water and the implications of the impacts of human development and use on water resources and their failure to adapt policies and laws which comport with the physical laws of nature. In order to address these challenges in a more effective and robust manner, federal, state, and tribal policy- and decision-makers need to develop a more systematic and integrated approach to managing U.S. water resources in the future.

A growing number of organizations believe that Integrated Water Resources Management (IWRM) can provide a more holistic, systematic, and integrated approach to water resources management (AWRA 2011, AwwaRF 1998, and USACE 2010). IWRM is most commonly defined as (GWP 2009):

> *A process, which promotes the coordinated development and 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.*

Broadly, IWRM (UNCED 1992) calls for developing a comprehensive and integrated approach to governing, understanding, and managing water and water-related resources within the context of a basin, sub-basin, or watershed (generically known as hydrologic units in the U.S.). It calls for, in part, (UNCED 1992):

- *The protection and conservation of potential sources of freshwater supply, including the inventorying of water resources, with land-use planning, forest resource utilization, protection of mountain slopes and riverbanks and other relevant development and conservation activities;*

- *Optimization of water resources allocation under physical and socio-economic constraints; and*

- *Integration of water (including surface and underground water resources) quantity and quality management.*

In order to accomplish these goals, federal, state, and tribal agencies, and the private sector need to develop a more holistic, systematic, and integrated understanding and approach to managing water and water-related resources in the U.S. In addition, they need to convey to policy- and decision-makers the need to develop water resources policies and laws that are physically based and supportive of this approach.

This research provides a conceptual framework for developing a scientifically-sound, physically-based framework for developing and instituting more integrated water resource programs in the U.S. Within that context, it recommends the development of a "competent hydrologic unit" framework to evaluate and manage water resources in a more integrated manner, where it is deemed desirable or necessary to do so. In addition, it evaluates some of the major socioeconomic, policy/legal, and physical aspects of water resources management that may affect the availability of and the potenital for using water resources within a given watershed or basin.

Water Availability and Use in the U.S.

Water is ubiquitous in our daily lives. It naturally occurs as a liquid (e.g., rain), solid (e.g., snow or ice) or a vapor in the atmosphere; as liquid or ice in oceans and surface waters on land; as a liquid, snow or ice on the land's surface in glaciers, lakes, wetlands, and streams; as a liquid, vapor, or ice in the subsurface, either in the vadose zone (e.g., permafrost) or in fresh and saline aquifers (e.g., groundwater or permafrost); and as biologically-incorporated water or water vapor. The major water supplies on earth are summarized in Figure 2.

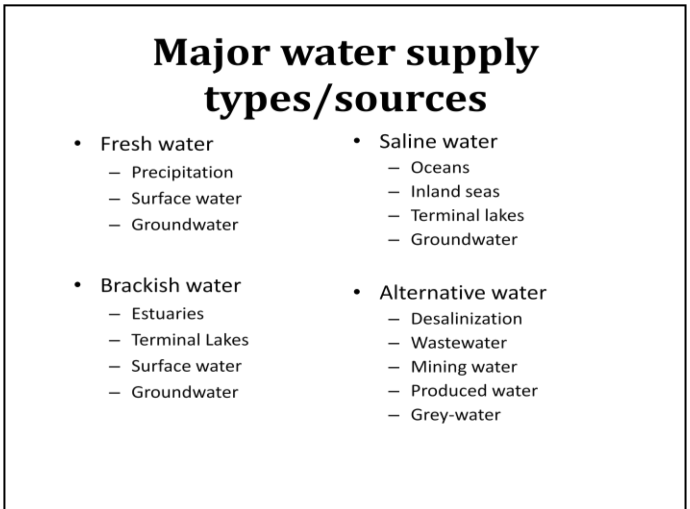

Figure 2. Primary sources of water on earth.

Contrary to popular misnomers, from a global perspective humans are not "using up" or "running out of" water (Lenton and Muller 2009) and in general, neither humans nor the environment are "making new water." The amount of water on earth is generally considered to be a finite, but infinitely renewable/reusable resource (Black 1996 and Healy et al.

2007). However, from a freshwater hydrologic-unit management perspective, water is an annually/seasonally finite renewable resource (Figure 3). Annual/seasonal precipitation and in-flows, in combination with longer-term natural and engineered storage, less evapotranspiration, and out-flows provide the total amount of water that is physically available to meet human and environmental needs within a hydrologic unit.

Taken on the whole, the U.S. has abundant supplies of water. However, natural water availability varies greatly around the country. For example, in the eastern U.S. from approximately the 100th parallel to the Atlantic Coast and the coastal areas west of the Cascade Mountains are generally "humid" climates. They can generally support crop growth and other needs based on the amount of water directly available to the land via precipitation (Figure 4).

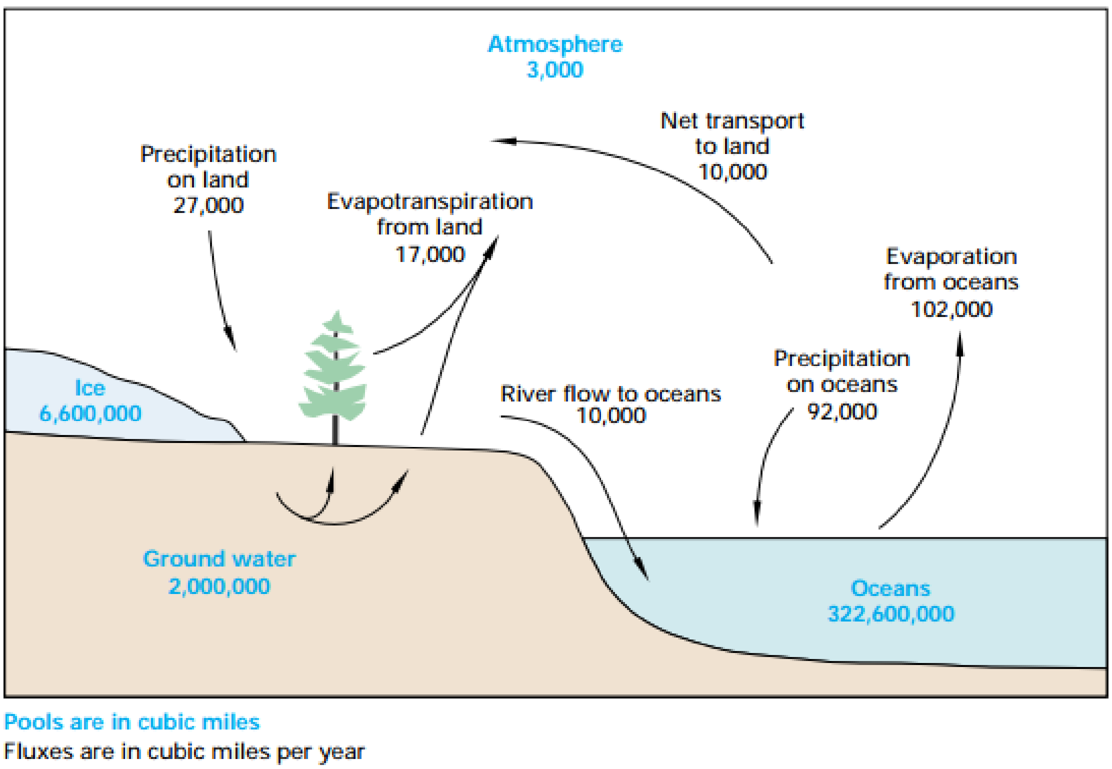

Figure 3. Schematic of the hydrologic cycle

Figure 4. Average precipitation in the U.S. (NA 2011).

The lands between approximately the 100th meridian and west to the Cascade Mountains are generally classified as either "semi-arid" (can grow limited types of crops) or "arid" (requires irrigation to grow crops). Water availability for meeting human and environmental needs in the arid/semi-arid west is largely based on capturing and using rain and snow which accumulates on the surrounding mountains; especially snowpack, which generally flows to the lower elevations as surface water or groundwater in the spring and early- to mid-summer.

Large-scale water use generally includes beneficial uses such as domestic, commercial, municipal, industrial, agricultural and energy production, navigational, and recreational uses. However, not all water uses are equal. The amount of water used and consumed and their impact on water quality and the environment varies greatly. Average water withdrawals in the U.S. were estimated to be 410,000 million gallons per day (Mgal/d); freshwater accounted for about 85% of those withdrawals (349,000 Mgal/d) with the remaining (61,000 Mgal/d) saline water (Barber 2009). Most saline-water withdrawals were seawater and brackish coastal water used to cool thermoelectric power or industrial plants. Smith, Belles, and Simon (2011) provide an informative breakdown of USGS's 2005 water use data (Barber 2009) that shows that thermoelectric power and irrigated agriculture are by far the largest users of water in the U.S. (Figure 5).

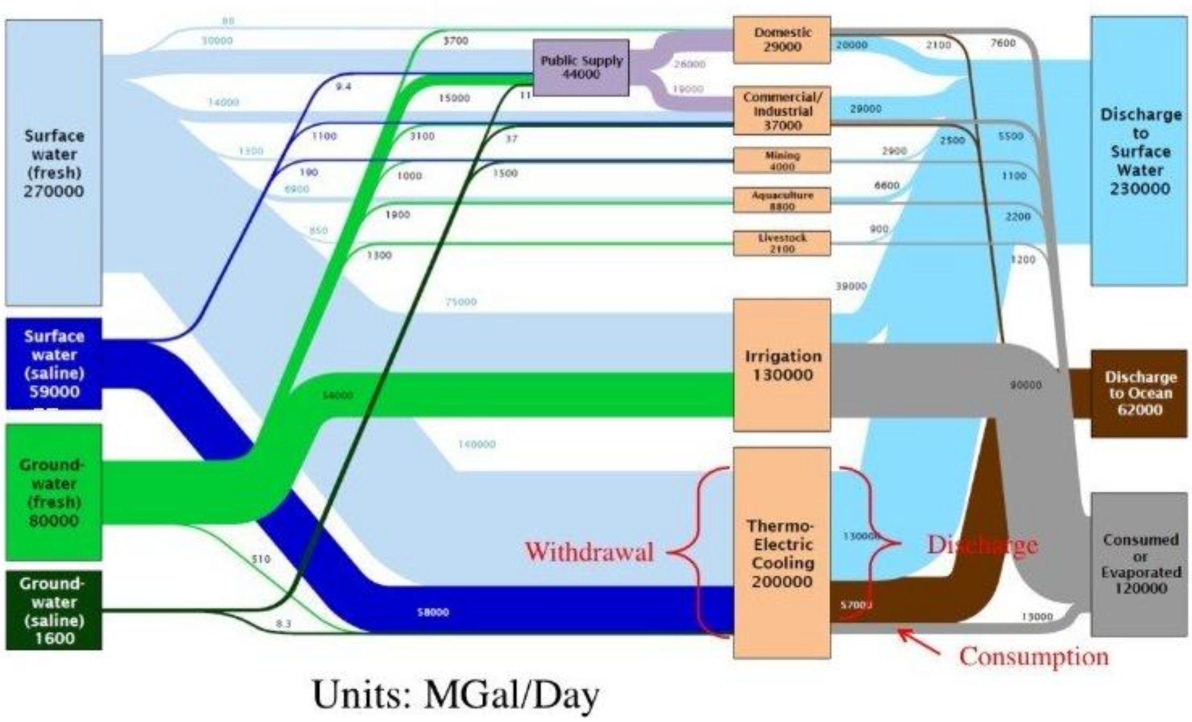

Figure 5. U.S. freshwater withdrawals and total freshwater consumption by beneficial use (Smith, Belles, and Simon 2011).

According to Barber (2009), a total of 130,000 Mgal/d of freshwater was withdrawn for irrigation, of which 76,000 Mgal/d was surface water and 54,000 Mgal/d was groundwater. A total of 200,000 Mgal/d of water was withdrawn for thermal power generation, of which 142,000 Mgal/d was freshwater and 58,000 Mgal/d of saline water. However, irrigation consumed a much larger percentage of water. Of the 130,000 Mgal/d, only 39,000 Mgal/d are returned to its source. The remaining 90,000 Mgal/d was either consumed or evaporated. Conversely, of the 200,000 Mgal/d of water diverted for thermoelectric power generation only13,000 Mgal/d was evaporated and the remainder was returned to its source. The amount of water used and consumed varies between each beneficial use (Figure 5), but those amounts consumed by each use will remain fairly characteristic.

However, the most important aspects of water availability and use are not well reflected in national averages. An evaluation of state- and county-level data shows that water availability and use varies greatly geographically, even in areas that are within close proximity of each other (Barber 2009 and Smith, Belles, and Simon 2011). Well-defined hydrologic units are hydrologically independent of each other; therefore, water supplies that are available for beneficial use in one may be very different from an adjacent hydrologic unit based on hydrologic unit-specific characteristics (e.g., being on the windward or leeward sides of a mountain range). In the end, water availability and the impacts of water use are based on the quantity, quality, timing and location of water, and the type and amount of use at the individual hydrologic-unit scale.

A Conceptual Model for Implementing IWRM in the U.S.

Many federal and state water policies and laws were written before the science of hydrology was developed, or at least before it fully matured, to address the full scope of a the hydrologic cycle with any level of certainty (Beck 1991a and Getches 1990). Since policies and laws are generally conservative, they tend to lag behind scientific advancements; hence, many existing federal and state water policies and laws are not well grounded in current science and knowledge (Paschal 1995). However, IWRM calls for a holistic, systematic, and integrated approach to understanding and managing water and water-related resources based on the best available scientific knowledge of the hydrologic cycle (ASCE 1997 and EWRI 2007).

In order to meet the overall IWRM objective to “satisfy the freshwater needs of water users for their sustainable development” (UNCED 1992), IWRM programs must develop a holistic approach that integrates and harmonizes water resources governance (policy and laws), socioeconomic policies and goals, and the physical and environmental aspects of water resources management. IWRM programs must develop the governance, institutional, scientific, and operational capacities necessary for implementing these activities. This includes developing water policies and laws that are scientifically-based such that they comport with the physical laws that govern the movement and storage of water (ASCE 1997 and EWRI 2006). In addition, IWRM calls for inventorying, developing, and managing all water resources as a unitary source from a hydrologic cycle perspective (GWP 2009 and UNCED 1992) at the appropriate basin, sub-basin or "catchment" (watershed) scale (AWRA 2011, AWRA 2005, UNCED 1992, and USACE 2010). The governance and institutional aspects of IWRM are addressed in Chapter 4. The physical aspects of IWRM are discussed as follows.

Hydrologic Cycles in Sub-basins and Watersheds

Effective/robust IWRM programs require a holistic, systematic, and integrated framework and a physically-base conceptual model for identifying, delineating, and linking hydrologically interconnected water resources in a consistent and scalable manner. Such models could be extremely valuable for visualizing, planning, monitoring, and managing hydrologically interconnected water resources and for managing, analyzing, and reporting the associated water resources related data. Although they are surely incomplete, two conceptual models are offered below. The intent of these models is to touch on each of the major aspects of IWRM and to show the hydrologic interconnections that need to be considered and potentially addressed in a fully competent, scientifically-based program to be implemented in a competent hydrologic unit. The conceptual models cannot provide all of the details necessary to fully understand all of the processes, but hopefully they can provide enough information in a systematic way to help stimulate decision makers, managers and researchers, and water users to consider water management in a more holistic, systematic, and integrated manner.

The freshwater hydrologic cycle is traditionally shown as originating from the evaporation of seawater from the oceans to the atmosphere, condensing and precipitating onto a hydrologic unit (Figure 3). From a hydrologic cycle perspective, the storage and flow through a hydrologic unit can be expressed using the general water balance equation:

$$P = Q + E + dS/t$$

Where:

dS/t	=	Rate of change of water stored
ET	=	Evapotranspiration (i.e., the sum of evaporation from soils, surface waters and plants)
P	=	Precipitation
Q	=	Water flow.

However, from an IWRM perspective, it is critical to also understand the details relative to the storage and flow of water within and between each competent hydrologic unit (Scanlon et al. 2002) because each of these aspects represents an opportunity to manage water more effectively and more sustainably (Figure 6). Note that within Figure 6 the subscript "gw" is saturated groundwater storage, or flow into, within or out of a unit; "bd" is bank discharge; "bf" is base-flow; "ld" is land; "of" is overland flow (e.g., runoff or flood flows onto land); "si" is snow and ice on the land surface; "sw" is surface water storage or flow into, within or out of a unit; "vz" is storage (e.g., water vapor) or vertical/horizontal flow of water in the vadose zone (e.g., infiltration through soil column, surface-water percolation, capillary/groundwater discharges to surface, or horizontal perched-water flow).

In addition, each of these aspects should be considered and evaluated relative to understanding and managing the presence, migration, and impacts of anthropogenic pollutants and natural contaminants.

Naturally Occurring Hydrologic Inputs/Outputs

From a hydrologic cycle perspective, all freshwater resources within an undeveloped hydrologic unit originate from precipitation (P), or from surface water (Q_{swin}) and/or groundwater inflows (Q_{gwin}) *from hydrologically connected up-stream/up-gradient hydrologic units* (Q_{gwin}) (Figure 6).

Precipitation (P) primarily falls on vegetation or impervious surfaces (interception), land surfaces or into surface-water bodies within a hydrologic unit. Precipitation (P) that is intercepted can return directly back to the atmosphere; this component is not typically accounted for or managed as part of a water management program. Precipitation (P) that falls on the land surface can be temporarily stored on the ground as depression storage (not normally tracked for water management purposes) or snow/ice ($S_{sw} + S_{si}$), it can evaporate back to the atmosphere (E), or it can run-off overland (Q_{of}) into surface water bodies/channels or it can infiltrate into the ground (Q_i).

*Surface water can flow t*hrough a channel (Q_{sw}), flow through or be stored in lakes, ponds, or wetlands ($Q_{sw} + S_{sw}$), it can overflow its banks onto the land surface, evaporate or be transpired (ET_{sw}) to the atmosphere, percolate into the ground (Q_p), or remain in a channel until it flows out of the hydrologic unit (Q_{swout}).

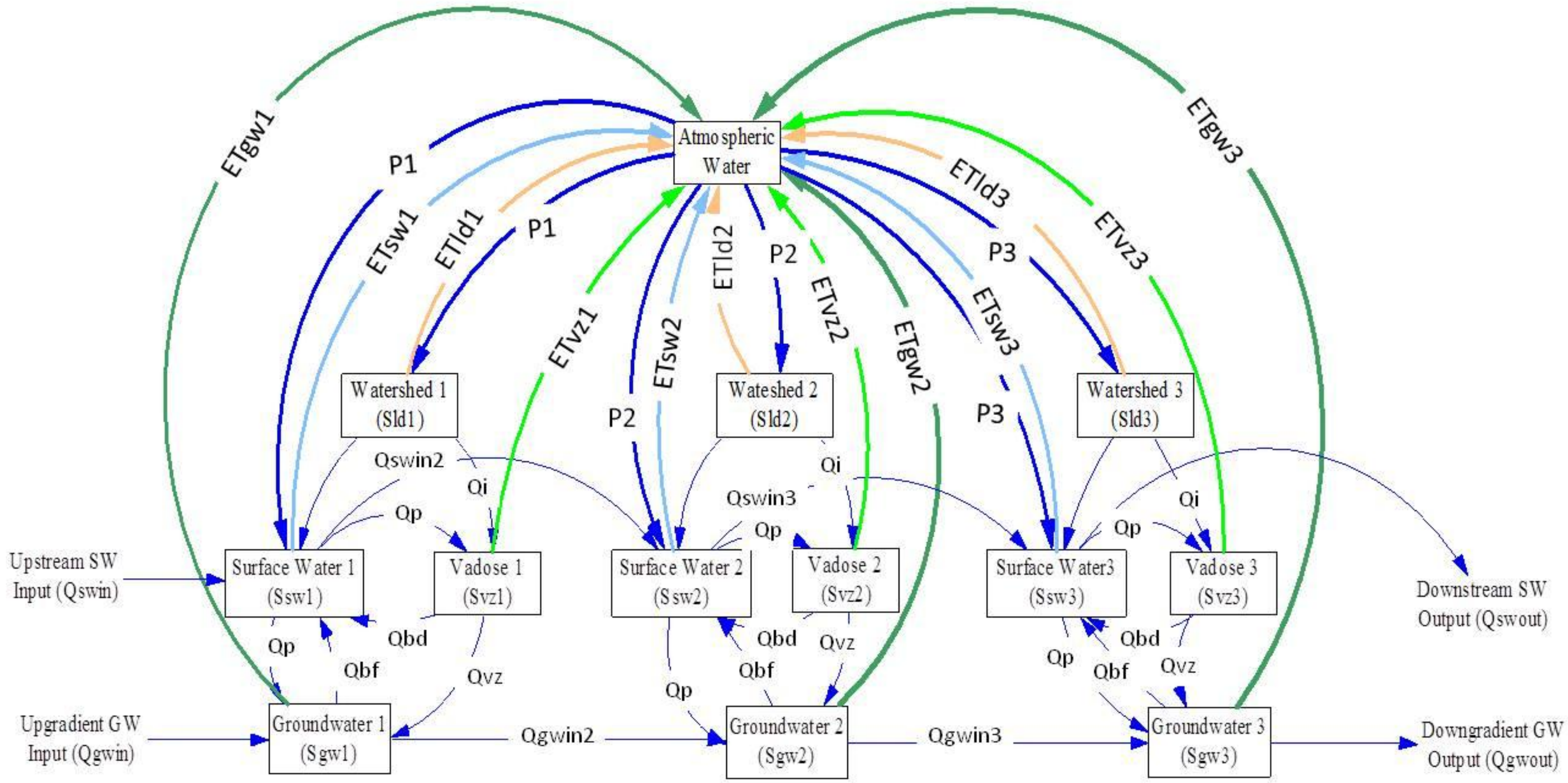

Figure 6. Generalized storage and flow of water through hydrologic units.

Essentially all water in the subsurface originates from the infiltration of precipitation through the land surface into the vadose zone (Q_i), percolation of water from surface water bodies (Q_p), or from groundwater inflows ($Q_{gw\text{in}}$) from an up-gradient hydrologic unit. Water that infiltrates (Q_i) into the vadose zone can become unsaturated soil moisture (S_{vz}), or it can become perched water storage or flow (S_{vz} + Q_{vz}). Water in the vadose zone can evaporate (E_{vz}) into the atmosphere via capillary forces or via the uptake and transpiration by plants (T_{vz}). Water that infiltrates into the saturated zone can become groundwater storage or flow (S_{gw} or Q_{gw}). Groundwater can evaporate directly into the atmosphere in springs and groundwater fed wetlands (ET_{gw}), flow through an aquifer (Q_{gw}), discharge to a surface-water body as base flow (Q_{bf}), or continue flowing underground out of the hydrologic unit ($Q_{gw\text{out}}$).

Eventually, all freshwater will leave an open hydrologic unit through evapotranspiration (ET) or it will flow from the point it enters the hydrologic unit to the lowest altitude in the hydrologic unit that it can achieve that is not blocked by a geological or other barrier. In an open hydrologic unit, water resources will naturally leave a hydrologic unit through surface water outflow *(*Q_{swout}*)* or groundwater outflow *(*Q_{gwout}*)* into another hydrologic unit and/or ultimately discharge to an ocean. Essentially all freshwater in closed hydrologic units will leave through evapotranspiration (ET) or terminate in hydrologic unit storage at the hydrologic low point of the hydrologic unit (e.g., a terminal lake or an aquifer), usually in a saline condition.

Water Availability

Precipitation that remains in the hydrologic unit (effective precipitation) in combination with surface water and groundwater inflows and existing hydrologic unit storage provides the maximum amount of water that is naturally available for use by humans and the environment. In humid regions, there is generally sufficient precipitation to meet environment and human needs (e.g., for agriculture) without being supplemented. In arid regions, precipitation must be artificially supplemented to meet the needs of most beneficial uses (e.g., irrigation). Supplemental supplies generally come from surface water withdrawals and/or groundwater pumping. However, the natural flow of water within a given hydrologic unit is not as simple as following a singular surface water or groundwater pathway. The flow may follow multiple, intertwined flow paths. Surface water and groundwater flows may stay separate or they may converge (e.g., surface water becoming groundwater and vice-a-versa) or water may evaporate and leave the hydrologic unit or it may evaporate and re-precipitate back into the hydrologic unit. These exchanges may occur many times in various parts of the hydrologic unit.

Further complicating our understanding and management of hydrologic unit water supplies, is the fact intentional or unintentional anthropogenic modifications to land and water resources can significantly alter a hydrologic unit's hydrologic cycle. In essence, any activities such as clearing land for agriculture and forestry purposes, compacting the land surface via activities such as grazing and urbanization, construction of impervious infrastructure (e.g., buildings and roads), armoring stream channels or shorelines, and other land-use changes can significantly alter the quality, quantity, timing, and/or location of surface water and groundwater supplies within a hydrologic unit.

For example, consideration must be given to anthropogenic sources of water (e.g., trans-hydrologic unit or sea-water imports) or exports of water to other hydrologic units (e.g., virtual or actual exports of water), the impacts of impounding and diverting surface water (e.g., withdrawals from streams, lakes, and wetlands), and the impacts of pumping and/or artificially recharging aquifers. However, the portion of a surface water withdrawals or groundwater pumping that is not consumptively lost to evapotranspiration remains in the hydrologic unit and can be discharged to the natural environment (return flows) for another beneficial uses or for environment flows (Figure 7). Return flows can be discharged back to their original source, transferred to another hydrologic compartment (e.g., groundwater withdrawals discharged to surface water bodies), or they can exported to other hydrologic units.

Both natural flows and return flows within a hydrologic unit may be iteratively and repeatedly withdrawn/pumped and returned to the hydrologic unit until they are either fully-consumed, become too polluted for a given use(s), are transferred out of the hydrologic unit, or until they naturally flow out of the hydrologic unit. Such reuse, from a water user perspective, is positive in that a single volume of water flowing through a hydrologic unit can be beneficially used multiple times. However, it should be noted that anthropogenic impacts to land and water resources can be either positive or negative. More specifically, in most cases, they will be positive for one portion of a hydrologic unit and negative for another; positive for one sector and negative for another; or positive for water users and negative for the environment (or vice versa). For example, from a water quantity perspective, dams change the timing of water flows and surface water diversions change the location of surface water flows; withdrawals from lakes and aquifers lower water levels and artificial recharge of lakes and aquifers can raise those levels; large scale consumptive uses can increase evapotranspiration, thereby reducing the amount of surface water or groundwater within a hydrologic unit and extensive infilling of wetlands and lakes can decrease water storage.

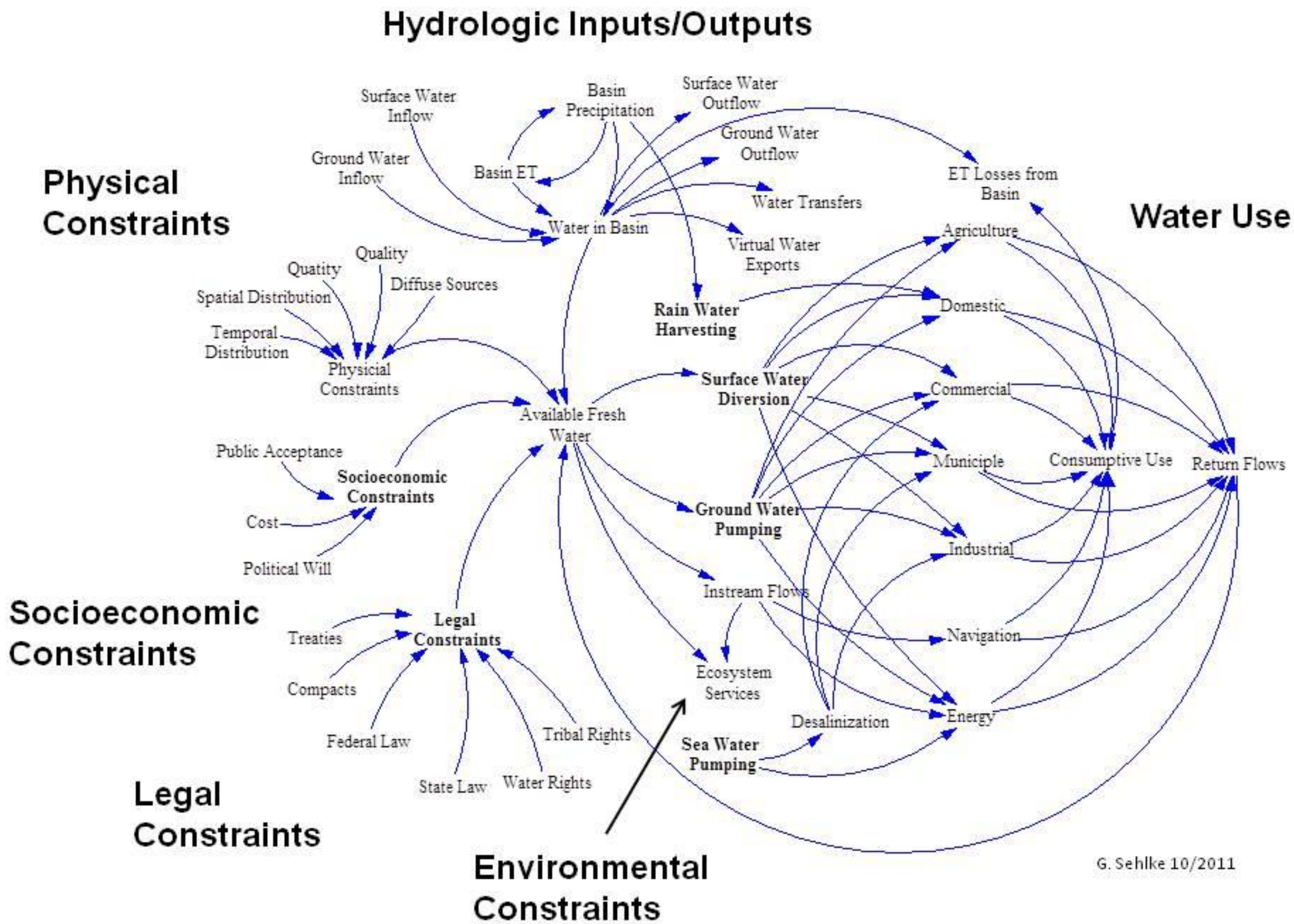

Figure 7. Example of a basin water cycle and potential water availability, beneficial uses, and constraints.

While the total quantity of naturally-occurring and anthropogenically-supplemented water available within a hydrologic unit establishes the maximum amount of water that is physically available for use by humans and the environment, the amount of water that is actually available for beneficial use can be reduced by poor water quality and a number of other physical, socioeconomic, legal, and/or environmental constraints. Some of these constraints can be seen in Figure 7.

Physical Constraints

Depending on the seasonal and annual precipitation and surface-water and groundwater flow patterns, water may not be available in sufficient quantities to meet the needs of all water users and/or environmental needs. Conversely, sufficient quantities of water may fall when and where they are needed; however, it may infiltrate/percolate into the ground or partition within the hydrologic unit in such a diffuse manner that it cannot be captured for beneficial use by humans or it may not available to various ecosystems or species.

Where precipitation falls and water flows into the hydrologic unit, and the specific flow path(s)/hydrologic compartment(s) that water flows through depends on the climatic conditions and hydrologic unit-specific physiographic characteristics. These factors may make large quantities of water naturally available in some areas and scarce in other areas within a hydrologic unit. In addition, the quality, quantity, timing, and location (both horizontally and vertically) of water storage and flows may be modified depending on how water is managed (e.g., diversion and impoundment) and used (e.g., consumptively or non-on-consumptively) by humans.

Poor water quality can also be considered a physical constraint. Anthropogenic pollutants, natural contaminants, sedimentation, and other physical alterations to water quality can impact the value and usability of a water source. For example, anthropogenic pollutants and naturally occurring windborne contaminants can be incorporated into atmospheric water and precipitate (e.g., acid rain) or suspended in the atmosphere (e.g., windblown salts or metals) and eventually precipitate or settle into a given hydrologic unit. In addition, surface water and groundwater inflows to a given hydrologic unit can entrain pollutants and contaminants from up-stream/up-gradient hydrologic units and transport them into down-stream/down-gradient hydrologic units. Those inputs, in addition to the anthropogenic land and water disturbances, uses/discharges, plus the naturally-occurring entrainment of constituents (e.g., minerals, soils, and biota) that occur within the hydrologic unit determine the total water quality with a given hydrologic unit.

Once pollutants and/or contaminants are deposited into a hydrologic unit, they can then be entrained into each component of the hydrologic unit's hydrologic cycle. For example, land-use changes may increase erosion, causing sedimentation and the release of harmful natural constituents (e.g., salts, minerals, and metals) into water bodies. Also, the discharge of anthropogenic pollutants (e.g., pesticides, fertilizers, hazardous chemicals, and radioactive wastes) by commercial, municipal and industrial activities, and urban, agricultural, and forest runoff in combination with natural contaminants can significantly degrade water quality and impact human health and the environment.

It should be noted that each of these pollutants and contaminants may flow through each of the flow pathways described above (i.e., atmospheric, surface water, vadose, and groundwater). As they flow through these hydrologic compartments, they may flow through conservatively. That is, unaffected by the surrounding environment. They may be partially or completely filtered out of the water through absorption/adsorption, partially or completely consumed by a biological process, and/or they may be partially or completely degraded by physical, chemical, or biological processes. Pollutants and contaminants that are not physically degraded by these processes may be diluted enough or sequestered and isolated enough such that they are not harmful to humans and/or the environment, or they may remain in high enough concentrations or even become concentrated (e.g., bioaccumulate) enough that they reduce the amount of water that can be used by humans or the environment or even cause significant direct harm to humans and/or the environment.

Without treatment, polluted and contaminated waters and waters laden with sediments may be unusable as supplies for certain types of beneficial uses (e.g., drinking water supplies or certain manufacturing and industrial processes). Untreated, polluted, contaminated, and sedimentation laden sources may harm water delivery and distribution infrastructure, and human and environmental health. Finally, if treatment is required for use, then the supply becomes more expensive to deliver; hence, it is less valuable.

Socioeconomic Constraints

The ability to use physically-available water within a hydrologic unit is also constrained by socioeconomic considerations. Social issues such as community preferences, historical practices and norms, and community and political issues can greatly affect whether a given region will be predominately pro-development or protective of the environment. Public acceptance and the buy-in of the appropriate stakeholders are and should be vitally important to shaping the development and management of water resources. For example, stakeholder sentiments directly influence the availability of public/private capital investments, social capital (e.g., whether there will be political support or rejection for a given project), and whether there will be legal objections raised against or restrictions placed on a given project.

Local customs also influence the use of existing water supplies and the viability of new water related activities and projects. For example, in some areas of the west, water allocation is regulated by strictly implemented, formal water rights systems whereas in other areas, despite equally formal water rights systems, water users choose to implement informal water sharing (e.g., informal "wheeling" of water) during droughts. In addition, local or regionally organized or *ad hoc* "movements" can occur where a subset of a given community engages public and/or private interests to either initiate or inhibit a given project despite general public acceptance or resistance to the proposed project (e.g., local farmers lobbying for or environmentalist protesting against the construction of a dam or levee).

Economics are often the primary factor for deciding whether a water project will or will not be developed. The economic "bottom line" applies to the owners (e.g., government agencies or private owners of the land and/or water rights), the developers and the regulators of the land, and water resources. In general, a private entity will not go forth with a proposed project unless it will provide sufficient profits to warrant the expenditure of funding and resources. Many states' water agencies will require proof that a water project is financially viable prior to issuing a permit to develop a water project. In addition, proposed federal water projects and federally-funded water projects must consider the general principles, objectives, and requirements contained in the recently implemented "Principles and Requirements for Federal Investments in Water Resources" (Principles and Requirements; CEQ 2013) and conduct benefit-cost analyses using the "Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies" (Principles and Guidelines; WRC 1983) to demonstrate that there will be sufficient economic and/or environmental benefits (a net positive benefit to cost ratio) to make it worthy of the federal investment

Legal Constraints

Legal requirements have a large bearing on whether a given water project will be required, allowed, or blocked. Many legal instruments have been developed over time including state and federal water quality and water appropriation policies and laws such as international treaties, interstate compacts, environmental laws, and Indian treaties. Generally, these legal instruments have been developed with the intent of providing some semblance of predictability and control concerning the financing, appropriation, and use of water resources; protecting access to water resources; protecting the physical integrity of natural water courses and bodies; and reducing the impacts of pollution discharges on water quality, human health, and the environment.

It has been a long established U.S. policy that, in general, states have ownership and authority over water resources within their jurisdictional boundaries (U.S. Supreme Court 1935, 1978). Therefore, each state has the legal authority to allocate (or not) the water resources within its jurisdiction, with a few exceptions. Because water allocation and management are primarily state functions, they are primarily responsible for developing and implementing the criteria and processes necessary to appropriate, allocate, and utilize water resources. In addition, they are primarily responsible for implementing the criteria and processes for protecting water resources, water users, and the environment from the negative impacts associated with water resources development.

Exceptions to state authority over the allocation and management of water may include un-adjudicated Federal Reserved Water Rights, when international or Indian tribal treaties are involved, when federally authorized water-related activities are conducted solely on federal lands, when an activity negatively impacts a federal project or activity that is specifically authorized by Congress (e.g., Bureau of Reclamation and Corps project authorizations), when there is an overriding federal interest such as the Commerce Clause, and/or when activities trigger the implementation of federal environmental protection laws.

Because the states have historically been focused on the socioeconomic benefits of land and water resources development and have given little deference to the protection of the environment, the federal government has retained broad authority over the regulation of water quality and environmental protection in the U.S. (Beck 1991b). These include many natural resource/environmental policies and laws (see Chapter 4). However, the primary water quality/environmental protection regulations in the U.S. of interest to water resources development include the Clean Water Act (CWA), the Safe Drinking Water Act (SDWA), and the Endangered Species Act (ESA). Each of these laws can establish restrictions on the development and use of water resources in order to protect human health and the environment.

Environmental Constraints

What constitutes an “environmental constraint” can be interpreted in several ways. For example, environmental constraints may be thought of as the physical limitations of environment to provide resources for development (e.g., limited ecosystem services). For example, there may be insufficient water supplies to meet human needs or desires. Or, it can be thought of as a point at which the environmental impacts associated with water resources development exceed regulatory or other standards; hence, development may be limited or curtailed.

The former example is primarily a physical supply issue that must be addressed via hydrologic, economic and engineering assessments, and tools. For example, quantifying the total hydrologic capacity a hydrologic unit by deciding if the benefits of development are worthy of the expenditures required to capture and deliver some or all of the hydrologic unit's potential supply and financing those costs, and designing and constructing the infrastructure necessary to capture, treat (if applicable), and deliver the supply where it is needed. At some point, there may not be enough water physically and economically available within a hydrologic unit to meet some societal needs and desires. At that point a decision must be made to either import supplemental water supplies from other hydrologic units or sources (e.g., desalinated sea water) or to limit further growth within the hydrologic unit.

The later example is largely a human construct. That is, the value society places on protecting and sustaining the environment will dictate how much impact it will allow development to have on the environment. All water resource developments by their very nature have some impact the natural environment. However, while some development projects may severely degrade some aspect(s) of the environment (e.g., associated aquatic or riparian ecosystems or extinguish some species), generally, societies will place limits on the level(s) of impact that will be allowed. The question is: how much environmental impact is socially acceptable?

For example, all surface-water impoundments inundate up-stream riparian and terrestrial lands block environmental flows at least to some extent, restrict migration of aquatic species, alter the quality of water in and below the impoundment (e.g., increasing water temperature and changing other physical and chemical properties), and they change the magnitude and timing of downstream flows.

Surface-water withdrawals affect the location of water by diverting flow from the natural channel to some other location and by decisions associated with determining if water is returned and where it is returned to the same stream channel. Diversions can reduce the amount of water available to an acceptable level or totally dewater the channel downstream of the diversion or somewhere in between. However, any diversion will affect the timing of flows (since flow velocity is head dependent) and it will affect water quality to some extent, based on how much water is removed from the stream channel, and the quality and location of return flows back into the channel.

The release of contaminants or pollutants into the atmosphere or onto the land may impact and discharge directly into surface water bodies or aquifers and thereby impact water quality.

Groundwater pumping and/or aquifer recharge will also impact the given aquifer, hydrologically interconnected aquifers and surface water bodies, and the environment. By removing water from an aquifer, pore pressure is reduced in the aquifer, thereby reducing water levels (in water table aquifers), or the potentiometric pressure (in artesian aquifers) reducing discharges to or increasing percolation from hydrologically interconnected surface water bodies, reducing discharges from associated springs, and potentially allowing for land subsidence.

Each of the above development-related activities can have either chronic or acute impacts on the associated water resources and hyporheic, aquatic, riparian, and potentially terrestrial ecosystems or species. How extensive those impacts may be are dependent on the type of activity, the specifics of the given hydrologic unit, water uses, the hydrologic capacity of the hydrologic unit, the location and intensity of those uses, the sensitivity of the associated ecosystems and species, and many other physical and biological factors. However, the total impacts of water development and water use on the environment will always be cumulative relative to both water availability and water quality, based on the sum of all water activities and uses within the given hydrologic unit.

How much impact society will allow water development to have on the environmental within a given hydrologic unit will depend on many of the socioeconomic and legal factors discussed above. In addition, it will depend on many other local, regional, and national considerations. In the U.S., these factors are largely encapsulated in local and state customs, and local, state, and federal water and environmental policies and laws. Each state has its own its own water and environmental policies and laws which reflect their specific customs, conditions, needs, and desires. On the federal level, these are reflected in water policies and laws like Reclamation Law, Corps project authorizations, the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA), land management policies and laws such as the Federal Land Management Policy Act, and in species protection policies and laws such as the Endangered Species Act (ESA). Each of these policies and laws establish criteria and/or restrictions on the development and use of water and water-related resources in order to protect land and water resources, human health, and the environment.

Competent Hydrologic Units

The connectivity between surface water and groundwater has been well known and described by scientists many years (Alley, Reilly, and Franke 1999; Butler et al. 1999; Jenkins 1968; Miller et al.

2007; and Winter et al. 1998). Many states have already established approaches for "conjunctively" administrating and managing their surface water and groundwater resources (i.e., administering and/or managing surface water and hydrologically interconnected groundwater resources as a single source) (Blomquist, Heikkila, and Schlager 2001; CDWR 2013; Delapenna 2013; Glasser et al. 2005; and Hazard and Shively 2011).

Several federal agencies have also discussed (Barlow and Leake 2012, and Galloway et al. 2003) and/or implemented conjunctive management approaches (CSU/USACE 2008, USBOR/CDWR 2008, and USFS 2007). In addition, the U.S. Geological Survey (USGS) has been conducting numerous assessments of the hydrologic, ecological, and biogeochemical processes associated with hydrologically interconnected surface water/groundwater systems as part of its National Water-Quality Assessment Program (USGS 2013b) and National Research Program (USGS 2015a). Unfortunately, some federal agencies such as the Bureau of Reclamation (BOR) do not believe that they have a direct role in conjunctive management; however, they may support state or local organizations which desire to implement conjunctive management (USBOR/CDWR 2008 and Peltier 2006).

Conjunctive management of hydrologically interconnected surface water and groundwater resources is essential for developing effective and robust IWRM programs (Winter et al 1998):

> *Effective policies and management practices must be built on a foundation that recognizes that surface water and ground water are simply two manifestations of a single integrated resource.*

A "competent hydrologic unit" framework should be designed to integrate all water and water-related data and information at the appropriate scale (e.g., basin, sub-basin, or watershed) across all three hydrologic compartments (e.g., atmospheric, surface water, and groundwater) (Figure 8).

A competent hydrologic unit is defined here as:

> *The full geographic extent of a hydrologically-distinct surface water unit and its hydrologically-distinct and interconnected groundwater unit, within a specified geographic area of interest.*

This framework could be developed by linking the best available USGS/Natural Resources Conservation Service (NRCS) surface water (hydrologic units), groundwater (principal aquifers), soil (e.g., STATSGO/SURGO) and other pertinent data, through the appropriate geographical information system (GIS) data/tools to develop a single, integrated interagency competent hydrologic unit framework for the U.S.

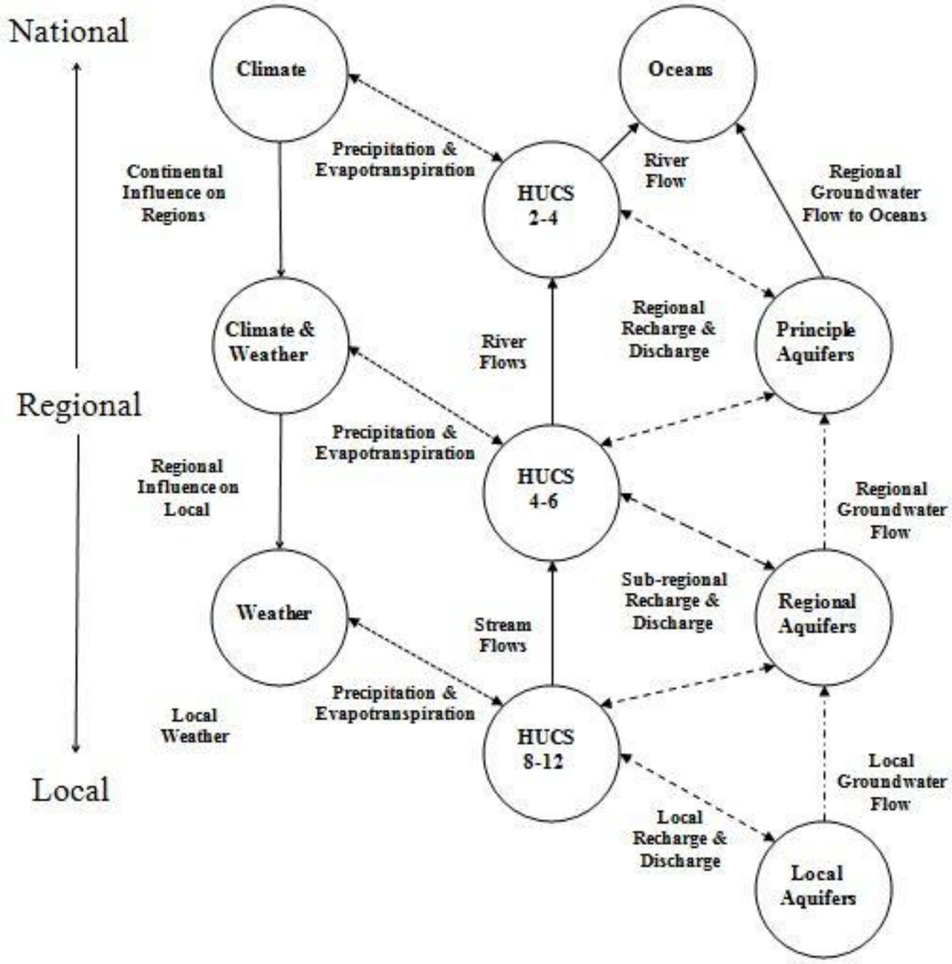

Figure 8. Generalized relationship between three hydrologic compartments at three scales.

Hydrologic Units

USGS established a seamless, scalable set of hydrologic unit boundaries to delineate the aerial extent of surface water drainages in the U.S. (Seber et al. 1987). This system subdivides the U.S. hierarchically into 21 regions (HUC Level 1) (Figure 9), 222 sub-regions (HUC Level 2), 352 basins (formally called accounting units) (HUC Level 3), and 2,149 sub-basins (formally called cataloging units) (HUC Level 4) (USGS 2013c). USGS and NRCS have further subdivided sub-basins into watersheds (HUC Level 5) and sub-watersheds (HUC Level 6) (NRCS 2013 and USGS 2013d). Overall, this system provides a hydrologically correct, seamless, and consistent national GIS database at a scale of 1:24,000 that matches to a minimum the USGS topographical 7.5 minute quad maps for land and water resources planning and management in the U.S. These results were digitized to develop the National Hydrography Dataset (NHD). This framework provides a systematic, nation-wide, scalable system for visualizing and assessing watersheds etc. and for organizing and managing water resources data.

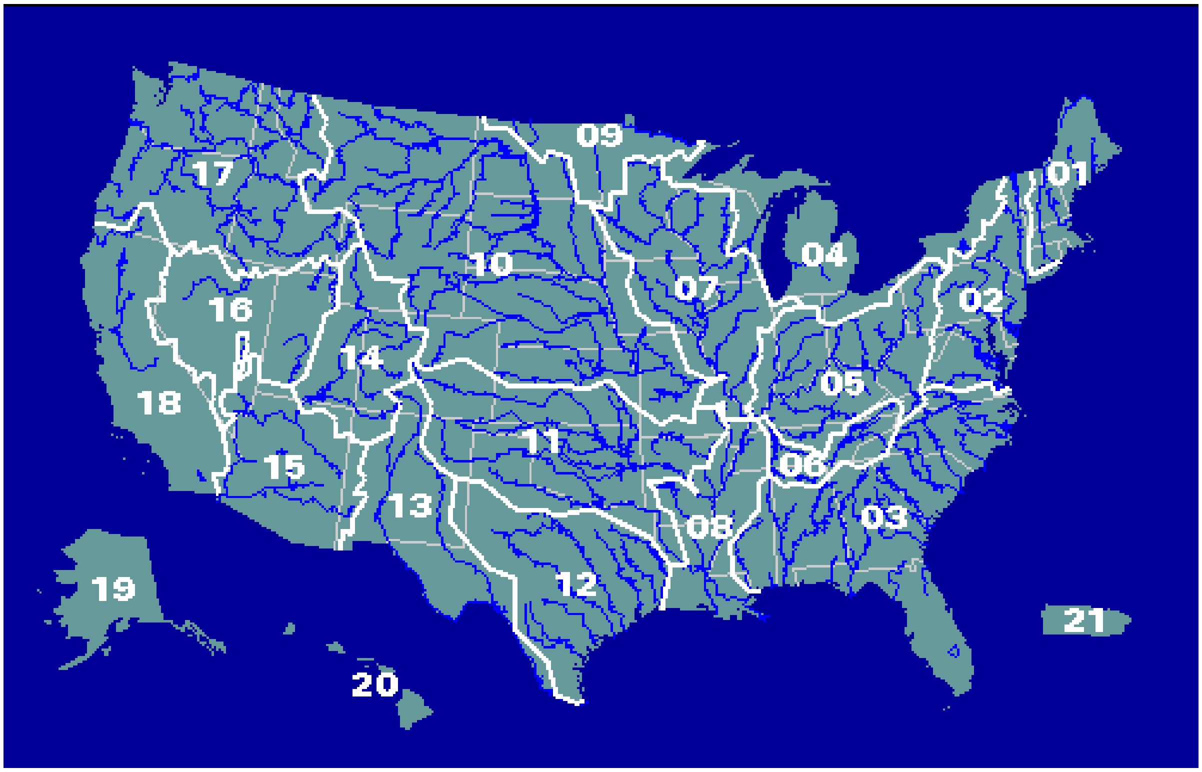

Figure 9. The 21 hydrologic regions in the U.S. (HUC Level 1; USGS 2013).

In the 1990s, the USGS and EPA expanded and refined the NHD framework to create the NHDPlus framework. NHDPlus includes and links all surface water features (e.g., lakes, ponds, streams, rivers, canals, dams, and stream gauges) at both medium (1:100,000) and high (1:24,000) resolutions. In addition, NHDPlus provides specific information (attributes) about the surface water bodies including flow directions, discharge rates, water quality, and fish populations in the context of the hydrologic unit boundaries established in the USGS Watershed Boundary Dataset (USGS 2013e).

Principal Aquifers

The USGS has mapped all national or principal aquifers in the U.S., Puerto Rico, and the U.S. Virgin Islands (Figure 10). The principal aquifers of the U.S. are defined as “regionally extensive aquifers or aquifer systems that have the potential to be used as a source of potable water” (USGS 2012). The USGS identified a total of 62 principal aquifers in the U.S. (USGS 2003). These aquifers were systematically mapped and published in the 1990’s as a series of 13 chapters in the Ground-Water Atlas of the United States (Miller et al. 1997), integrated into a single map in 1999 and digitized in 2003 (USGS 2003). The map layer was developed at a resolution of 1:2,500,000 and it generally contains the upper most aquifers and aquifers systems (USGS 2003).

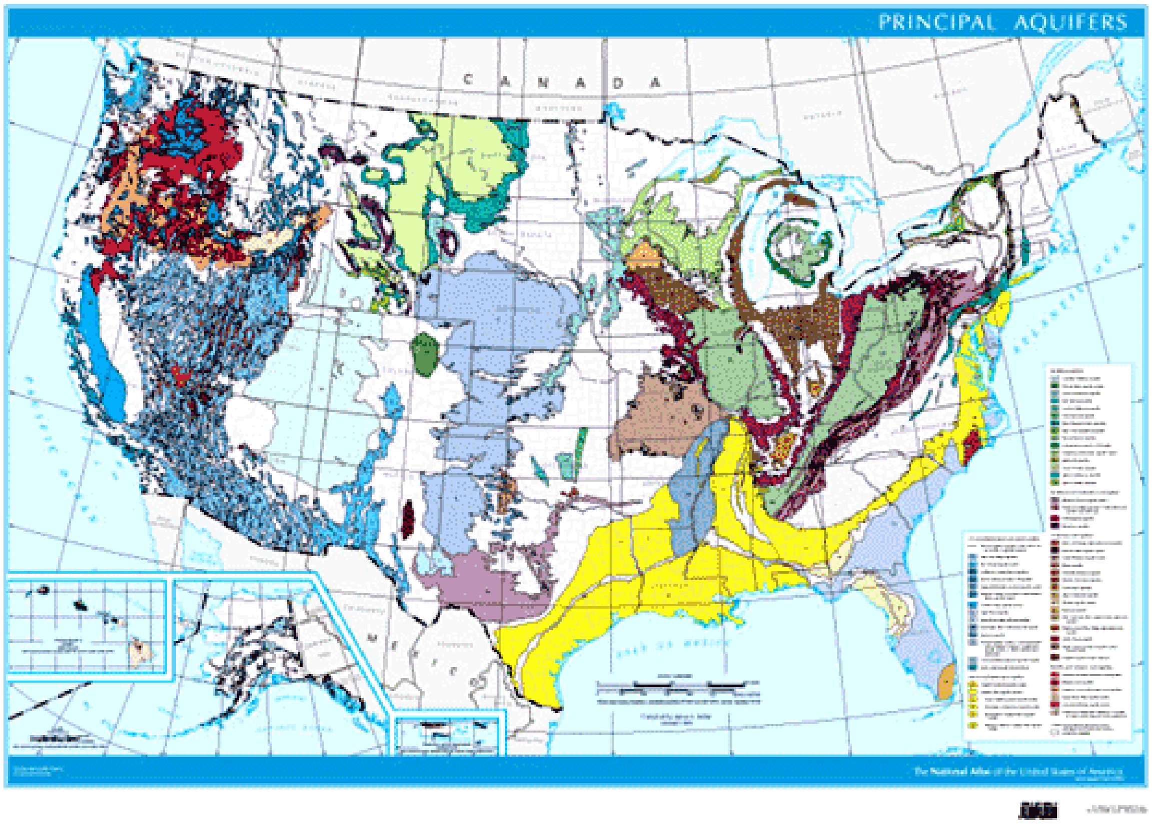

Figure 10. Principal aquifers of the U.S. (USGS 2003).

While the principal aquifer system provides a big picture view and information on the major aquifers of the U.S., in general, the scale is too coarse for most scientific and management purposes. It does not yet provide a systematic, nation-wide, scalable system for visualizing, assessing, organizing, and managing groundwater resources and water resources data at the sub-basin or watershed scales where most water resources are actually managed. Therefore, it should be enhanced by decomposing the aquifer groups into smaller components and constructing a scalable aquifer framework and accounting system equivalent to the nested hydrologic units and river reaches frameworks. Such a system should be co-developed and agreed upon by the appropriate federal, state, and tribal agencies, as appropriate.

Competent Hydrologic Units

An initial nation-wide competent hydrologic unit framework could be developed relatively quickly and inexpensively if the appropriate state, tribal, and federal water agencies would cooperate and collaborate on such an effort. A national competent hydrologic unit framework could be developed by integrating and linking the surface water data contained in the NHDPlus GIS coverages with the appropriate groundwater data and information contained in the principal aquifers GIS coverages, once the principal aquifers data/information are decomposed into the appropriate scales, as described above.

The framework should be designed to capture atmospheric inputs, surface water and groundwater storage and flows, and to delineate the hydrologic interconnectivity between surface water and groundwater bodies (where known) to develop an understanding of precipitation inputs, the flow of water between the surface water and groundwater components, and the impacts of surface water availability and use on groundwater availability and use (and *vice versa*). Similar to the flow information provided in NHDPlus, the framework should be designed to link and provide flow data and information between hydrologically interconnected aquifers (e.g., groundwater flow directions, recharge/discharge rates, groundwater quality, and hyporheic populations, and connections with up-gradient and down-gradient aquifers). Finally, it should incorporate into the framework or link the framework to analogous groundwater quality data and information.

The goal of this framework should be to develop aquifer data/coverages that are appropriately scaled and linked with each level of the NHDPlus surface water coverages/data. That is, integrated and scalable to match up with the surface water units from sub-watershed to basin levels. It should be designed to capture and integrate the data and information associated with each of the physically-based aspects outlined in Figure 6 (above) including hydrologic-unit specific inputs and outputs, water availability, water use, and the associated/potentially impacted environment (e.g., water quality and aquatic, riparian, and hyporheic species and ecosystems).

This effort should be co-developed and reviewed by the appropriate federal, state, and tribal agencies to ensure that the hydrologic unit and principal aquifers boundaries, river reaches, wetlands, etc. are geographically/topographically correct and appropriately matched, the alignment between the hydrologic units and decomposed principal aquifers are correct, and that the naming and numbering conventions for the decomposed principal aquifers are considered appropriate and acceptable to both federal and state agencies. A preliminary example of a national competent hydrologic unit map can be seen Figure 11.

Why Develop a Competent Hydrologic Unit Framework?

Properly designed, a competent hydrologic unit framework could provide decision makers, water managers, and water users a visual representation and data management framework for the full extent of the water resources within their unit of interest. Hence, it could better inform them of the available

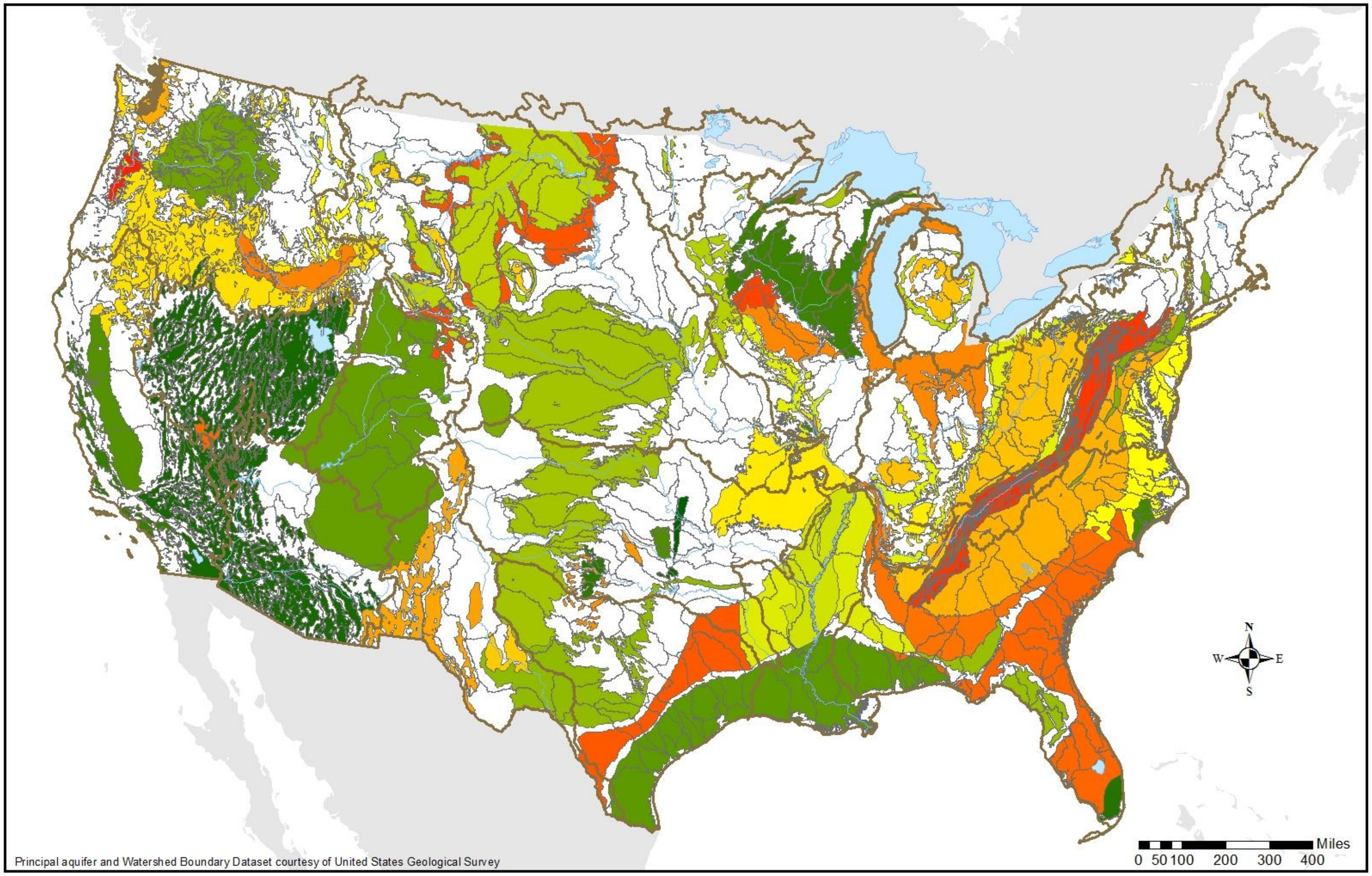

Figure 11. Example of potential competent hydrologic unit framework for the U.S.

surface-water and groundwater supplies and it could provide them with a better understanding of the full extent of their potential impacts on the hydrologic cycle within their unit(s) of interest. It would also provide federal, state, and tribal agencies and others a conceptual model and framework for systematically designing new and assessing the efficiency and effectiveness of existing hydrologically-related weather and climate, surface water, and groundwater monitoring networks and programs at various scales throughout the U.S. Such a framework would also allow scientists to more systematically integrate the appropriate water and water-related data necessary for conducting management/adaptive-management programs and for informing management and policy-makers.

While the geographic area of interest will vary by an organization's or agency's authorities, scope and needs, establishment of a systematic, scalable, "backbone" framework could provide significant benefits for all water and water-related organizations and agencies in the U.S. By using physically-constrained units, it should be possible to develop holistic water budgets and water quality assessments at the appropriate scale and to integrate data and information from each unit with other hydrologically connected units at other scales. For example, such a framework would provide a systematic approach for focusing and coordinating state and local agency efforts within a state or regional and federal agency's on the regional or national scale.

Such a framework should allow the systematic development of water and water-related planning, monitoring, and management programs across all three hydrologic compartments at each scale. This would allow for systematic interagency assessments of the efficiency and effectiveness of existing monitoring networks and programs at various scales and locations throughout the U.S. It would also help inform gap analyses to better design and coordinate new monitoring networks that explicitly integrate hydrological data and information across the three hydrologic compartments despite the given agency or program.

An Example of Competent Hydrologic Units – The Eastern Snake River Plain

To evaluate the potential of developing competent hydrologic unit maps for Idaho, GIS coverage, which included all of the hydrologic units (watersheds) in the State of Idaho (Seber et al. 1987), were intersected with the detailed state-wide aquifer map developed by IDWR for assessing drinking water sources in Idaho (Graham and Campbell 1981) (Figure 12). Those corresponding to the Upper Snake Sub-Basin (Accounting Unit 170402), in southeastern Idaho, were extracted here for analysis and the results are discussed below.

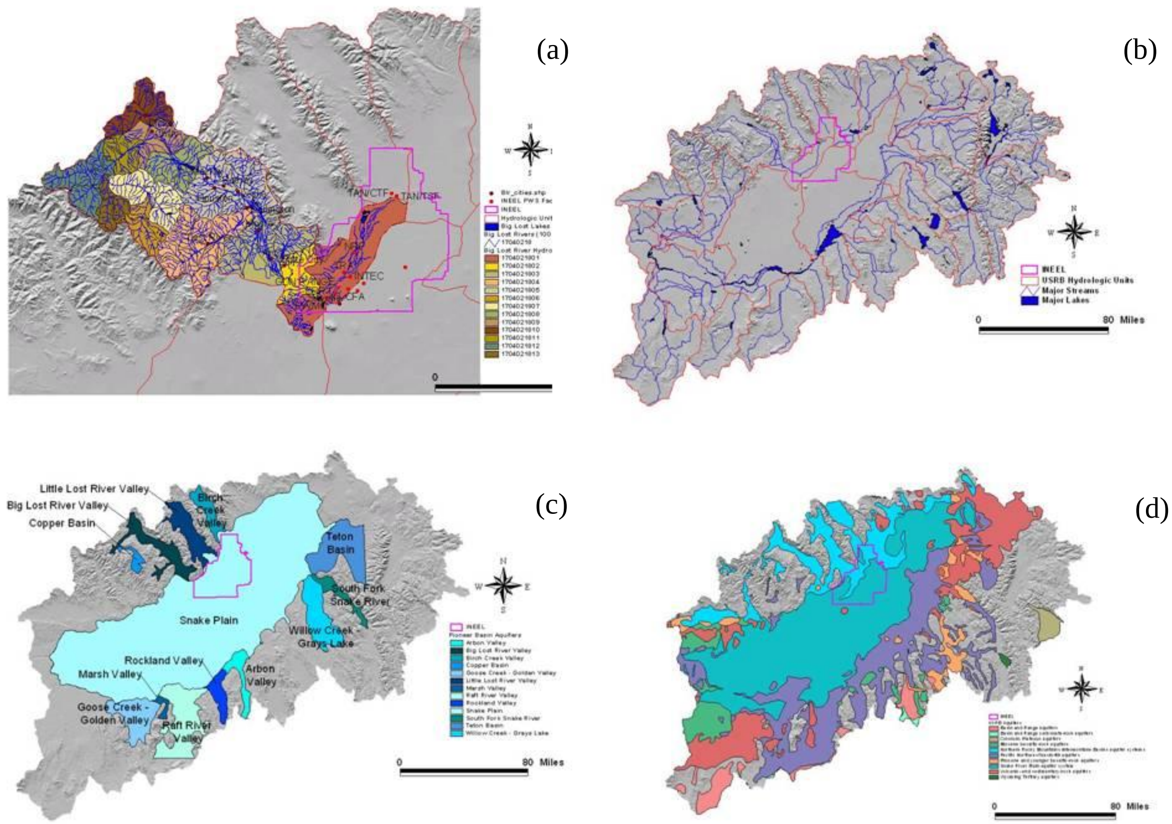

Figure 12. “Competent Hydrologic Units” in the Big Lost River Watershed and the surface waters, hydrologic units, aquifers, and geology of the Upper Snake River Basin and Sub-Basin (170402).

The Upper Snake Sub-Basin provides an example of developing competent hydrologic units. The sub-basin is 29,900 square miles, and it is mostly bounded by mountains, with the exception of receiving surface-water inflow via the Snake River from the Snake Headwaters Sub-Basin (Accounting Unit 170401) at Heise, Idaho, and discharging surface water outflow via the Snake River to the Middle Snake Sub-Basin (Accounting Unit 170403), at King Hill, Idaho. Because of geological constraints, little groundwater flows past the gauging stations at Heise or King Hill; therefore, basin inflows and outflows are relatively easily and accurately measured.

The dominant hydrologic feature within the Upper Snake Basin is the eastern Snake River Plain and its underlying aquifer, the eastern Snake Plain Aquifer. This aquifer underlies approximately 10,800 square miles of the plain between Ashton, Idaho and Thousand Springs, Idaho (USGS 1994). The eastern Snake Plain Aquifer is directly or mostly overlain by five watersheds (Idaho Falls, American Falls, Blackfoot, Lake Walcott, and Upper Snake-Rock). In addition, eight tributary watersheds directly contribute tributary surface water inflows to the eastern Snake River Plain aquifer (Beaver-

Camas, Big Lost, Big Wood, Birch, Little Lost, Lower Henrys, Medicine Lodge, and Teton). Nine aquifers are tributary and directly contribute groundwater to the Snake Plain Aquifer. These features are shown in Figure 12 and provided in Table 5. Figure 12 shows GIS coverage of: (a) competent hydrologic units in the Big Lost River watershed; and (b) surface waters and hydrologic units, (c) aquifers, and (d) the geology in the Upper Snake River Basin and Sub-basin (170402).

From a hydrologic perspective, "effective precipitation" falling in any of the tributary sub-basins should be stored within the sub-basin, run off to recharge the streams or other surface water bodies within the sub-basin, infiltrate/percolate into their underlying aquifer(s) the Big Lost Watershed

Table 5. Example of a competent hydrologic unit in the Upper Snake Sub-Basin, Idaho.

IDWR Aquifer #[1]	IDWR Aquifer Name[1]	HUC[2]	USGS Hydrologic Unit Name[2]	Primary Local Aquifer(s)[3]
39	Snake Plain	17040201	Idaho Falls	Snake Plain (39)
		17040202	Upper Henrys	Island Park (61)
		17040203	Lower Henrys	Snake Plain (39)
		17040204	Teton	Teton Basin (60)
		17040205	Willow	Willow Creek – Grays Lake (57)
		17040206	American Falls	Snake Plain (39)
		17040207	Blackfoot	Blackfoot Reservoir (56)
		17040208	Portneuf	Portneuf Valley – Gem Valley (51)
		17040209	Lake Walcott	Snake Plain (39)
		17040210	Raft River	Raft River Valley (43)
		17040211	Goose	Goose Creek – Golden Valley (41)
		17040212	Upper Snake – Rock	Rockland Valley (45)
		17040213	Salmon Falls	Salmon Falls Creek – Rock Creek (40)
		17040214	Beaver - Camas	NA[4]
		17040215	Medicine Lodge	NA[4]
		17040216	Birch	Birch Creek Valley (62)
		17040217	Little Lost	Little Lost River Valley (64)
		17040218	Big Lost	Copper Basin (67)
				Big Lost (66)
		17040219	Big Wood	Big Wood River – Silver Creek (38)
		17040220	Camas	Camas Prairie (37)
		17040221	Little Wood	NA[4]

1. The eastern Snake Plain Aquifer is the regional aquifer.
2. The hydrologic units which overlie or are tributary to the eastern Snake River Plain aquifer.
3. The primary aquifer(s) associated with the specified hydrologic unit. Note that the mouths of most tributary watersheds open onto the eastern Snake River Plain and partially overlie the eastern Snake Plain Aquifer.
4. These hydrologic units do not have an associated, recognized local aquifer.

infiltrating into the Copper Basin or Big Lost Aquifers) or infiltrate/ percolate directly into the eastern Snake Plain Aquifer (the lower ends of each tributary watershed overlies the eastern Snake Plain Aquifer). Surface water and groundwater from each of the tributary watersheds or tributary aquifers that is not consumed (lost from the sub-basin due to evapotranspiration) should eventually flow onto the eastern Snake River Plain or into the eastern Snake Plain Aquifer, which eventually discharges to the Snake River and flows out of the Upper Snake Basin Sub-Basin at King Hill, Idaho. Therefore, from a "big picture" perspective, any natural or anthropogenic activity that affects the water availability or quality in one of the tributary watershed or aquifers may potentially affect the water availability or quality on the eastern Snake River Plain and/or in the eastern Snake Plain Aquifer, and eventually flow into the Middle Snake Sub-Basin, hydrologically downstream of the Upper Snake Sub-Basin.

By delineating these competent hydrologic units:

- Policy objectives can be better met (e.g., provide better information for conjunctively managing the eastern Snake River Plain as is required under Idaho's conjunctive management rules; IDAPA 37.03.11). Scientists can better design and implement more effective and robust monitoring and measurement systems, and models for assessing the natural water storage and flow and the impacts of water and land use on water storage, flow, and quality through all three hydrologic compartments.
- Engineers can design and construct more effective and robust water and water-related infrastructure and control systems for managing water.
- Water managers and water users can better understand and manage the overall hydrologic system and the impacts of water use and other anthropogenic impacts on the available water supply.

Summary and Conclusions

The overall objective for IWRM is to "…satisfy the freshwater needs of water users for their sustainable development." (UNCED 1992) IWRM calls for developing a comprehensive and integrated approach to governing, understanding, and managing water and water-related resources within the context of a watershed or sub-basin (UNCED 1992). Implementation of such an approach requires a holistic, systematic, and integrated approach to understanding and managing water and water-related resources based on the best available scientific knowledge of the hydrologic cycle (ASCE 1997 and EWRI 2007). This includes activities such as protecting and conserving potential sources of freshwater supply, inventorying of water resources, with land-use planning, forest resource utilization, protection of mountain slopes and riverbanks, and other relevant development and conservation activities; optimization of water resources allocation under physical and socio-economic constraints; and integrating atmospheric, surface, and underground water resources relative to both quantity and quality management.

This research provides a generalized conceptual model for developing a better understanding of the integrated nature of the natural hydrologic cycle, water availability, and the impacts of water use on hydrologically interconnected resources. In addition, it discusses the interactions between the hydrologic, socioeconomic, legal, and environmental aspects of managing water and water-related resources on a watershed and/or sub-basin scale.

The conceptual model is intended to provide a systematic framework for scientists, water policy- and decision-makers, and water managers relative to developing more holistic, systematic, and integrated approaches to managing water and water-related resources. Such an approach includes the development of more comprehensive monitoring, measuring and management tools, methods and programs, and developing more physically-based policies, laws, and management schema for managing water resources in the U.S.

In addition, this research introduces the concept of "competent hydrologic units." Scientifically, it is well known/understood that each hydrologic compartment (e.g., atmospheric-, surface-, vadose-, and ground-waters within a watershed and/or sub-basin are inextricably linked. Therefore, any modification or impact to water resources in one hydrologic compartment will impact all other hydrologically interconnected water resources. However, this fact is not typically ensconced in U.S. water policy and law, or fully considered/ integrated into most day-to-day water management operations and practices, or integrated/ designed into most water resources monitoring and measurement programs.

The U.S. currently has sufficient knowledge, tools (e.g., GIS and computer models), and infrastructure (e.g., weather monitoring systems, stream gages, and monitoring wells) to begin linking the data and information associated with each hydrologic compartment within most watersheds/sub-basins in the U.S. to form a more holistic, systematic, and integrated hydrologic framework to better understand and manage water resources throughout the U.S. For example, the National Watershed Boundary and National Hydrography Datasets link surface water resources for every watershed and sub-basin in the U.S. in an integrated and hierarchical manner (USGS 2014). The principal aquifers are mapped throughout the U.S. (USGS 2003); all have some level of characterization associated with them and many of them are well monitored and characterized. In addition, more in-depth analyses have been/are being conducted to better delineate and understand groundwater resources, and the interaction between surface water and groundwater bodies relative to water storage and flow and water quality impacts (e.g., the National Water Quality Assessment Program, USGS 2015b). Such systems should be linked within the context of competent hydrologic units.

Wolock, Winter, and McMahon (2004) demonstrated the ability to and the power of linking available atmospheric, surface water, groundwater, and ecological (i.e., ecoregions) datasets with other datasets to conduct a nation-wide GIS-modeling assessment of water resources. Such assessments currently lack the granularity necessary to fully understand the hydrologic cycle at a scale useful for watershed and/or basin management. However, this research demonstrates the ability and utility of linking these large datasets to better understand water storage and flow and the movement of water and contaminants between surface water and groundwater resources at the watershed/sub-basin and larger scales.

As surface water and groundwater datasets and their linkages continue to improve and are linked to comprehensive atmospheric datasets (e.g., National Oceanic and Atmospheric Administration's U.S. Historical Climatology and Cooperative Observer Program Networks, NOAA 2015a), the U.S. would have the initial development of a truly integrated atmospheric-surface water-groundwater conceptual and computer models for understanding water resources at the watershed and sub-basin levels throughout the U.S. The hydrologic aspects could further be improved by directly linking other nation-wide datasets such as NRCS's STATSGO/SURGO (NRCS 2013) and EPA's Ecoregion (Omernik and Griffith 2014) datasets. Such a "system-of-systems," carefully designed and implemented, could then be used as the baseline for water and water-related research and planning within watersheds and sub-basins throughout the U.S.

By using a comprehensive hydrologic unit approach and linking the appropriate datasets to those units, we can develop a more holistic, systematic, and integrated approach to understanding the physical aspects of (e.g., hydrological and ecological) of water and water-related resources on a watershed or sub-basin scale, and for informing socioeconomic and legal decision-making processes. However, developing a more holistic, systematic, and integrated approach to actually managing these resources requires the development of the appropriate policies and laws necessary to manage not only the physical aspects, but also the socioeconomic and legal aspects of managing water and water-related resources in each watershed and/or sub-basin. The development of such policies and laws are addressed in Chapter 4.

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CHAPTER 4: WATER POLICIES AND LAWS AMENABLE TO THE DEVELOPMENT AND IMPLEMENTATION OF INTEGRATED WATER RESOURCES MANAGEMENT IN THE U.S.

Introduction

Water resource, land, and environmental management in the U.S. are based on a mix of federal, state, tribal, and local policies, laws, regulations and ordinances, and treaties and compacts. Some of these legal instruments have been well thought out, are comprehensive, and have stood the test of time. A few of them have had profound, positive implications in furthering the development goals of the U.S. (e.g., the Reclamation Act and Rivers and Harbors Act) or reducing harmful pollution in the U.S. (e.g., the Clean Water Act and Safe Drinking Water Act). However, other water policies and laws have been developed and implemented on an *ad hoc* basis to meet immediate pressing needs or to meet the desires of a specific time, place, situation, or stakeholder group; often, with mixed results. Some water policies and laws have not been well grounded in science (e.g., they are not physically based). In addition, many water policies and laws are not well integrated with each other (e.g., water allocation and water quality policies and laws) or with other natural resource policies and laws (e.g., with land and/or fish and wildlife management policies and laws).

Water management in the U.S. has evolved over time to meet growing demands and changing needs. Historically, water management in the U.S. has progressed from "squatters' rights," to local coordination and agreements, to single-purpose, multiple-purpose, and then to multi-objective management practices (EWRI 2006). Due to increasing demands and conflicts, some water resources professional and professional organizations believe that a more integrated approach is needed for managing water resources (Grigg 1998 and 2008, CEQ 2013, NRC 1999, and WPRAC 1988). Some professionals believe an Integrated Water Resources Management (IWRM) approach is the most logical and appropriate next step for managing water resources needs in the U.S. (AWRA 2011, ASCE 2001, 1998a, 1998b, 1997, EWRI 2007, and USACE 2010 and 2013). However, others (Biswas 2008, 2004, and 2001) have argued that IWRM is not well defined and the linkage between water use/users and between water resources and other natural resources are too interlinked and too complex to effectively manage them in such an integrated manner.

IWRM advocates for a holistic, systematic, and integrated approach of managing water and "water-related" (e.g., riparian lands and aquatic/riparian ecosystems) resources at a sub-basin or watershed level to balance social, economic, and environmental needs (GWP 2005, GWP 2000, UNCED 1992b, and UNEP 2012). This approach includes such activities as (UNCED 1992a): harmonizing water policies and laws based on the physical laws of nature that govern the storage and flow of water, understanding and managing hydrologically interconnected water resources as a unified source, the management of water quality and water allocation, addressing socioeconomic needs and constraints to meet the needs of all stakeholders, and balancing anthropogenic and environmental needs in a holistic and sustainable management framework.

Such an approach requires implementing activities, such as: developing the necessary science and information; integrating and harmonizing policies and laws based, in part, on the best available science; having well designed and operated institutions; and having the appropriate operational capacities and infrastructure. However, policies and laws are the lynchpins relative to the potential success or failure of developing, managing, and protecting water resources in the U.S. policies and laws set the basis and the framework for what activities can and should be implemented and what can or should be prohibited. In addition, they establish the direction and authority for agency implementation, and they authorize the funding and incentives necessary to accomplish many of the activities necessary for implementing water resources management the U.S.

The questions at hand are whether the existing body of U.S. federal, state, and tribal water-related policies and laws provide an effective and robust basis for managing current and future water resource needs and challenges in the U.S. or do they need to be modified? If they need to be modified, is IWRM an appropriate approach to pursue in the future? If so, what attributes should be incorporated into a U.S. IWRM framework?

This research provides an overview of the key federal, state, and tribal water policies and laws and selected water-related land-management and environmental laws that may be useful for developing and implementing an IWRM program in the U.S. In addition, it provides some suggestions for harmonizing federal, state, and tribal water policies and laws that may be beneficial, whether or not the U.S. water community decides to fully embrace an IWRM approach to water resources management in the future.

Federal Water Policy and Law

Federal Water Allocation

The U.S. Bureau of Reclamation (BOR) and the U.S. Army Corps of Engineers (Corps) are the primary federal water agencies in the U.S. BOR and Corps water projects and activities are governed by a myriad of policies and laws (e.g., the compendiums of policies and laws for the BOR [Mauro and Pelz 1988 and 1989 and Pelz 1972a, 1972b, and 1972c] and for the Corps [USACE-IWR 2002]).

However, when federal agencies need to utilize water for a beneficial use, they generally have three potential avenues for obtaining the rights to use water (1) obtaining water rights through the appropriate state water-right system, (2) obtaining water rights through congressionally authorized project-specific water rights, or (3) through Federal Reserved Water Rights.

Federal agencies have the same rights as any other individual or organization in a given state to apply for a state water right, based on the specific requirements of the given state (e.g., via riparian- or prior appropriation-based water laws). In most cases, federal agencies have to apply for water rights through the appropriate state water rights system to meet their needs (e.g., for offices buildings and facilities within towns or on purchased lands). However, when Congress authorizes federal water projects to provide specific beneficial uses (e.g., municipal, industrial, irrigation, flood control, navigation) it can establish project-specific water rights through the authorizing statute (e.g., via the Reclamation Act, various Water Resources Development Acts, Flood Control Acts, and Water Supply Act of 1958). These water rights are superior to state water rights, but are limited to utilizing water within the confines of the project scope and authorization. The original water rights established may be repurposed for other uses at a later date, depending on the specific project authorization; however, repurposing these water rights may require Congressional approval (Brougher and Carter 2012).

In addition, Federal Reserved Water Rights are implicitly attached to most federal reservations (e.g., federal public lands, military lands, and Indian reservations and trust lands). Federal Reserved Water Rights are based on a U.S. Supreme Court ruling in *Winters v. United States*, 207 U.S. 564 (1908) (the "Winters Doctrine"). In this case, the U.S. Supreme Court decided that when Congress withdraws land from the public domain to meet a specific federal purpose (Goldfarb 1989):

> *...it is presumed to have reserved enough unappropriated water to accomplish the purposes of the reservation...It takes effect on the date of the land reservation and exempts reserved waters from appropriation under state law. It is unnecessary for the federal government to perfect its reserved right by applying for a state diversion permit."*

This doctrine is applicable to all federal reservations, unless specifically excluded by Congress (e.g., new U.S. Fish and Wildlife Refuges).

Federal Water Resources Development

The federal government has long supported the development and use of water resources within the U.S. by conducting resource surveys and resource planning, funding, and providing technical and/or physical support to states, tribes, and private individuals and organizations (e.g., Gallatin report of 1808, General Survey Act of 1824, Rivers and Harbors Act of 1824, National Reclamation Act of

1902, Flood Control Act of 1917, Watershed Protection and Flood Prevention Act of 1954, and Water Resources Development Act of 1986). However, the proper roles, responsibilities, and authorities of federal versus state and tribal agencies have also been long and vigorously debated and they are continuously evolving (Reuss 1991). Key federal laws associated with developing and managing water resources in the U.S. are briefly summarized below.

Rivers and Harbors Acts

Congress has funded federal water resource projects since the first Rivers and Harbors Act in 1824 (Adams 1993 and Holmes 1972). The number and scope of these projects were initially modest; however, the number, size and complexity of projects increased significantly after the Civil War and they have increased ever since (Adams 1993; Billington, Jackson, and Melosi 2005; and Reuss 1991). Various river and harbor acts funded most Corps water-related civil works projects until 1974. The acts funded many of the early water resources development studies, plans, and development work implemented within U.S. river basins and territorial waters. Initially, funding was primarily focused on navigation-related studies and projects (e.g., dredging harbors and rivers and removal of obstacles from navigable rivers) and later the construction of dams, reservoirs, locks, and levees. Ultimately, the acts also funded other Corps-related infrastructure projects related to hydroelectric power, flood control, recreation, water supply, and water quality projects (Adams 1993).

National Reclamation Act of 1902

There have been many policies and laws associated with the development of land and water resources in the U.S.; however, arguably one of the important water development laws in the U.S. is the National Reclamation Act of 1902 (Public Law 57–161). This Act originally authorized the Secretary of the Interior to develop irrigation and hydropower projects in 13 semiarid western states. Currently, it is primarily focused on the 17 western states (California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming). The Act is implemented by BOR.

The Act authorized the withdrawal of public lands for the development of irrigation projects, and authorized funding for surveying lands and waters for the planning and developing these projects through the sale of lands within authorized project boundaries. While the primary focus of the Act is irrigation, other authorized beneficial uses include municipal and industrial water use, and power generation, flood control, fish and wildlife enhancement, transportation, and recreation. Under the Act, the BOR is required to manage water rights based on, for the most part, state water law. The BOR is authorized to develop and manage both surface water and groundwater resources; however, the vast majority of the water managed by the BOR is surface water. Funding for most reclamation projects and activities is primarily allocated through the annual congressional Energy and Water Appropriations Bill and through reimbursable costs repaid by the project's beneficiaries (GAO 1997).

Water Resources Development Act (WRDA)

Since 1974, Congress has authorized most Corps water-related activities and projects in periodic omnibus Corps authorization bills called the Water Resources Development Act (WRDA) (Public Law 93-251 *et seq.*). Most recently, Congress passed the Water Resources Reform and Development Act (WRRDA) (P.L. 113-121). In addition to authorizing funding for the construction and management of various federal water resources projects, the acts also provide policy direction and various authorities and instructions, primarily to the Corps, relative to managing its major mission areas.

The Corps primary water-related missions associated with this Act include commercial navigation, flood risk management, environmental restoration, hydroelectric power, recreation, and municipal and industrial water supply, regulation of construction in navigable waters and the deposition of dredged and fill materials in waters of the U.S., and disaster preparedness and response (Corps 2015a). More recently, significant amounts of funds have been allocated for environmental protection and restoration projects. Many are associated with restoring habitat and mitigating species impacts caused by historical Corps water resources development projects.

Funding for most Corps water-related projects and activities is allocated through annual congressional energy and water appropriations bills and various supplemental appropriations acts (Carter and Stern 2014). Like the Reclamation Act related projects, some project development and operational costs are reimbursable to the federal government.

Flood Control Acts

Starting with the Flood Control Act of 1917 (Public Law 64-367), Congress passed numerous "Flood Control Acts." Initially, the acts were primarily intended to authorize Corps development of large infrastructure projects to control flooding in response to major flood disasters. However, the Flood Control Act of 1948 (Public Law 80-858) authorized the Corps to fund the construction of small projects for flood control and "related" purposes and to work cooperatively with the U.S. Department of Agriculture (USDA) and others to protect smaller watersheds from flooding.

Starting with the Flood Control Act of 1936 (Public Law 74–738), Congress tasked the USDA to investigate the impacts of agriculture on flooding. The Watershed Protection and Flood Prevention

Act of 1954 (Public Law 83-566) authorized the USDA to provide technical and financial assistance to various state and local government agencies, and to recognized tribes for:

> *…any undertaking for - (1) flood prevention (including structural and land treatment measures), (2) the conservation, development, utilization, and disposal of water, or (3) the conservation and proper utilization of land, in watershed or subwatershed area not exceeding two hundred and fifty thousand acres and not including any single structure which provides more than twelve thousand five hundred acre-feet of floodwater detention capacity, and more than twenty-five thousand acre-feet of total capacity.*

This Act is managed by the Natural Resources Conservation Service (NRCS). Projects funded under this Act can address almost any natural resource related issue, including flood prevention, agricultural water management, fish and wildlife habitat development, public recreation development, groundwater recharge, water quality, conservation and proper utilization of land, and municipal and industrial water supply (NWC 2002). In general, NRCS's watershed and flood protection projects are limited to smaller projects (< 250,000 acres) higher up in tributary watersheds and the Corps' flood control projects lower in a given watershed or basin.

NRCS' small watershed plans are funded through the annual Agriculture Appropriations Bill (Farm Bill). Funding for Corps flood-related projects and activities is allocated through annual congressional energy and water appropriation bills and various supplemental appropriation bills (Carter and Stern 2014).

Federal Water Quality Laws

There are numerous federal water-quality related laws in the U.S. that are intended to protect human health and the environment. Some of these laws are designed to generally protect, monitor, and/or remediate water resources in the U.S. (e.g., the Clean Water Act and Safe Drinking Water Act). In addition, other federal policies and laws are more focused on other environmental issues, but contain important water protection, monitoring and/or remediation components (e.g., Atomic Energy Act; Comprehensive Environmental Response, Compensation, and Liability Act; and Resource Conservation and Recovery Act). Each of the federal water-quality related laws has its own goals, requirements, methods, and standards, which are generally distinct but compatible with the other federal water quality laws. The key federal water quality laws that may be applicable to IWRM are briefly summarized below.

Safe Drinking Water Act of 1974

The primary purpose of the Safe Drinking Water Act of 1974 (SDWA) (Public Law 93–523, 42 U.S.C. 300 et seq.), as amended, is to protect human health from contaminants in the nation's drinking water supplies. It regulates all public water systems (systems which provide water regularly to 15 or more connections or 25 or more people at least 60 days per year) in the U.S. Smaller drinking water systems and individual private water wells are not regulated by the SDWA.

The Act establishes health-based maximum contaminate levels for about 90 contaminants and designates specific treatment technologies for removing or reducing the contaminant levels in public water supply systems if they exceed their specified limits. It also establishes water distribution system requirements such as banning lead in drinking water distribution systems, establishing disinfection and filtration criteria, and providing financial assistance for constructing drinking water systems. In addition, the Act establishes water supply protection programs such as establishing minimum criteria for underground injection programs, defines and designates sole-source aquifers, and it establishes voluntary wellhead protection programs and mandatory state source water assessment programs. The resource protection standards are applicable to all known and potential surface water and groundwater sources that may supply public drinking water systems. A number of key provisions in the SDWA that could lend themselves to developing more integrated water programs in the U.S. are provided in Table 6.

Table 6. Key sections of the Safe Drinking Water Act potentially applicable to IWRM.

Section	Purpose
§1411	Establishes national primary (health-related) and secondary (nuisance-related) drinking water standards (maximum contaminate levels) for protecting drinking water supplies provided by public water systems.
§1421 et seq.	Establishes the Underground Injection Control Program that regulates the underground injection of fluids via wells to underground sources of drinking water.
§1424	Establishes the Sole-Source Aquifer Program to protect aquifers that serve as the sole or principal drinking water source for a community or a given area.
§1428	Requires states to submit Wellhead Protection Programs to EPA detailing how they will protect drinking water "wellheads" from potential sources of contamination from surface water or groundwater sources.
§1453	Requires all states to establish Source Water Assessment Programs and submit a source water assessment plan to EPA.

Clean Water Act

The Federal Water Pollution Control Act Amendments of 1972 (Clean Water Act [CWA]) (Public Law 92-500) established a framework "…to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." This Act was amended and significantly expanded by the

Water Quality Act of 1977 (Public Law 95-217) and the Water Quality Act of 1987 (Public Law 100-4). CWA establishes a two-part water quality scheme; a technology-based discharge permitting program and a water-quality-standard based approach to protect the “waters of the U.S.” from pollution (EPA 2012a).

CWA makes it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit is obtained. The Act includes programs which set minimum national effluent standards, by industry, to control pollutant discharges from “point sources” (e.g., industrial plant and municipal sewage treatment plant discharges) water quality standards; a permit system which translates the standards into enforceable limits, including discharges from “non-point sources” (e.g., runoff from urban areas, agricultural fields and feedlots, and from mining and logging activities); contains provisions to address toxic chemicals and oil spills; and establishes a revolving loan program for constructing publicly-owned treatment works. In addition, it regulates “dredge and fill” operations to protect waters of the U.S., including wetlands. A number of key provisions in the CWA that could lend themselves to developing more integrated water programs in the U.S. are provided in Table 7.

Other Water-Quality Related Federal Regulations

In addition to the SDWA and CWA, there are a number of other key environmental policies and laws that are critical to protecting water quality in the U.S. that could be more tightly integrated with the SDWA and CWA (Table 8).

Federal Land Management Policies and Laws with Significant Water Implications

In addition to advocating for the protection and sustainable development of water resources, IWRM also calls for the protection and sustainable development of water-related resources (e.g., riparian lands and aquatic and riparian ecosystems).

The federal government retains ownership of approximately 650 million acres of land in the U.S., primarily west of the Mississippi. Of that land, the five federal land management agencies (Bureau of Land Management [BLM], Fish and Wildlife Service [F&WS], National Park Service [NPS], and the Forest Service [USFS]), and the Department of Defense [DOD] own and manage approximately 629 million acres of land or about 28% of the land in the U.S. (Gorte et al. 2012). This includes approximately 62% of the land in Alaska, 47% of the land in the 11 western states, and 4% of the land in the remaining states (Table 9). In addition, many of the 566 federally-recognized Indian tribes (BIA 2015a) live on the 325 federally-recognized Indian reservations and trust lands in the U.S. (BIA

Table 7. Key sections of the Clean Water Act potentially applicable to IWRM.

Section	Purpose
§301	Establishes the requirement that pollutants may not be discharged to waters of the U.S. without an National Pollutant Discharge Elimination System (NPDES) permit, the processes and criteria for authorizing states, tribes and territories specific water quality programs, and the criteria for implementing those programs within their jurisdiction.
§303	Requires each state (and tribes and territories which choose to do so) to develop water quality standards that are protective of public health and welfare and that enhance the quality of water.
§303(d)	Establishes the rules for Total Maximum Daily Loads (TMDLs) and Impaired Waters requiring states, territories, and authorized tribes to develop lists of "impaired waters" which are either polluted or otherwise degraded such that they do not meet the established water quality standards.
§311	Prohibits discharges of oil and reportable quantities of hazardous substances to waters of the U.S., establishes an Oil Spill Liability Trust Fund, requires the proper handling, storage, and transportation of oil, requires prompt and full reporting to the National Response Center and response to discharges, requires spill prevention control and countermeasure plans, and requires the federal government to assure proper removal of oil by either conducting the removal or overseeing removal by the appropriate state, local or private entity consistent with the National Contingency Plan.
§316	Establishes technology-based effluent limitations imposed on thermal discharges to waters of the U.S.
§319	Requires each state to complete state-wide evaluations of water quality within their jurisdiction and to develop a management program to control non-point pollution. Those bodies of water that do not meet the appropriate water quality standards must be reported annually per § 303(d) of the Act.
§401	Allows states to established a water quality certification process under which they may issue or deny water quality certifications relative to the Corps issuing a §404 dredged or fill permit. Any effluent or other limitations or monitoring requirements established in under the state certification become enforceable requirements under the 404 permit.
§402	Establishes the requirements for implementing the NPDES for regulating point-source pollutants and the criteria for authorizing states, tribes and territories to administer NPDES programs within their jurisdiction (i.e., establishes "primacy").
§404	Establishes a program to minimize the adverse impacts of the discharging of material into "waters of the U.S." This program is jointly administered by the Corps and the U.S. Environmental Protection Agency (EPA).

2015b). These lands encompass approximately 56.2 million acres. Private entities own the remaining lands in the U.S. federal lands and their associated natural resources are managed under federal law by the agency which owns the given lands, within the scope of the appropriate Organic Acts and/or Presidential Proclamations (e.g., under the Antiquities Act) that authorizes the reservation and establishes the purpose(s) and constraints associated with the reservation. In addition, later congressional acts, authorizations and appropriations may provide additional policy directions and funding that influences how agencies manage their lands and activities thereafter.

There are a number of major federal laws that govern these lands, some of which provide goals or requirements relative to water resources protection and management (Table 10). For example, the Federal Land Policy and Management Act of 1976 (43 U.S.C. 35) establishes policies and goals for

Table 8. Examples of other key water-quality related federal regulations potentially applicable to IWRM.

Act	Purpose
Atomic Energy Act of 1954 (42 U.S.C. § 2011 et seq.)	This Act, in part, governs the management, storage and/or disposal of spent nuclear fuels, high-level wastes, transuranic wastes, uranium mill tailings, byproduct materials, and naturally occurring and accelerator-produced radioactive materials. This Act includes human health, and environmental protection and monitoring requirements.
Coastal Zone Management Act of 1972 (16 U.S.C. § 1451 et seq.)	The Act establishes two major programs, National Coastal Zone Management Program, focused on balancing competing land and water issues in the coastal zone, and the National Estuarine Research Reserve System, focused on conducting research to provide a greater understanding of estuaries and how humans impact estuaries. It is intended to help balance economic development and environmental conservation and to "…preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone."
Comprehensive Environmental Response, Compensation and Liability Act of 1980 (42 U.S.C. §9601 et seq.; 40 CFR 300 - 375)	This Act was initially designed to identifying sites where hazardous substances have been or may be released to the environment, to assess the environmental damages due to these releases, ensure cleanup of such releases, to fund the cost of remediating releases when necessary, and to establish a claims process for recovering funding for the cleanup from the responsible parties. It was amended by the Superfund Amendments and Reauthorization Act, which includes the National Oil and Hazardous Substances Pollution Contingency Plan, and the Community Right-to-Know Act.
Resource Conservation and Recovery Act of 1976 (RCRA) (40 CFR 239 – 282)	This Act was designed to regulate the management, recycling, recovery, transportation, treatment, storage and disposal of hazardous and non-hazardous solid wastes. It establishes criteria for siting, surface water and ground water protection, characterization, monitoring and remediating contamination at solid and hazardous waste facilities.
Natural Resources Damage Act of 1980 (NRDA; 33 U.S.C. 2701 et seq.)	This Act was designed to allow federal responses to prevent potential releases of oil or hazardous substances or to restore environmental media impacted by actual releases of oil or hazardous substances using the authority of CERCLA and the Oil Pollution Act. It contains requirements for preventing, reporting and responding to releases of oil and hazardous materials.
Surface Mining Control and Reclamation Act of 1977 (SMCRA)	This Act was designed to regulate the environmental impacts of coal mining in the U.S. including regulating active coal mines and reclaiming abandoned mine lands, including monitoring, protection, and restoration of water resources.
Toxic Substances Control Act of 1976 (TSCA) (40CFR 700 – 799)	This Act was designed to regulate toxic substances including PCBs, asbestos and the abatement of indoor radon, including the monitoring, protection, and remediation of water resources.
Federal Insecticide, Fungicide, and Rodenticide Act	This Act was designed to regulate the availability of pesticides, including those that may run off into surface water resources or that have the ability to leach into groundwater resources.

public lands that require, in part, planning and management to be conducted to protect water resources and watersheds, as does the National Forest Management Act of 1976 (6 U.S.C. 1600-1614, as amended) for forest reserves. The National Wildlife Refuge System Administration Act of 1966 (16 U.S.C. 668dd-668ee) requires the maintenance of adequate water quantity and quality to fulfill

Table 9. Federal acreage by state or region and by agency, 2010[1].

	Alaska	11 Western States[2]	Other States	U.S. Total
BLM	72,958,757	174,512,265	388,054	247,859,076
DOD	1,686,371	13,222,343	4,512,826	19,421,540
FWS	76,626,272	6,424,637	5,897,790[3]	88,948,699
NPS	52,620,514	20,140,186	6,930,784	79,691,484
USFS	21,956,250	141,762,880	29,161,710	192,880,840
Federal total[4]	225,848,164	356,062,311	46,891,164	628,801,639
Acreage of states	365,481,600	752,947,840	1,152,914,460	2,271,343,360
Percent federal	61.80%	47.30%	4.10%	27.70%

1. Gorte et al. 2012.
2. The 11 western states are Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.
3. Excludes Papahanaumokuakea Marine National Monument (88,647,881 acres) in Hawaii.
4. This understates total federal land, because it includes only lands of the four major federal land management agencies and DOD.

the mission of the refuge system; however, it specifically requires new water rights to be obtained via the appropriate state water rights system. The Act to Establish the National Park Service (16 U.S.C. 1) (the Park Service's Organic Act) is void of any explicit mention of water resources.

The National Wilderness Preservation System of 1964 (16 U.S.C. 23) (Wilderness Act) does not establish new federal reservations, it simply designates existing federal reservations (e.g., national forests, parks, and refuges) as wilderness areas, which must be "…protected and managed so as to preserve its natural conditions..." Ironically, this Act provides that within such wilderness areas, the President may "authorize prospecting for water resources, the establishment and maintenance of reservoirs, water-conservation works, power projects, transmission lines, and other facilities needed in the public interest…" (16 U.S.C. 1133(d)(4)).

Key Federal Water-Related Environmental Policies and Laws

In addition to advocating for the sustainable development and management of water and water-related resources at the sub-basin or watershed scale, IWRM also calls for the protection of ecosystems and their component species (UNCED 1992a). Numerous environmental laws have been promulgated in the U.S. since the 1960s. However, three very different laws require a special note relative to protecting the environment: the Endangered Species Preservation Act of 1973 (16 U.S.C. §§1531 - 1544) (Endangered Species Act), the National Environmental Policy Act of 1969 (NEPA) (42 U.S.C. §4321 et seq.), and the Wild and Scenic Rivers Act of 1968 (16 U.S.C. 1271-1287) (Table 11).

Table 10. Federal land management laws regulations potentially applicable to IWRM.

Act	Purpose
Federal Land Policy and Management Act of 1976 (43 U.S.C. 35)	This Act establishes a national policy for managing all federally-owned "public lands" (**federally-owned lands not set aside for national forests and parks, wildlife preservation areas, military bases, or other specific federal purposes)**. The goals and objectives, in part, include that lands be: ... *managed in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archeological values...* [43 U.S.C. 35, § 1701] Section 501 authorizes the Secretary of Agriculture allow water resources related rights-of-ways on National Forest reserves (excluding wilderness areas).
The National Forest Management Act of 1976 (6 U.S.C. §§ 1600-1614, as amended)	This Act is the primary statute governing the administration of national forests. It provides some direction relative to protecting water resources on forest reserves, including recognizing; *...the fundamental need to protect and where appropriate, improve the quality of soil, water and air resources…* (Sec. 5(C)). Section 17(a) amends the "Weeks Act" authorizing the Secretary of Agriculture *…to examine, locate, and purchase such forested, cut-over, or denuded lands within the watersheds of navigable streams as in his judgment may be necessary to the regulation of the flow of navigable streams or the production of timber..."* in the eastern U.S.
National Wildlife Refuge System Administration Act of 1966 (16 U.S.C. 668dd-668ee), as amended	This Act is essentially the Organic Act for the National Wildlife Refuge System. Relative to water management, the Act states that the Secretary shall*…assist in the maintenance of adequate water quantity and water quality to fulfill the mission of the System and the purposes of each refuge…acquire, under State law, water rights that are needed for refuge purposes… Nothing in this Act shall diminish or affect the ability to join the United States in the adjudication of rights to the use of water pursuant to section 666 of title 43.*
"Act to Establish the National Park Service" (16 USC 1)	This Act states that that the general purpose of national parks, monuments, and reservations is: *…to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.*
The National Wilderness Preservation System of 1964 (16 U.S.C. 23)	This Act established a system of wilderness areas within existing federally owned lands. Wilderness areas are required to be managed such that the land retains its "...primeval character and influence, without permanent improvements or human habitation, that is protected and managed so as to preserve its natural conditions..." However, § 1131(d)(4)(1) states that: *...the President may, within a specific area and in accordance with such regulations as he may deem desirable, authorize prospecting for water resources, the establishment and maintenance of reservoirs, water- conservation works, power projects, transmission lines, and other facilities needed in the public interest…*

The Endangered Species Act was enacted to prevent the extinction of species whose populations are approaching extinction "...as a consequence of economic growth and development untempered by adequate concern and conservation..." This Act requires all federal agencies to protect federally listed threatened and endangered species, generally through the protection of their habitat (including riparian and aquatic habitats), and it requires federal agencies to cooperate with state and local agencies to resolve water resource issues applicable to protecting endangered species (16 U.S.C. 1535).

NEPA was the first federal legislation in the U.S. to attempt balancing the nation's social and economic needs with a commitment to protect the environment. The Act itself contains no explicit

Table 11. Federal environmental laws potentially applicable to IWRM.

Environmental Law	Purpose
Endangered Species Preservation Act of 1973 (16 U.S.C. §§1531 - 1544)	This Act was enacted to prevent the extinction of species whose populations are approaching extinction "...as a consequence of economic growth and development untempered by adequate concern and conservation..." The Act requires all federal departments and agencies to protect threatened and endangered species, generally through the protection of their habitat (including riparian and aquatic habitats). The Act also states that federal agencies must cooperate with state and local agencies to resolve water resource issues to protect endangered species (16 U.S.C. §1535).
National Environmental Policy Act of 1969 [42 U.S.C. §4321]	This Act was the first federal legislation to attempt balancing the nation's social and economic needs with a commitment to protect the environment. Although the Act itself contains no specific environmental/resource protection requirements, it has had a significant impact on how federal projects are planned and implemented. NEPA requires that all "major federal actions" use a systematic, interdisciplinary approach to evaluate the potential impacts of major actions or projects on the environment, and to vet the assessment and findings with the public.
Wild and Scenic Rivers Act of 1968 (16 U.S.C. 28)	This Act was enacted to: "...implement the policy set out in section 1271 of this title [...certain selected rivers... with their immediate environments...shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations...preserve... selected rivers or sections thereof in their free-flowing condition to protect the water quality of such rivers and to fulfill other vital national conservation purposes."] *...by instituting a national wild and scenic rivers system, by designating the initial components of that system, and by prescribing the methods by which and standards according to which additional components may be added to the system from time to time.* [16 U.S.C. §1272]

water or water-related requirements. Yet, the Act has significantly affected how federal water and water-related projects are planned, and arguably, how they are implemented. This is due to the fact that NEPA requires a systematic and interdisciplinary assessment of the potential costs, benefits, and impacts of major federal actions (e.g., large water projects) on the environment, relative to all viable alternatives. In addition, it requires the results of the analyses to be vetted with the public. Therefore, NEPA allows public scrutiny and input on each major federal action; thereby, allowing the public to help shape which alternative will be implemented and/or whether the project/activity should even be allowed to be implemented.

The Wild and Scenic Rivers Act of 1968 (16 U.S.C. 28) was enacted to protect certain rivers or portions of rivers with "outstanding natural, cultural, and recreational values in a free-flowing condition for the enjoyment of present and future generations" from hydropower development. This Act restricts the Federal Energy Regulatory Commission from licensing the construction of any "... dam, water conduit, reservoir, powerhouse, transmission line, or other project works ..." and it restricts other federal departments and agencies from providing assistance (e.g., loans, grants, or licenses) for any water resource projects that would adversely affect the values for which a given river has been designated or for which a river under study for protection may be proposed for in the future.

International Treaties

The U.S. has a rich history of developing cooperative international fresh water and water related treaties with both of its international neighbors, Canada, and Mexico (IJC 2013a-c, IBWC 2013 a-c and USFWS 2013). These treaties include, in part, the Boundary Water Treaty of 1909 and the Columbia River Treaty of 1961 (NWPCC 2013a) with Canada (IJC 2012 a-c); and the Conventions of 1906, 1933, and 1963 with Mexico; and the Treaty of 1944 with Mexico (IBWC 2013a-c) (Table 12).

The Columbia River Treaty was signed in 1961 and implemented in 1964. It established an agreement for the cooperative development and regulation of hydropower production and flood control in the upper Columbia River Basin. This included the construction and operation of water-storage dams in British Columbia and Montana to provide flood control and to optimize hydropower generation in the Columbia River Basin (NWPCC 2013b).

Table 12. International water treaties potentially applicable to IWRM.

Treaty	Purpose
Boundary Water Treaty of 1909	This Treaty establishes the principles between Canada and the U.S. for the diversion and use of water resources which cross the international boundary (IJC 2012). It requires both countries to agree to new projects that affect natural levels or flows of common water bodies and it bans the discharge of pollutants on either side of the boundary that will cause injury to human health or property on the other side of the boundary. In addition
Columbia River Treaty of 1961	This Treaty established an agreement for the cooperative development and regulation of hydropower production and flood control in the upper Columbia River Basin. The Treaty mandated the construction and operation of three water-storage dams in British Columbia to provide flood control and to optimize hydropower generation in the Columbia River Basin.
The Conventions of 1906, 1933, and 1963 with Mexico	Conventions of 1906, 1933, and 1963 allocated the waters of the Rio Grande in the El Paso-Juárez Valley from El Paso to Fort Quitman; authorized straightening and stabilization of the river boundary between the U.S. and Mexico and provided for flood control in the Paso-Juárez Valley.
Treaty of 1944 with Mexico	This Treaty allocated the water of numerous rivers between the U.S. and Mexico; authorized the two governments to jointly construct, operate, and maintain the dams required for the conservation, storage and regulation flow of the main channel of the Rio Grande River; addressed border sanitation problems; and authorized the two countries to conduct studies on potential hydropower facilities along the border.

A number of freshwater treaties have been signed by the U.S. and Mexico; including the Conventions of 1906, 1933, and 1963, and the Treaty of 1944 (IBWC 2013b). These treaties, implemented by the International Boundary and Water Commission (IWBC) are primarily associated with the storage and allocation of water between the two countries; straightening and stabilization of the river boundaries between the U.S. and Mexico; authorizing the joint construction, operation, and maintenance of dams; addressing border sanitation and water quality problems; and conducting water-related studies along the border.

All water treaties between the U.S. and Canada and Mexico explicitly include surface water quantity and/or water quality issues, and they implicitly or explicitly recognize and they could or do include groundwater resources. For example, both the IJC and the IBWC have conducted scientific studies and have managed groundwater resources based on their respective treaties (Campana, Neir, and Klise 2007). However, for the most part, groundwater is a “hidden resource” under both sets of treaties. Relatively little is known about the groundwater systems along the U.S.’s two international borders, let alone managing these waters as a transboundary resource, either independently or in an integrated manner.

Executive Orders

Grigg (2011) states:

> *The combination of all legislation, executive orders and judicial decisions comprise national water policy.*

In the U.S., Congress establishes policies, laws, and budgets for the federal government and the judicial branch ensures that, among other things, the federal policies and laws are constitutional and that the executive branch implements them according to the applicable statute. Executive Orders are the administrative tool the President uses to provide management direction to Executive Branch agencies for implementing those federal policies, laws, and budgets. Each President has discretion in how he actually implements the established policies, laws, and budgets, as long as they are implemented within the letter of the law.

Historically, there are more than 40 executive orders that have/had some bearing on federal water and water-related activities (National Archives 2013). Some orders were used to develop water and water-related programs and activities, and some were used to kill water and water-related programs and activities. For example, Executive Order 11988, “Floodplain Management,” signed by President Carter in 1977, requires each federal agency to provide leadership and take action to reduce the risk of flood loss to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural and beneficial values provided by floodplains. Conversely, Executive Order 12319, "River Basin Commissions," signed by President Reagan in 1981, dissolved the Pacific Northwest River Basins, Great Lakes Basin, Ohio River Basin, New England River Basins, Missouri River Basin, and Upper Mississippi River Basin Commissions.

Executive Orders can be a very important tool for the President relative to providing direction, and improving coordination and cooperation between federal agencies. Executive Orders are vital for improving the efficiency and effectiveness of federal agencies, programs, and processes. However, the impact of executive orders can be very short lived (e.g., less than the term of the President who issues the order) or they can be relatively long-term in their impact (e.g., Executive Order 11988 has been in place since 1977).

State and Tribal Water Policies and Laws

State-specific land and environmental policies and laws are too large and diverse to tackle in this dissertation. Therefore, the discussion below is primarily focused on state and tribal water allocation and water quality policies and laws.

State and Tribal Water Allocation Policies and Laws

States generally have authority over the allocation and use of most water within their jurisdiction (e.g., 1866 Mining Act [30 U.S.C. 51 and 43 U.S.C. 661], Desert Land Act of 1877 [43 U.S. Code § 321], and California Oregon Power Co. v. Beaver Portland Cement Co., 1935). Federally-recognized Indian tribes with federally-recognized reservations have "ownership" over the water on their reservation via their treaty rights. In addition, under the concept of "cooperative federalism" states and Indian tribes have the ability to gain authority (primacy) over a number of federal environmental protection programs (Goldfarb 1989).

Relative to water allocation, state water policies and laws in the U.S. vary widely in their policies and laws, even when implementing similar legal doctrines in nearby locations (e.g., between two or more adjoining states that implement riparian rights water law). How each state uses and regulates water within their jurisdiction is unique and based on a number of factors such as the physiographic characteristics (e.g., climate, hydrology, and geology), population demands, socioeconomic and cultural background, needs and desires of its current citizenry, and historical legal precedence's. State water quality laws are much more uniform in the U.S., since federal water quality laws require states to, at a minimum; meet all of the legal and procedural requirements contained within the federal law. State water quality laws can be more stringent but not less stringent than the federal law.

State Water Allocation

State water allocation laws generally govern three or four sources of water depending on the given state. These include atmospheric water, diffused surface water, surface waters in defined water bodies (e.g., streams and lakes), and/or groundwater. The water allocation laws associated with each of these potential sources of water supply are summarized below.

Atmospheric Water

Atmospheric water is the ultimate natural water supply for all freshwater sub-basins and watersheds and therefore, should be considered and ideally, integrated as part of comprehensive state water resources planning and management programs.

Historically, weather modification projects (e.g., cloud seeding) in the U.S. have been focused on precipitation enhancement, hail suppression, and fog dissipation (NRC 2001). They were primarily located in the southern and western states and sponsored by local, state, or private (non-federal) entities. Weather modification research peaked in the U.S. in the 1970s (NRC 2001). However, weather modification research and management projects are still being conducted in the U.S. and other countries (WMA 2015 and WMI 2015).

Professor Ray J. Davis was probably the most prolific legal scholar in the U.S. to write on state weather modification policies and laws (Davis 1975, 1974, 1970, and 1968). Unfortunately, relatively little information has been published on this topic in the past 30 or so years. Of the states that have policies or laws regulating weather modification, most are generally focused on ensuring that commercial weather modification companies are competent and are financially capable of compensating those harmed by weather modification activities (Standler 2006), and/or on authorizing funding for research and/or operations within the State (CRS 1978). Some state policies and laws encourage the development and use of weather modification technologies. Other states discourage such activities. The only federal law associated with atmospheric water management is 15 U.S.C 330 (Weather Modification Activities or Attempts; Reporting Requirement), which requires the reporting of weather modification activities to the Secretary of Commerce (Standler 2006).

Thirty states appear to regulate weather modification activities in some fashion. These states include: Arizona, California, Colorado, Connecticut, Florida, Hawaii, Idaho, Illinois, Iowa, Kansas, Louisiana, Massachusetts, Minnesota, Montana, Nebraska, Nevada, New Hampshire, New Mexico, North

Dakota, Oklahoma, Oregon, Pennsylvania, South Dakota, Texas, Utah, Washington, West Virginia, Wisconsin, and Wyoming (Busto 2008, DiGiulian and Charak 1974, CRS 1978, and Farhar and Mewes 1975) (see Appendix A).

Diffused Surface Water

Diffused surface water generally includes precipitation and unconsolidated overland flow prior to its entry into a natural water body or water course. Legally, the regulation of diffused surface water has been generally "ill-defined and …until recently, [it has] been all but ignored in practice and theory…" and the little focus there was on diffused surface water was usually associated with surface water drainage rather than consumptive use (Dellapenna 1991a). However, there are two issues associated with diffused water (1) the right to dispose of diffused water (e.g., drainage) and (2) the right to capture and use it (Beck 1991a, Dellapenna 1991f, and Getches 1990).

Relative to disposing of water, there have been three approaches practiced in the U.S. (1) the natural flow, (2) the common enemy, and (3) the natural servitude doctrines. Under the natural flow doctrine, a land owner has no right to impede the flow of diffused water over his/her land (e.g., overland flows and floods). The common enemy doctrine generally allows a land owner to protect their property from damage caused by diffuse water without liability as long as the work is accomplished in good faith, is not negligent, and does not cause substantial harm; hence, it meets the concept of reasonable use (Getches 1990). Under the natural servitude doctrine, much like the natural flow rule for surface waters, a landowner has the right/obligation to drain the land as it would drain naturally. However, the landowner also has the obligation to receive overland flow from the natural drainage of adjoining lands (Dellapenna 1991f). Most eastern states have adapted the "reasonable use" doctrine relative to disposing diffuse water (Beck 1991a and1991b and FEMA 2014), as have most western states (Beck 1991a).

Relative to using diffused water for a beneficial use, with few exceptions, eastern common law riparian states consider diffused water to belong to the owner of the property where it is found (Dellapenna 1991a, FEMA 2014, and Getches 1990). Relative to regulated riparian states, only Delaware and Virginia actually regulate the use of diffused surface water (Dellapenna 1991a). Ten regulated riparian statutes expressly exclude some or all diffused surface waters from their statutory scheme (Arkansas, Georgia, Indiana, Iowa, Kentucky, Maryland, Massachusetts, Minnesota, Mississippi, and Wisconsin) (Dellapenna 1991a). Western states that regulate diffused water for beneficial use generally regulate it as part of their surface water appropriation system (Getches 1990).

Surface Water

All surface water rights in eastern states are based on the common-law principle that land owners adjacent to surface water bodies (riparians) have an equitable right to utilize that water source to meet their needs. Historically, the common-law riparian doctrine for surface water was based on two variations, the natural flow (English rule) and reasonable use (American rule) doctrines (Beck 1991a). Under the Natural Flow Doctrine, riparian land owners were allowed to utilize the water and water-related resources in-stream, but they could not block flows or withdraw water from the surface water body; thus, protecting the natural flow in streams. However, since the advent of the industrial revolution, essentially all eastern states have adopted the “reasonable use” doctrine (Getches 1990).

The reasonable use doctrine allows riparians to withdraw and use surface water on their land as long as those withdrawals/uses do not unreasonably interfere with other riparian owner’s opportunity for reasonable use from that source (Getches 1990 and Weston 2007). What is considered to be reasonable is determined by “a myriad of factors” and on a case-by-case basis (Weston 2007). In most common-law riparian states, all water withdrawn must be used on the riparian’s land and generally it cannot be transferred to other non-riparian lands or uses.

Thirteen states practice reasonable use riparian water law for managing surface water allocations, including: Arkansas, Illinois, Indiana, Louisiana, Maine, Missouri, New Hampshire, Pennsylvania, Rhode Island, Tennessee, Vermont, Virginia, and West Virginia (Table 13 and Appendix A).

However, many of eastern states experiencing increased competition and conflicts over water resources have modified their riparian water laws and management programs to what is known as the Regulated Riparian Doctrine (ASCE 1997, NALC 2014, and Weston 2007). Common features among regulated riparian systems include (Dellapenna 1991d and Weston 2007):

- Enactment of an administrative permitting or withdrawal approval program, typically applicable to new, expanded, and (sometimes) existing withdrawals in excess of a trigger quantity
- Assignment of an executive agency (e.g., a board, commission, or department) to oversee, implement, and enforce the withdrawal approval program
- Statutory or regulatory declaration of policies and criteria governing the approval and operation of regulated withdrawals (frequently involving a restatement or adjustment of reasonable use principles)

Table 13. States doctrines for allocating surface water
(modified from Dellapenna 2015 and 2013).

Appropriative Rights	Hybrid (Riparian & Appropriative Rights)	Reasonable Use	Regulated Riparian
Arizona	Alaska[1]	Arkansas[2]	Alabama[2]
Colorado	California	Illinois	Connecticut
Idaho	Kansas	Indiana	Delaware
Montana	Nebraska	Louisiana[3]	Florida
Nevada	North Dakota	Maine	Georgia
New Mexico	Oklahoma	Missouri	Hawaii[4]
Utah	Oregon	New Hampshire	Iowa
Wyoming[5]	South Dakota	Pennsylvania	Kentucky
	Texas	Rhode Island	Maryland
	Washington	Tennessee	Massachusetts[3]
		Vermont	Michigan[5]
		Virginia[2]	Minnesota
		West Virginia	Mississippi
			New Jersey
			New York[5]
			North Carolina
			Ohio
			South Carolina
			Wisconsin

1. Many authors agree that Alaska is an appropriative rights state. However, some question whether it has truly extinguished all of its riparian rights, as it never compensated the holders of riparian rights (Dellapenna 2015). Generally, taking such rights would be unconstitutional without compensation, and it is not clear that these water users were ever compensated for their losses (Dellapenna 2015).
2. State has enacted a regulated riparian statute water allocation; however, it has largely failed to implement it.
3. Louisiana follows riparian principles, but as derived from French law and expressed in its civil code rather than as part of the common law tradition.
4. Hawaii has a compound of ancient customary and prescriptive rights and regulated riparianism.
5. The state has enacted a regulated riparian statute that applies only to very large users on certain water sources.

- A dispute resolution process for addressing conflicts between water users (such as interference between wells or interference with stream flows).

In regulated riparian states, a designated agency is responsible for reviewing, registering, and/or permitting water uses in advance of a water user appropriating the water. The agency is authorized to determine who may use the water and how much water constitutes a reasonable use relative to the needs of other water users and other societal needs. Unlike common-law riparian or prior appropriation states, the agency can set the duration of the given use through a permitting system, typically based upon the cost and resource commitments required to develop the resource (ASCE 1997 and Dellapenna 1991f). Permits can also be adjusted to meet public interest criteria during times of shortage and/or to protect environmental resources. Some regulated riparian states only require permits for large withdrawals and consumptive uses (e.g., Michigan and New York).

Nineteen states have adopted some version of a regulated riparian system for managing surface water allocations. Eighteen eastern states have adopted the regulated riparian doctrine, including; Alabama, Connecticut, Delaware, Florida, Georgia, Iowa, Kentucky, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, New Jersey, New York, North Carolina, Ohio, South Carolina, and Wisconsin (ASCE 1997, Dellapenna 2013, and MSU-IWR 2007). Hawaii is the only western state that utilizes a regulated riparian system for allocating surface waters (Table 13 and Appendix A).

Every western state has established administrative and permitting processes (with the exception of Colorado, which uses water courts rather than a permitting process) (Getches 1990). In addition, they have management programs; an executive agency which oversees the implement and enforcement of water allocation and use; statutes, regulations, policies, and criteria for approving and regulating water withdrawals and use; and a dispute resolution process for addressing conflicts between surface water users (Getches 1990).

With the exception of Hawaii, all western states utilize the Appropriative Rights Doctrine (Prior Appropriation Doctrine) (e.g., “first in time, first in right”), in part or whole, for allocating surface water. The specifics of each state’s water program vary. In general, under the Appropriative Rights Doctrine anyone may withdraw and use a reasonable amount of water from a water body for a state-approved beneficial use wherever they wish to use it, if the water is physically available, it is not already appropriated for another state-recognized beneficial use, and as long as it is used without waste (Getches 1990).

Eight western states use the Appropriative Rights Doctrine exclusively for managing surface water appropriations. Of these states, six have always embraced the prior appropriation doctrine, arguably having never recognized any form of riparianism for regulating consumptive water use. These states include: Arizona, Colorado, Idaho, New Mexico, Utah, and Wyoming (Beck 1991b and Getches 1990). Montana and Nevada originally adopted the riparian doctrine and then completely extinguished those rights and converted them to the Appropriative Rights Doctrine (Beck 1991b and Getches 1990) (Table 13 and Appendix A).

In addition, 10 western states utilized a dual (or hybrid) appropriation system for managing surface water allocations (Dellapenna 1991c). Each of these states has both humid and arid regions within their jurisdiction; therefore, they developed a riparian water rights system for the humid-areas within their state and an appropriative rights water rights system for the arid-areas within their state. California is the only western state that still retains an active common law riparian water-right system; hence, water users can still apply for new riparian water rights (Getches 1990). The remaining states extinguished their riparian water-rights systems to the extent they could (Beck 1991b). However, in these hybrid states existing riparian water rights were generally considered to be private property rights and the courts ruled that vested rights were protected from the changes in water law schemes (Getches 1990). Therefore, water rights vested prior to the state adopting the prior appropriation doctrine where grandfathered into their new permit systems. However, water users in these states cannot apply for new riparian water rights.

Ten western states use the hybrid doctrine for surface water allocation, including: Alaska, California, Kansas, Nebraska, North Dakota, Oklahoma, Oregon, South Dakota, Texas, and Washington (Table 13 and Appendix A).

Groundwater Water

In general, there are five basic variations of groundwater law practiced in the U.S. These include the absolute dominion, appropriative rights, correlative rights, reasonable use, and regulated riparian doctrines (Getches 1990, NCSL 2013, and Weston 2007).

The Absolute Ownership Doctrine (also called the "rule of capture") provides a landowner the absolute right to utilize any and all groundwater beneath his or her land (NAP 1997). This doctrine allows the owner to pump as much groundwater as he or she wishes, for whatever purposes desired, without incurring any liability relative to harming neighboring owners (Beck 1991a and Getches 1990). In general, this doctrine was developed prior to hydrologists developing a sufficient understanding of the location and movement of groundwater; therefore, many states considered it to be unfair to hold groundwater pumpers liable for harm caused to neighboring landowners when the state was unable to quantify the specific impacts of pumping on other water users.

Three states have adopted some form of the Absolute Ownership Doctrine for managing groundwater appropriations. The eastern states using this system include Indiana and Maine. Texas is the only western state which utilizes this doctrine for managing groundwater appropriations (NCSL 2013) (Table 14 and Appendix A).

Appropriative rights for groundwater resources generally follow the same rules and requirements as for surface waters (e.g., "first in time, first in right"). The specifics of each state's program vary. However, in general, under the appropriative rights doctrine anyone may withdraw and use a

Table 14. States doctrines for allocating groundwater.[6]

Absolute Dominion	Appropriative Rights	Correlative Rights	Reasonable Use	Regulated Riparian
Indiana	Alaska	California	Arkansas[1]	Alabama[2,3]
Maine	Colorado	Nebraska[4]	Georgia[1]	Arizona[3,5]
Texas	Idaho		Louisiana	Connecticut[2]
	Kansas		Missouri	Delaware[2]
	Montana		New York	Florida[2]
	Nevada[6]		Ohio	Hawaii[2]
	North Dakota		Oklahoma	Illinois[5]
	New Mexico		Pennsylvania	Iowa[2]
	Oregon		Rhode Island	Kentucky[2]
	South Dakota		South Carolina[1]	Maryland[2]
	Utah[6]		Tennessee	Massachusetts[2]
	Washington		Vermont	Michigan[2]
			Virginia[1]	Minnesota[2]
			West Virginia	Mississippi[2]
			Wisconsin[1]	New Hampshire[5]
			Wyoming	New Jersey[2]
				North Carolina[2]

1. State has regulated riparian statutory provisions for managing surface water allocations, but uses reasonable use for groundwater (Dellapenna 2013).
2. State has regulated riparian statutory provisions for managing surface water and groundwater resources, under a single statute. Hence, it has an integrated surface water/groundwater allocation system (Dellapenna 2013).
3. State has regulated riparian statutory provisions; however, it does not appear to actually utilize those provisions (Dellapenna 2015).
4. Nebraska has statutory provisions for managing its groundwater resources using correlative rights; however, it also appears to manage these resources using a regulated riparian approach (Dellapenna 2013).
5. State has regulated riparian statutory provisions for groundwater and uses reasonable use for surface water allocations (Dellapenna 2013).
6. State has statutory provisions for managing both surface water and groundwater resources using appropriative rights under a single statute, as a single source. Hence, it has an integrated surface water/groundwater system (Hazard and Shively 2011).

reasonable amount of water from an aquifer for a state- approved beneficial use, wherever they wish to use it, if the water is physically available, it has not already allocated for another state-recognized beneficial use and as long as it is used without waste (Getches 1990). However, some states establish specific rules relative to establishing safe yields or equivalent requirements to protect aquifer levels and/or artesian pressures. In addition, some states have specific requirements relative to protecting surface-water water- rights in hydrologically interconnected surface water bodies (e.g., they require conjunctive management).

Twelve of the 17 western states use the appropriative rights doctrine for managing groundwater appropriations, including: Alaska, Colorado, Idaho, Kansas, Montana, Nevada, North Dakota, New Mexico, Oregon, South Dakota, Utah, and Washington (Table 14 and Appendix A). Nevada and Utah have appropriative rights statutory provisions for managing both surface water and groundwater resources as a single source, under a single statute. Hence, they have integrated surface water/groundwater systems (Hazard and Shively 2011). However, in Nevada, this only applies in areas where the State Engineer determines surface water and groundwater are hydrologically interconnected.

Under the Correlative Rights Doctrine, generally speaking, each land owner in a basin has an equal right to use groundwater from an underlying aquifer(s) within their basin as long as the user doesn't significantly deplete a neighbor's supply (Getches 1990 and Goldfarb 1989). During times of shortage, each land owner is generally allotted an equal proportionate share (i.e., a right to his or her percentage share of the maximum annual yield of the basin, relative to the percentage of land they own within the basin). When there are conflicts between water users, the state may allocate water resources to the most beneficial use, giving consideration to a wide variety of factors, including the priority of use and whether the use is reasonable.

California uses correlative rights for managing all groundwater resources in the state. Nebraska also utilizes correlative rights to manage its groundwater resources; however, it also appears to manage it groundwater resources as a regulated riparian system (Dellapenna 2013) (Table 14 and Appendix A).

Many eastern states utilize the Reasonable Use Doctrine for managing groundwater resources. Under this doctrine, landowners are entitled to pump groundwater from beneath their own land and use it on their land as long as those withdrawals/uses do not unreasonably interfere with other groundwater pumper's opportunity for reasonable use from that source and as long as the water is not wasted or used maliciously (Dellapenna 2013 and Weston 2007). Note that while this doctrine is called the reasonable use doctrine, most eastern states generally hold that almost all water uses made on the lands from which it is extracted are "reasonable" unless the use is malicious or the water is being wasted. Therefore, there is really little difference in practice between the absolute and reasonable use doctrines relative to groundwater management in many states in the east (Weston 2007).

Sixteen states utilize the Reasonable Use Doctrine for managing groundwater allocations. Fifteen eastern states use the Reasonable Use Doctrine, including; Arkansas, Louisiana, Georgia, Louisiana, Missouri, New York, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Tennessee, Vermont, Wisconsin, Virginia, and West Virginia. Wyoming is the only western state that uses the Reasonable Use Doctrine for groundwater allocation (Table 14 and Appendix A).

Seventeen states have adopted the Regulated Riparian Doctrine for regulating groundwater withdrawals, either independently or in conjunction with surface water. These states essentially implement the Reasonable Use Doctrine relative to groundwater, but through a formal permitting/

management system, as discussed above. However, how rigorously each state implements their statutes varies greatly between the states (Dellapenna 2013 and 2014).

Fifteen eastern states utilize the Regulated Riparian Doctrine for managing groundwater allocations. Fourteen of these states manage both their surface water and groundwater resources under the same statute, including: Alabama, Connecticut, Delaware, Florida, Illinois, Iowa, Kentucky, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, New Jersey, and North Carolina. New Hampshire has regulated riparian statutes for allocating groundwater only. Arizona and Hawaii are the only western states that use the Regulated Riparian Doctrine for groundwater allocation (Table 14 and Appendix A). Arizona manages groundwater in Active Management Areas (AMAs) like a regulated riparian water rights program (Dellapenna 2015) and it manages groundwater outside those management areas using the Reasonable Use Doctrine.

Since Arizona, Illinois, and New Hampshire only implement regulated riparian systems for groundwater and use other systems for surface water allocation, it would be difficult for them to manage their surface water and groundwater resources conjunctively. However, since the same state water management agencies manage both the surface water and groundwater resources in these states, those agencies may have some discretion that could allow them to effectively integrate surface water and groundwater allocations in the future (Dellapenna 2013).

The Restatement (Second) of Torts (Restatement), written by the American Law Institute, is a review of the general principles of common law in the U.S. The Restatement is used by some riparian states to help balance inequities and hardships between competing water users (Weston 2007). While some experts claim that some states implement the restatement as a matter of law for groundwater allocation (Delleur 2006), others argue that the restatement is essentially a clarification of how the reasonable use doctrine should be implemented during a conflict, not a separate water law doctrine in itself (Dellapenna 2015). This analysis follows the latter train of thought and lists the supposed “restatement states” (i.e., Michigan, Ohio and Wisconsin) with the reasonable use states.

Tribal Water Rights

A summary of federally-recognized Native Alaskan and Native American trust lands is provided by the Bureau of Indian Affairs (BIA; BIA 2015b). According to the BIA (2015b), approximately 370 treaties were ratified by Congress between 1778 and 1871. At present, there are 566 federally recognized Native Alaskan and Native American tribes and villages. However, not every federally-recognized tribe has a reservation. According to Walke (2015), 229 of those federally-recognized tribes are Alaska Native tribes within the State of Alaska. Of the approximately 326 Indian land areas designated as federally-recognized Indian reservations (e.g., reservations, pueblos, rancherias, missions, villages, and communities), only one reservation is located in Alaska: the Annette Island Reserve of the Metlakatla Tribe (Walke 2015).

In addition to federally-recognized reservations, the U.S. government allotted lands directly to individual tribal members in the continental U.S. (BIA 2015b). From 1778 to 1885, over 11,000 patents were issued to individual tribal members under various treaties and laws (BIA 2015b). However, since the allotments were taken out of trust (i.e., restricted status or restricted fee lands), they became subject to state and local taxation; therefore, thousands of acres of lands passed out of tribal control (BIA 2015b). Between 1887 and 1934, allotments were conveyed to individual tribal members and held in trust by the federal government. In addition, thousands of individual trust lands were allotted in Alaska under the Alaska Native Allotment Act of 1906 (34 Stat. 197; 48 U.S.C. 376–377) and the Alaska Native Townsite Act of 1926 (44 Stat. 629; 43 U.S.C. 733–736) (Walke 2015).

In 1971, the Alaska Native Claims Settlement Act (Public Law 92-203) (ANCSA) established Alaskan Native corporations (i.e., regional, village, urban, and group level corporations) as separate legally incorporated entities. Therefore, unlike Native American tribes, members of the Alaskan Native tribes may have individual ownership in non-trust, fee-simple lands and shares in a village, regional, urban group or corporation that that owns ANCSA lands and resources. However, water rights are not explicitly addressed in the ANCSA. Therefore, it is not certain whether water resources associated with corporate lands are owned by the corporation, if they are appurtenant to the land as water rights that are owned by the state of Alaska or if this issue still needs to be settled in the future.

Currently, there are approximately 10 million acres of land still held in trust for individual Alaskan Native and Native American allotees and their heirs (BIA 2015b). Collectively, there is a total of approximately 56.2 million acres of land held in federal trust by the U.S. government for federally recognized tribes and individuals. In addition, it should be noted that some states have state-recognized Indian reservations, where lands are held in trust by the state for Indian tribes.

All federally-recognized reservations and trust lands have associated Federal Reserved Water Rights, which are held in trust for the given federally recognized Indian tribe or individual allottee by the U.S. Government. These water rights remain unquantified and available for use by the appropriate tribe(s), unless those rights are integrated into a state water allocation program via adjudication under the McCarran Act or via a negotiated settlement.

According to the U.S. Supreme Court's decision in Cappaert v. United States, (426 U.S. 128, 1976), the quantity of water that will be allotted to a given reservation is based on the amount of water necessary to meet the implicit or explicit intent of the reservation; that amount will be based on "only that amount of water necessary to fulfill the purpose of the reservation, no more" (quoted in Getches 1990). However, based on Arizona v. California (373 U.S. 546, 1963) once the quantity of the water rights has been established for a reservation, the Indian tribe(s) associated with the reservation may use those rights for purposes other than the original purposes (Getches 1990). Hence, the original purpose of the reservation is used to establish the total quantity of water to be allotted to the reservation, but not necessarily for establishing the beneficial uses that the allotment can be used for.

How water rights are managed on reservations by the various Indian tribes is not well documented or well vetted in the literature. Therefore, it is not clear what specific legal doctrines and process are used or how successfully water allocation is implemented on the various reservations. This remains an important area of future research.

State and Tribal Water Quality Policies and Laws

Unlike water resource management and allocation, which is primarily under state authority, the federal government has primary responsibility for the development and implementation of environmental quality policies and laws (e.g. CWA, SDWA, RCRA, and CERCLA) in the U.S. Relative to water quality, this is due to the fact that, in general, most states historically resisted balancing the costs and benefits of economic growth with the protection of human health and the environment. According to Beck (1991c), relative to passing the CWA:

Congress originally tried to cajole, encourage and entice the states to enact comprehensive water quality and pollution control legislation. This effort, in the eyes of Congress, had failed. Too many rivers, lakes and wetlands areas were still being used to dispose of waste rather than to support life and health. Therefore, Congress passed the CWA of 1972 and retained overall responsibility for regulating water pollution control at the federal level (Beck 1991c).

Of all the federal water-quality-related policies and laws, the SDWA and CWA are clearly the most important and overarching in the U.S. relative to protecting human health and the environment from water pollution. These acts establish national standards for drinking water and surface water quality that must be implemented in all federally regulated waters in the U.S.

Under the concept of cooperative federalism, Congress has authorized EPA to give states and tribes the authority (primacy) over certain environmental laws (e.g., SDWA and CWA) within their jurisdictions (Goldfarb 1989). Therefore, states and tribes can choose to develop their own water quality standards and programs or remain federally regulated. However, in order to gain primacy the states and tribes must meet at least the minimum federal water quality requirements in all federally regulated waters (i.e., in waters of the U.S. for the CWA and in known or potential drinking water sources for public water supplies for the SDWA). States and tribes can choose to voluntarily implement more stringent requirements in federally regulated waters (40 CFR 123.25) and/or develop their own state-based water quality programs for waters that are not regulated by the SDWA or the CWA (e.g., certain intra-state or intra-reservation waters).

The requirements for obtaining state primacy over SDWA programs can be found under §1413 and §1451 of the SDWA (see 40 CFR 142, Subpart B), and §§304(i), 101(e), 405, and 518(e) for obtaining state primacy over CWA (see 40 CFR 123). The requirements for Indian tribes to obtain primacy can be found under §1451 of the SDWA and §518 under the CWA (see 40 CFR 123.33 and 501.12). Indian tribes have one more set of requirements than states in order to apply for primacy under both the SDWA and CWA. Indian tribes must first apply for and receive treatment as states (TAS) status (DOE 1998 and EPA 2008) by demonstrating that they:

- Are a federally-recognized tribe
- Have and are able to exercise substantial governmental powers over their reservation
- Have the appropriate authority (jurisdiction) over the area they wish to administer (e.g., over surface water or groundwater resources on their reservation)
- Be reasonably expected to have the capability to effectively implement a program.

Criteria 1, 2, and 4 are identical for both the SDWA and for the CWA. The third criterion is slightly different between the two acts. For the CWA, a tribe must show that the functions to be exercised by the Indian tribe pertain to the management and protection of water resources which are (1) held by an Indian tribe, (2) held by the U.S. in trust for Indians, (3) held by a member of an Indian tribe if such property interest is subject to a trust restriction on alienation, or (4) otherwise within the borders of an Indian reservation (Royster and Blumm 2002). For the SDWA, a tribe must show that the functions to be exercised by the Indian tribe are within the area of the tribal government's jurisdiction. Based on the difference in language, the EPA has determined that a tribe may seek TAS under the CWA for the surface waters within its reservation only, whereas it does not limit a tribe under the SDWA from applying for TAS as to "any lands over which it believes it has jurisdiction" (Royster and Blumm 2002).

Once an Indian tribe achieves TAS status, like states, it must develop the appropriate water quality programs that meet the minimum federal programmatic and regulatory requirements under the SDWA and/or CWA and then apply to EPA for the appropriate authority. Of the 325 federally-recognized Indian reservations in the U.S. (BIA 2015b), 49 Indian tribes have achieved TAS status and are currently eligible to administer SDWA and CWA programs (DOE 1998 and EPA 2015c) (Table 15).

Table 15. Indian tribes approved to administer SDWA and CWA water quality standards programs (EPA 2015c).

EPA Approved WQS (in Part or Whole)			Eligible but not EPA Approved WQS
Assiniboine and Sioux Tribes of the Fort Peck Indian Reservation (MT)	Lac du Flambeau Band of Chippewa (WI)	Pueblo of Pojoaque (NM)	Blackfeet Tribe (MT)
Bad River Band of Lake Superior Chippewa (WI)	Lummi Tribe (WA)	Pueblo of Sandia (NM)	Confederated Tribes of the Colville Reservation (WA)*
Big Pine Band of Owens Valley (CA)	Makah Indian Nation (WA)	Pueblo of Santa Clara (NM)	Dry Creek Rancheria Band of Pomo Indians (CA)
Coeur d'Alene Tribe (ID)	Miccosukee Tribe (FL)	Pueblo of Taos (NM)	Eastern Band of Cherokee Indians (NC)
Confederated Salish and Kootenai Tribes of the Flathead Reservation (MT)	Mole Lake Band of the Lake Superior Tribe of Chippewa Indians, Sokaogon Chippewa Community (WI)	Pueblo of Tesuque (NM)	Havasupai Tribe (AZ)
Confederated Tribes of the Chehalis Reservation (WA)	Navajo Nation (AZ, NM, UT)	Puyallup Tribe of Indians (WA)	Pawnee Nation (OK)
Confederated Tribes of Umatilla (OR)	Northern Cheyenne (MT)	Pyramid Lake Paiute (NV)	Shoshone-Bannock Tribes (ID)
Confederated Tribes of the Warm Springs Reservation (OR)	Ohkay Owingeh (NM) (formerly the Pueblo of San Juan)	Seminole Tribe (FL)	Swinomish Indian Tribal Community (WA)
Fond du Lac Band of Chippewa (MN)	Paiute-Shoshone Indians of the Bishop Community (CA)	Spokane Tribe of Indians (WA)	Tulalip Tribes (WA)
Grand Portage Band of Chippewa (MN)	Port Gamble S'Klallam (WA)	St. Regis Mohawk Tribe (NY)	Twenty-Nine Palms (CA)
Hoopa Valley Tribe (CA)	Pueblo of Acoma (NM)	Ute Mountain Ute (CO)	
Hopi Tribe (AZ)	Pueblo of Isleta (NM)	White Mountain Apache Tribe (AZ)	
Hualapai Indian Tribe (AZ)	Pueblo of Nambe (NM)		
Kalispel Indian Community (WA)	Pueblo of Picuris (NM)		
* The Colville tribe's WQS program is a federal program developed by EPA.			

Currently, all states except Wyoming have received primacy to implement the SDWA within their boundaries (ECOS 2015a). In addition, 46 states have primacy over the CWA NPDES program within their jurisdiction; ID, MA, NH and NM currently do not have primacy (ECOS 2015) (Table 16). SDWA §1451 authorizes Indian tribes to apply for development grant and contract assistance (§1442–1444), for primacy over the public water systems (§1412–1416) and underground injection control programs (1422–1425). In addition, EPA treats Indian tribes the same as states for the Sole Source Aquifer Demonstration Program (§1427) and the State Programs to Establish Wellhead Protection Areas (§1428). However, only one tribe to date, the Navajo Nation, has received primacy under the SDWA (EPA 2008).

Currently, all states have received primacy to implement most CWA programs within their jurisdictions (ECOS 2015a) (Table 16). CWA §518 authorizes TAS status for a number of programs including: allocation of quantities of water within the tribes' jurisdictions (§101(g)), various grant programs (§§104, 106, 205(j)(1–4)), 319(j)), water quality standards (§303), nonpoint source management (§303(d)), water quality inventory (§305), inspections, monitoring and entry (§308), federal enforcement (§309), clean lakes (§314), groundwater quality protection (§319(j)), certification (§401), the national pollution discharge elimination system (NPDES) (§402), dredge and fill permits (§404), and sewage sludge management (§405) (DOE 1998). However, presently, the only CWA program that Indian tribes can actually apply for primacy is the Water Quality Standards (WQS) program on their reservation under §303 of the Act. Although EPA states that it desires to expand the authority for Indian tribes to administer other CWA programs on Indian reservations, it has yet to develop the processes and requirements necessary to authorize the tribes to engage in the same suite of authorities that the states can currently obtain from EPA (Zokan 2015).

Of the 49 Indian tribes that have achieved TAS status and are currently eligible to administer CWA programs (Table 15), EPA has approved at least initial WQS for 40 Indian tribes and it has promulgated one federal WQS, for the Colville Indian tribe (EPA 2015c). EPA has approved 27 Indian tribes to set water quality standards under §303 of the CWA (EPA 2008). However, currently, no Indian tribes have been given authority to craft their own 303(d) list of impaired waters (Bridges 2015). In addition, no Indian tribe has been approved to administer a §301 NPDES program to date, as there has not been a TAS process established for them to assume that role (Zokan 2015).

Interstate Compacts

Interstate compacts are congressionally-approved legal agreements between two or more states. There are at least 45 water-related interstate compacts and/or commissions in the U.S. (Table 17). Of these,

Table 16. State delegations for Safe Drinking Water Act and Clean Water Act[1].

State	SDWA[2]	CWA					
		Construction Grants	NPDES 402	Pretreatment	Sludge Management	State Revolving Fund	Wetlands
AL	Y	Y	Y	Y	N	Y	N
AK	Y	Y	N	N	N	S	N
AZ	Y	S	N	N	N	S	N
AR	Y	Y	Y	Y	N	S	N
CA	Y	S	Y	Y	N	S	N
CO	Y	Y	P	IN	IN	Y	ND
CT	Y	Y	Y	Y	N	Y	N
DE	Y	Y	Y	N	N	S	N
DC	Y	N	N	N	N	N	N
FL	Y	Y	P6	Y	N	Y	N
GA	Y	Y	Y	Y	IN	Y	N
HI	Y	S	Y	Y	IN	S	N
ID	Y	Y	N	N	N	S	N
IL	Y	Y	Y	N	S	S	N
IN	Y	Y	Y	N	S	S	N
KS	Y	Y	Y	N	N	Y	N
LA	Y	Y2	Y	Y	N	S	N
ME	Y	Y	N	N	N	Y	N
MD	Y	NA	Y	Y	N	S	N
MA	Y	Y	N	N	N	Y	N
MI	Y	Y	Y	Y	S	S	Y
MN	Y	Y	Y	Y	S	S	N
MS	Y	N9	Y	Y	N	Y	N
MO	Y	Y	Y	Y	N	Y	N
MT	Y	Y	Y	N	N	Y	ND
NE	Y	Y	Y	Y	N	Y	N
NV	Y	S	Y	N	N	S	N
NH	Y	Y	N	N	N	Y	N
NJ	Y	Y	Y	Y	N	S	Y
NM	Y	Y2	ND	ND	ND	S	N
NY	Y	Y	Y	N	N	S	N
NC	Y	Y	Y	Y	N	Y	N
ND	Y	Y	Y	N	N	Y	ND
OH	Y	Y	Y	Y	N	S	N
OK	Y	Y2	Y	Y	Y	S	N
OR	Y	Y	P	Y	Y	S	N
PA	Y	Y	Y	N	N	S	N
PR	Y	N	Y	N	N	N	N
RI	Y	Y	Y	Y	N	Y	N
SC	Y	Y	Y	Y	N	Y	N
SD	Y	Y	Y	Y	N3	Y	ND
TN	Y	Y	Y	Y	N	Y	N
TX	Y	Y2	N	N	N	S	N
UT	Y	Y	Y	Y	Y	Y	ND
VT	Y	Y	Y	Y	N	Y	N
VA	Y	Y	Y	Y	N	S	N
WA	Y	Y	P	Y	Y	S	N
WI	Y	Y	Y	Y	S	S	N

State	SDWA[2]	CWA					
		Construction Grants	NPDES 402	Pretreatment	Sludge Management	State Revolving Fund	Wetlands
WV	Y	Y	Y	Y	N	S	N
WY	N	Y	Y	N	N	Y	ND

1. Source: Modified from The Environmental Council of the States (ECOS 2015b) http://www.ecos.org/section/states/enviro_actlist/states_enviro_actlist_cwa?printable=1

2. SDWA programs include: development grant and contract assistance (§1442 – 1444), public water systems (§1412 - 1416), underground injection control programs (1422 - 1425), Sole Source Aquifer Demonstration Program (§1427), and the State Programs to Establish Wellhead Protection Areas (§1428).

Key to abbreviations in delegation tables: I - Interim Status state is operating the program pending final EPA authorizations; A - Approved State program or State Implementation Plan -- state's plan for meeting the applicable national standards; IN - In the process of being delegated/authorized or SIP approved; N - Not Delegated/ Authorized/Approved; N/A - Not Applicable; ND - Not subject to delegation, but states may have approved program; P - Partial Delegation/Authorization/Approval -- some parts of the programs have been approved but not the entire program; S - State program -- operated by the state, for which EPA approval is not applicable; Y - delegated or authorized, the state runs the program under EPA oversight.

Qualifications: 1. The State has the authority to enforce some or all of these regulations; some approved through the SIP process, while others were delegated; 2. EPA still maintains responsibility for audit resolution; 3. Only the enforcement portion can be delegated; 4. EPA still maintains authority over point-source discharges and federal facilities until the year 2000; 5. All elements approved, except field filtering for ground water sampling; 6. Delegated for commercial applicators only; not for individual applicators; 7. Program close-out.

26 are water-allocation compacts, seven are water-quality related compacts, seven are water-resource and flood-control compacts, and five are "compact commissions." Of the 26 water allocation compacts, 21 of them are associated with states west of the 100th meridian; the remaining five are associated with states east of the 100th meridian. All of the pollution control (seven) and flood control (three) compacts are associated with states east of the 100th meridian. Of the five basin compacts/commissions, three are associated with states east of the 100th meridian and two are associated with states in the western U.S. Each of the commissions, except the Tennessee Valley Authority is associated with coastal river basins.

Associated Environmental Policies and Laws

The ESA, NEPA, and the Wild and Scenic Rivers Act are very important laws relative to protecting water and water-related resources in the U.S. The ESA and the NEPA are not water centric laws; however, both very much affect the development and the use of water and water-related resources. The ESA is one of the most powerful federal laws for protecting the environment and it is especially critical relative to requiring federal agencies to consider the potential impacts of their projects and activities that affect listed threatened and endangered species (e.g., through Section 7, Consultations).

Table 17. Summary of interstate water compacts and basin compacts in the U.S. (USFWS 2013).

Interstate Water Apportionment Compacts

- Alabama-Coosa-Tallapoosa (ACT) River Basin Compact (AL & GA)
- Animas-La Plata Project Compact (CO & NM)
- Apalachicola-Chattahoochee-Flint (ACF) River Basin Compact (AL, FL, & GA)
- Arkansas River Basin Compact (AR & OK)
- Arkansas River Compact of 1949 (CO & KS)
- Arkansas River Compact of 1965 (KS & OK)
- Bear River Compact (ID, UT, & WY)
- Belle Fourche River Compact (SD & WY)
- Big Blue River Compact (KS & NE)
- California-Nevada Interstate Compact (CA & NV)
- Canadian River Compact (NM, OK, & TX)
- Colorado River Compact (AZ, CA, CO, NV, NM, UT, & WY)
- Connecticut River Compact (CT, MA, NH, & VT)
- Costilla Creek Compact (CO & NM)
- Klamath River Compact (CA & OR)
- La Plata River Compact (CO & NM)
- Pecos River Compact (NM & TX)
- Red River Compact (AR, LA, OK, &TX)
- Republican River Compact (CO, KS, & NE)
- Rio Grande Interstate Compact (CO, NM, &TX)
- Sabine River Compact LA &TX)
- Snake River Compact (ID &WY)
- South Platte River Compact (CO & NE)
- Upper Colorado River Basin Compact (AZ, CO, NM, UT, & WY)
- Upper Niobrara River Compact (NE & WY)
- Yellowstone River Compact (ND & WY)

Water Pollution Control Compacts

- Bi-State Metropolitan Development District Compact (MO & IL)
- New England Interstate Water Pollution Control Compact (ME, NH, VT, MA, & CT)
- New Hampshire-Vermont Interstate Sewage and Waste Disposal Facilities Compact (NH & VT)
- Ohio River Valley Water Sanitation Compact (IL, IN, KY, NY, OH, PA, TN, & WV)
- Red River of the North (MN, ND, &SD)
- Tennessee River Basin Water Pollution Control Compact (KY, TN, &MI)
- Tri-State Sanitation Compact (CT, NJ, & NY)

Flood Control Compacts

- Connecticut River Valley Flood Control Compact (CT, MA, NH, & VT)
- Thames River Flood Control Compact (CT & MA)
- Wheeling Creek Watershed Protection & Flood Prevention Compact (PA & WV)

Basin Management Compacts and Commissions

- Bonneville Project Act (ID, MT, OR, & WA)
- Delaware River Basin Commission (DE, NJ, PA, & NY)
- Delaware River Basin Compact (DE, NJ, NY, & PA)
- Great Lakes Basin Compact (IL, ID, MI, MN, NY, OH, PA, & WI)
- Pacific Northwest Electric Power Planning and Conservation Act (ID, MT, OR, & WA)
- Potomac Valley Compact (MD, PA, VI, & WV)
- Susquehanna River Basin Commission (NY, PA, & MD)
- Susquehanna River Basin Compact (MD, NY, & PA)
- Tennessee Valley Authority (AL, GA, KY, MI, NC, TN, & VA)

- However, the ESA is primarily focused on the management of individual species that are already threatened or endangered, rather than protecting ecosystems and populations of species prior to be listed under the ESA.

- The NEPA planning process can affect water resources development and use by requiring a comprehensive assessment of the potential social, economic and environmental impacts of major federal actions. The process does not require an agency to pick the best alternative but it requires broad public involvement in the planning process and by publicly "sun shining" the details of the various alternatives it can very much shape the debate and the decisions made by federal agencies.

The Wild and Scenic Rivers Act is a water-centric law that is intended to preserve free flowing rivers and their surrounding environment from development.

All three acts require extensive planning and analyses prior to implementing a federal water resources development project or activity, or designating a river as a wild and scenic river. Those analyses can significantly impact how federal water and water-related development projects and activities are implemented and/or whether or not they are allowed to be implemented at all.

The Principles and Requirements for Federal Investments in Water Resources (Principles and Requirements) (78 FR 18562; 18562-18563, March 23, 2013) are not federal law; however, they are a critical set of policies relative to assessing the value and the potential social, economic and environmental impacts of all major federal water projects and activities in the U.S. The Principles and Requirements were established pursuant to Section 2031 of the Water Resources Development Act of 2007 (Public Law 110-114, 121 Stat. 1041). The processes used to achieve the Principles and Requirements are analogous to the NEPA process in many ways. For example, both require a comprehensive assessment of potential social, economic and environmental benefits and impacts of major federal projects and activities.

The draft Principles and Requirements (CEQ 2009) appeared to advocate a very holistic, systematic, and integrated watershed management approach. It stated that:

> *The watershed approach is based on: (a) Sustaining water resources; (b) Integrating water and related resources management; (c) Considering future water resources demands; (d) Coordinating planning and management; (e) Collaborating among governmental entities at all levels and ensuring broad stakeholder participation; (f) Evaluating monetary and non-monetary trade-offs; (g) Utilizing interdisciplinary teams; (h) Applying principles of adaptive management; and (i) Using sound science and data.*

In addition, it required the incorporation of IWRM principles into the federal planning process (CEQ 2009):

> *Water resources planning shall use contemporary water resources paradigms such as integrated water resources management and adaptive management, and consider the effects of climate change.*

CEQ (2009) defined IWRM as:

> *"… a deliberate, systematic and balanced approach to making management and development decisions for water resources. It considers potential effects on all of the different yet interdependent uses of water resources. It accounts for the needs of a sustainable environment and the many different and competing social and economic interests.*

Unfortunately, all references to IWRM were struck from the final version. In many ways the proposed Principles and Requirements (CEQ 2009) were more holistic, systematic, and integrated that the final product that was finalized four years later (CEQ 2013).

Overview of IWRM Relative to Developing an IWRM Framework in the U.S.

One approach to better manage water and water-related resources in the U.S. is IWRM. IWRM has primarily been developed, advocated, and implemented by the international water resources community. The most broadly accepted definition of IWRM comes from the GWP (2000) which defines IWRM as:

> *A process, which promotes the coordinated development and 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.*

As was stated in a recent UN review of the status of IWRM internationally (UNSD 2012):

> *Agenda 21 recognised that freshwater resources are needed for all aspects of life; it recognised the interconnected nature of water across sectors and geopolitical boundaries and that to protect them effectively would need management strategies that were far-reaching and dynamic. Primarily the intention was to shift the common approach from the supply-oriented mindset to a more holistic catchment conscious approach, integrating all stakeholders, users, polluters and regulators to inform governance processes and develop compatible monitoring systems to inform those processes.*

The pertinent objectives of IWRM established in Agenda 21(Objectives 18.8 – 18.10, UNCED 1992), modified as necessary for the U.S., include:

- The overall objective is to satisfy the freshwater needs of the U.S. for its sustainable development.

- Integrated water resources management is based on the perception of water as an integral part of the ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its utilization. To this end, water resources have to be protected, taking into account the functioning of aquatic ecosystems and the perenniality of the resource, in order to satisfy and reconcile needs for water in human activities. In developing and using water resources, priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems. However, beyond these requirements, water users should be charged appropriately.
- Integrated water resources management, including the integration of land- and water-related aspects, should be carried out at the level of the watershed or sub-basin.
- Four principal objectives should be pursued, as follows:

  (a) To promote a dynamic, interactive, iterative and multi-sectoral approach to water resources management, including the identification and protection of potential sources of freshwater supply that integrates technological, socio-economic, environmental, and human health considerations.

  (b) To plan for the sustainable and rational utilization, protection, conservation and management of water resources based on community needs and priorities within the framework of the applicable federal, state, and tribal economic development policy.

  (c) To design, implement and evaluate projects and programs that are both economically efficient and socially appropriate within clearly defined strategies, based on an approach of full public participation, including that of men, women, youth, native Americans and Alaskans, local communities, in water management policy-making and decision-making.

  (d) To identify and strengthen or develop, as required the appropriate institutional, legal, and financial mechanisms to ensure that water policy and its implementation are a catalyst for sustainable social progress and economic growth.

In the case of transboundary water resources, there is a need for riparian states (i.e., the U.S., Canada, Mexico, states, and tribes) to formulate water resources strategies, prepare water resources action programs and consider, where appropriate, the harmonization of those strategies and action programs.

In summary, IWRM is intended to be a framework that promotes the sustainable development and the management of water and water-related resources in order to maximize the economic and social welfare of humans without compromising the sustainability of the environment (GWP 2000). In addition, IWRM is designed to be a comprehensive, interdisciplinary, stakeholder-driven approach to developing and implementing efficient, equitable and sustainable solutions to water, and water-related development challenges.

Recently, a number of organizations have promoted the use of IWRM or IWRM-like programs in the U.S. (ASCE 1997, AWRA 2011, AwwaRF 1998, EWRI 2006, and USACE 2010). Each of these organizations has tried to some degree to distill and rectify what these objectives mean relative to implementing IWRM within the U.S. context. However, as Biswas (2008) points out, there isn't a consensus on what IWRM actually means or what it entails. For example, he points out that there are at least 41 different major objectives defined in the literature as being important for developing IWRM programs and that many of these objectives may conflict with each other (Biswas 2008).

There are at least 41 different major objectives defined in the literature, which is not at all surprising. To be successful, IWRM needs to provide an overarching set of objectives that is customized to meet the existing and future water management needs and desires of the country or locality that develops and implements the program. Therefore, IWRM should not be viewed as a "cookie cutter" approach for stamping out identical planning and management programs. Nor should it be viewed as a "Mulligan Stew" that incorporates "everything but the kitchen sink." IWRM should be viewed more as a "menu of recipes" that can be tried, tested and then modified to meet the needs and desires of those implementing the program. Hence, the U.S. water community should not get lost in process by trying to address every possible objective tried and tested elsewhere throughout the world. It should focus on developing the appropriate framework and distilling the core goals and objectives that make sense and that can support sustainable water management in the context of U.S. needs and desires.

A review of select U.S. water policies and that may be useful for developing an IWRM approach to water resources management and protection in the U.S. is provided below.

Observations and Recommendations

While many countries and organizations in the international community have embraced the goals and objective of IWRM, it has largely been ignored in the U.S. Likely, this is due to the belief of many within U.S. water community that the U.S. already has a well-established and robust water resources planning and management approach in place that is comparable to or possibly superior to IWRM. Indeed, relative to much of the world, water resources management in the U.S. is quite advanced, from a policy/legal, scientific, operational, and infrastructure perspective. However, water resources management in the U.S. is far from a perfect system (or more accurately, a perfect set of federal, state, tribal, and local systems). If the U.S. water community is interested in developing a more effective, robust and sustainable approach water management in the U.S., it should establish a framework that integrates water science, policy, and law, and management practices in an appropriate manner to meet the needs and desires of those living within each watershed and other interested stakeholders, as appropriate. IWRM may be able to provide such a framework.

The U.S. is a nation governed by policies and laws, including a significant body of water and water-related policies and laws. These policies and laws establish what activities are legal and illegal, they establish what types of activities the government will promote or try to prevent, and they establish what government resources and finances will be authorized and allocated to promote or to prevent those activities. Therefore, in order to have more effective and robust water programs, the U.S. needs to have well designed and well integrated water and water-related policies and laws. The question is whether the U.S.' current water and water-related policies and laws are a cohesive, effective and robust framework that can provide for (modified from Objectives 18.6 and 18.7, UNCED 1992):

> *The holistic management of freshwater as a finite and vulnerable resource, and the integration of sectoral water plans and programs within the framework of the appropriate federal, state and/or tribal economic and social policies...to satisfy the freshwater needs of water users for their sustainable development.*

If they do not, how can we best adjust our current water and water-related policies and laws to effectively and robustly meet this goal?

The U.S. has many water and water-related policies and laws; unfortunately, many of them have been designed and/or are implemented in relative isolation (e.g., separate land and water development, and separate water allocation and water quality policies and laws). In addition, they are implemented relatively independently on different governmental levels (e.g., federal, state, local, and tribal levels), by a myriad of agencies at each level and by a multitude of individuals and organizations in the private sector. Hence, many of these policies and laws were not necessarily developed or implemented in an integrated or well-coordinated manner. The results of this can be seen by the increasing number of conflicts that the U.S. has experienced between water users/sectors and the cumulative impacts of water resources development on the environment throughout the U.S.

The key question is whether the U.S., in part or whole, desires to develop more effective, robust and sustainable water resources programs and, if so, can a more holistic, systematic, and integrated set of water policies and laws be developed using an IWRM approach within the context of existing water policies and laws? While the full breadth of U.S. water policies and laws cannot be addressed here, selected observations and recommendations are provided below.

Physically-Based Water Policies and Law

Arguably, the most important step that can be made towards developing an integrated approach to water resources management in the U.S. is to frame all water policies and laws such that they comport with the physical laws of nature that control the natural storage and flow of water and to implement water resources management, based on the best available science (see Chapter 3). While many in the U.S. believe that water resources management in the U.S. is quite advanced, there is often a great chasm between the state of scientific knowledge and U.S. water policy and law, on the federal, state, and tribal levels. For example, in a decision concerning the Klamath Indian tribes in Oregon, the Ninth Circuit Court pointed out (Paschal 1995, p. 5):

> *Scientist have long delighted in pointing out to lawyers that all waters are interrelated in one continuous hydrological cycle. As a result, it has become fashionable to argue that an effective legal regime should govern all forms and uses of water in a consistent and uniform manner. The law is otherwise.*

Although this is likely a legally factual statement, it is likely an anathema to many scientists: that many of our most essential water resource policies and laws are not based on the physical laws that regulate the storage and flow of water. Science should not necessarily dictate policies and laws, but science can provide a factual basis for evaluating rational alternatives and developing well-grounded policies and laws.

Unfortunately, this disconnect is not limited to the Ninth Circuit Court's area of jurisdiction; many federal, state and tribal policies and laws treat each compartment of the hydrosphere (e.g., atmospheric, surface water, and groundwater compartments) as separate entities. Many policies and laws treat issues such as water quality and water allocation and the impacts of land development and use on water quality and availability as being independent of one another. By not managing surface water and groundwater resources within a given sub-basin or watershed as a single hydrologically interconnected resource, water resources management is less effective and robust, and more expensive when considering water management as a whole. For example, Winters et al. (1998) states:

> *Understanding the interaction of ground water and surface water is essential to water managers and water scientists. Management of one component of the hydrologic system, such as a stream or an aquifer, commonly is only partly effective because each hydrologic component is in continuing interaction with other components.*

However, incorporation of this knowledge into federal, state, and tribal water policies and laws has often been slow, and the implementation of this knowledge in practice has been even slower. For example, some states and tribes still do not legally recognize the interconnection between surface water and groundwater resources in their water policies and laws and/or in practice. In addition, federal, state, and tribal agencies have been slow to actively monitor and manage atmospheric water, surface water, and groundwater conjunctively or to manage water allocations/use and water quality protection in an integrated manner.

While many states have rules in place that explicitly require or implicitly allow conjunctive management of surface water and groundwater resources (Hazard and Shively 2011 and Dellapenna 2013), most only implement those rules when the cumulative impacts become great and/or a crisis occurs. In addition, when Congress passed the CWA to “restore and maintain the chemical, physical, and biological integrity of the Nation’s waters,” it specifically exempted the allocation of water from being regulated under the Act (CWA §1251, Congressional declaration of goals and policy):

> *(g) Authority of States over water It is the policy of Congress that the authority of each State to allocate quantities of water within its jurisdiction shall not be superseded, abrogated or otherwise impaired by this chapter.*

State and tribal ownership over waters within their jurisdictions is well established in law. However, many of the activities associated with water allocation and use (e.g., water withdrawals and transfers and constructing cannels, dams, and other related infrastructure) significantly degrade water resources and ecosystems in many parts of the U.S. Many other activities that are favored and promoted by the states and tribes for economic development purposes (e.g., silviculture, farming and ranching) cause significant amounts of pollution runoff that cumulatively degrades water quality/availability and ecosystem health also (e.g., GWPC 2007). Given the cumulative impacts of these and other activities, it is not surprising that 43 years after the CWA was passed, more than 50% of the surface waters of the U.S. that have been monitored recently are still considered to be threatened or impaired (EPA 2013a) and many groundwater resources are over-allocated and polluted (e.g., one of every five wells sampled by the USGS have potential human-health concerns; DeSimone, McMahon, and Rosen 2014), primarily by non-point sources of pollution.

Hydrologically interconnected atmospheric, surface water, and groundwater resources are inextricably linked, as are water quality, water allocation, and land and water use. Despite who takes the lead (e.g., federal, state, or tribal agencies) in monitoring, regulating and managing the nation’s water resources, these resources should be linked in policy and law, they should be designed to be effective and robust, they should be designed to balance social, economic, and environmental needs, and they should be phased into practice long before a series of crises forces water policy- and decision-makers, and the water community to respond under duress.

Federal Reserved Water Rights

Federal Reserved Water Rights and water rights established through congressionally authorized land withdrawals/reservations and water projects have been critical for developing and maintaining federal/tribal lands and water resources in accordance with their intended purposes. However, while they have been essential for the development, management, and protection of these lands and resources they are also an impediment to developing an integrated approach to managing water resources in the U.S. because they are often managed and accounted for separately from state water rights systems. Therefore, they are disruptive to state water planning and allocation programs; especially unquantified water rights.

States' rights have been established under numerous authorities (e.g., 1866 Mining Act [30 U.S.C. 51 and 43 U.S.C. 661], Desert Land Act of 1877 [43 U.S. Code § 321], and California Oregon Power Co. v. Beaver Portland Cement Co., 1935) and Federal Reserved Water Rights have been established on the federal public lands and Indian reservations based on the Winters Doctrine (*Winters v. United States*, 207 U.S. 564, 1908). Under the Winters Doctrine, the federal government and Indian tribes have legitimate claims to the full amount of water necessary to maintain the established purpose of the given reservation/land withdrawal. However, in many cases the established purpose of the given reservation/federal land withdrawal is not clear. Therefore, the type (e.g., groundwater or surface water), location and amount of water that should be granted to the given reservation or withdrawal is not clear and it is therefore open to vigorous debate, often leading to litigation and costly settlements. Until Federal Reserved Water Rights are settled, the states, tribes and federal agencies may all have legitimate but competing claims over the control and use of any waters that are on or adjacent to a given reservation or public land withdrawal.

In order to develop holistic, systematic, and integrated water planning and management programs within U.S. sub-basins or watersheds, Federal Reserved Water Rights need to be quantified and incorporated into a common allocation system with state water rights. Therefore, it is recommended that Congress and the states establish a long-term, systematic, and orderly process, timeline, and funding for quantifying and integrating all Federal Reserved Water Rights throughout the U.S. into the appropriate state water allocation systems rather than continuing with the current *ad hoc* process. However, such a process needs to respect and balance the rights and needs of each of the parties (i.e., federal, state, and tribal rights and needs).

Relative to federally-recognized Indian reservations, all Federal Reserved Water Rights associated with those reservations are held in trust by the U.S. government (BIA 2015c). Over the years, the federal and some state governments have entered into water rights settlements or have adjudicated Indian water rights for numerous tribes (e.g., Titles IV – VIII of the Claims Resolution Act of 2010 [124 STAT. 3064, Public Law 111–291]) (DOJ 2015, NAWRS 2015, and RWRCC 2015). In addition, Congress has an established formal process for integrating Federal Reserved Water Rights with state water allocation systems through general basin adjudications under the McCarran Act (43 U.S.C. §666 [1952]). However, for the most part, these processes have been developed and implemented independently and on an as needed or *ad hoc* basis.

The primary difficulties associated with settling Federal Reserved Water Rights relative will likely be in negotiating equitable settlements that are to the satisfaction of the affected states, Indian tribes and the federal government; meeting the long-term needs and desires of the Indian tribes which reside on a given reservation and the federal agencies which manage public lands; and the cost of implementing those agreements. However, these issues can be addressed satisfactorily.

For example, in the Snake River Basin Adjudication (SRBA) in Idaho, the Nez Perce tribe filed water rights claims for in-stream flows to maintain both their on- and off-reservation fishing rights, which implies a right to sufficient in-stream flows to sustain the native fishery in all of their usual and accustomed fishing areas, based on its established treaties. Contrary to this claim, the state of Idaho, through a 1999 SRBA court decision, concluded that Nez Perce Treaty rights implied no in-stream flow rights to protect salmon in the tribe's usual and accustomed fishing areas. These diametrically opposed world views represent two very different opinions between the two parties relative to the ownership and the acceptable use of water. In more practical terms, this case represented two competing claims for the ownership and authority over very valuable water rights.

Although the case was litigated, an agreement limiting the tribe's water rights was reached via a negotiated settlement that lasted approximately 6 years and the cost the settlement was high (Hays 2006). This included in part: establishing a tribal water right to 50,000 acre-feet water, with a priority date of 1855; transferring over 11,000 acres of federal land to be held in trust for the tribe; transferring two federal fish hatcheries to the tribe; establishing in-stream flows on select streams; 200,000 acre-feet of water for flow augmentation benefiting listed species, and a $50 million fund for habitat restoration and various water resources-related development projects (DOI 2004 and Hays 2006).

While this case shows that Federal Reserved Water Rights can be settled, it also demonstrates that such settlements can take a significant amount of time and that the price of settlement can be relatively expensive. However, the certainty that is provided by such settlements is critical to both parties in that each party establishes their right to control and manage their legally-entitled resources. In this case, the Nez Perce were able to meet their long-term goals of consolidating control over the lands within their reservation, and improving the habitat and stream flows and control over several hatcheries that are necessary for developing a long-term, sustainable fishery. The state of Idaho on the other hand was able to protect the flows necessary to fill water rights used on an estimated 3.5 million acres of land in southern Idaho, which generates $2.9 billion of annual income (Hays 2006). From that perspective, the settlement was really a win-win solution with a relatively small investment (mostly coming from the federal government), and relatively large positive benefits to both parties.

While this will likely be a long, difficult, and expensive process, it is essential to bringing order and security to water resource management in the U.S. By implementing adjudications and settlements piecemeal, Congress and the states will only make them more difficult and more expensive. In contrast, by developing a systematic process and timeline for implementing such a process, Congress and the states can better plan and allocate the appropriate funding and resources necessary to implement this process. Settling these rights should increase certainty and stability within the federal, state, and tribal water allocation systems.

Federal Water Development Projects

Federal, state, and to a lesser degree tribal water development and allocation policies and laws have spurred and sustained water development throughout the U.S. Conversely, by not requiring the integration of hydrologically interconnected surface water and ground water resources; by managing water resources by political, project, or other artificial boundaries rather than “competent hydrologic units” (see Chapter 3); by managing water quality and water allocation for the most part, separately; by giving minimal consideration to the impacts of land development and use on water availability and quality; and by giving less import to the protection of the environment relative to economic gains, the federal, state, and tribal water policies and laws have increased the cost and complexity of managing water, increased conflicts between water users and between water sectors, and they have caused significant harm to many ecosystems and species. Below are a number of approaches that federal, state, and tribal governments could test and/or implement relative to improving water resources management and developing a better balance between meeting society’s socioeconomic needs and meeting the needs of the environment in a sustainable manner.

Federal, state, and tribal governments could establish more holistic, systematic, and integrated approach to water resources management. For example, as a first step, Congress could conduct a systematic and comprehensive review of all major federal water development policies and laws with an eye for developing a more streamlined and integrated water management framework. This review should at least include an assessment of the Reclamation Act, Rivers and Harbors Act, Water Resources Development Act, Flood Control Acts, and related policies and laws. Each of these Acts could be amended, if appropriate, to explicitly recognize the interconnectedness of the hydrologic cycle and the principals of sustainability when authorizing and funding the development, operations, and management of federal water projects and activities.

Congress could amend these policies and laws to be explicit that all federal water projects and activities authorized and funded under these Acts will be planned for, assessed, monitored, and managed in an integrated and holistic manner using the best available science. This could include assessing, planning, and managing water and water-related resources within authorized project boundaries on a sub-basin or watershed basis and in an integrated manner. It could explicitly require federal agencies to manage the benefits and impacts of federal projects and activities in a balanced manner for both humans and the environment. It could require federal agencies to manage the quality and quantity of the affected surface water and hydrologically connected groundwater resources throughout the affected sub-basin or watershed in an integrated manner. It could also include consideration of project impacts on the associated lands (e.g., riparian lands, stream channels, and uplands), where appropriate, and riparian and aquatic ecosystems throughout the effected sub-basins or watersheds. Finally, federal agencies could be required to conduct ongoing monitoring and adaptive management to ensure that their projects meet their established project-/activity- specific socioeconomic and environmental performance goals on a sub-basin or watershed basis.

While these criteria may sound daunting, most federal land and water management agencies already conduct many of these activities to some degree (e.g., through the planning and assessments required under the Principles and Requirements and NEPA). However, the Principles and Requirements and NEPA are focused on planning and analysis of potential new projects rather than establishing operational and management requirements, and they do not address existing projects and activities. In addition, water and water-related planning, assessments, monitoring and management are conducted to various degrees in various ways by each water and water-related agency (or subdivisions of a given agency), through the development of complex program- or project-specific policies and regulatory matrixes, interpreted each time through the prism of each agency’s mission, policies, and program/ project specific needs. To overcome some of these issues, Congress could consider standardizing, streamlining and improving the management of the land, water, and ecosystem resources associated with federal lands and water projects within an IWRM or IWRM-like framework.

State Water Development and Allocation

State legislators should also consider developing explicit polices and laws requiring that all state land and water development projects and activities authorized and/or funded under their jurisdictions be planned for, assessed, monitored, and managed in a more integrated and holistic manner using the best available science.

Relative to water allocation, very few states actively manage all three hydrologic compartments (i.e., atmosphere, surface water, and groundwater) and currently no states are known to actively manage all three compartments state-wide in an integrated manner. For example, few states actively manage atmospheric water (Busto 2008, DiGiulian and Charak 1974, CRS 1978, and Farhar and Mewes 1975) or diffuse surface water (Dellapenna 1991a, FEMA 2014, and Getches 1990) resources for allocation purposes. However, states that allow weather modification and that manage diffuse waters within their jurisdiction should review their existing policies and laws to ensure that they are based on the best available science, they are integrated appropriately into their surface water/groundwater management and allocation programs and that they can protect against potential negative impacts to human health and the environment (ASCE 2012, ASCE 1997, ASCE 2006, EWRI 2007, AMS 2012, NRC 2001, and WMA 2013).

Most states that actively manage their water resources, focus on surface waters in well-defined surface water bodies (e.g., streams and lakes) and groundwater systems (e.g., aquifers), as those are the most physically available for use and most economically important to humans. However, some states do not actively manage the withdrawal and consumptive use of their surface water and/or groundwater resources (e.g., states that embrace the common law doctrines of reasonable use and/or absolute dominion for surface water and/or groundwater allocation) (see Tables 13 and 14).

From an administrative perspective, reasonable use and absolute dominion states have little to no ability to make large-scale (e.g., sub-basin or watershed wide), real-time decisions to actively manage part or all of their water resources. For example, in reasonable use states the appropriate management agency would have to make a determination that the water was not being used in a reasonable manner. Based on the fact that most reasonable use states have historically treated the Reasonable Use Doctrine in a similar fashion to the Absolute Dominion Doctrine, it seems that it would be very difficult for state agencies to make such a determination, especially for groundwater resources. In an absolute dominion doctrine state, administrative agencies seem to have almost no ability to actively manage their groundwater resources, as these rights are considered to be private property rather than public resources.

In both cases, the administrative agency would effectively have to take the water users to court every time they needed to enforce a management action (e.g., to reduce water use during a drought). While the courts could impose requirements to change water user's activities and practices, they are generally less efficient and effective at implementing such processes; especially for actions requiring quick responses or for meeting smaller, more nuanced needs. Therefore, states that do not currently actively manage their water resources should consider amending their water policies and laws to allow state and/or local agencies to do so. The capacity to do so may be very critical during times of severe shortages (e.g., due to droughts or climate change) and/or in response to growing populations and increased demands. Since most of these states are located in the eastern U.S., they should consider the benefits of instituting a regulated riparian appropriation system although there are other active management options as well.

Those states that actively manage their surface water and ground water allocations (e.g., prior appropriation and some regulated riparian states), should conjunctively administer their surface water and groundwater resources wherever they are hydrologically interconnected, as they are physically/hydrologically one source of water. However, in order to do so, those states must first have the appropriate policies and laws in place. A summary of the those water law doctrines that are potentially compatible for conjunctively administering surface water and groundwater allocations is provide in Table 18. In order to actively manage those resources, states, and tribes must also have the necessary funding, scientific and institutional capacities to monitor and regulate surface water and ground water as a unitary source. It also means that there must be sufficient infrastructure to actually monitoring and manage these resources.

Using the framework provided in Table 18, it appears that 30 states have the appropriate water policies and laws in place to potentially implement conjunctive administration of surface water and groundwater allocations within their jurisdiction). Essentially, each state that has unified policies and laws for surface-water and groundwater allocation and those that have polices and laws that give their State Engineer (or equivalent) the authority to selectively implement conjunctive administration as he/she deems necessary (see "Unified Systems" and "Selective Implementation" in Table 19), can

Table 18. Assessment of water doctrines that can facilitate the conjunctive administration of surface water and groundwater resources in the U.S.

		Surface Water			
		Appropriative Rights	Hybrid (Riparian & Appropriative Rights)	Regulated Riparian	Reasonable Use
Groundwater	**Absolute Dominion**	N	N	N	N
	Appropriative Rights	Y	Y	Y	N
	Correlative Rights	Y	Y	Y	N
	Reasonable Use	N	N	N	N
	Regulated Riparian	Y	Y	Y	N

potentially implement such programs. It would be highly unlikely for those states that have "bifurcated" or "other" (primarily reasonable use) water policies and laws as the basis of their existing policies and laws to successfully implement conjunctive administration of their surface water and groundwater resources (see "Bifurcated Systems" and "Other" in Table 19).

The exception is California. Generally in California the state only manages surface water; local water organizations manage groundwater (CADWR 2013). However, the state actively promotes and incentivizes conjunctive management of surface water and groundwater through its water plans and many local organizations are choosing to conjunctively administer and manage their water resources (CADWR 2013). That said the end-goal of locally-controlled conjunctive administration in California is not clear. The current rate of groundwater depletion in California (Richey et al. 2015) indicate that groundwater resources are being mined once the available surface water resources have been depleted. Whereas the primary goal of IWRM is to find a balance between human and environmental needs, this information may indicate that conjunctive administration is primarily focused on meeting human socioeconomic needs and desires at the expense of environmental needs.

The Western Governors' Association (WGA 2008) has advocated for the development of an IWRM at the federal level:

> *The Western States Water Council (WSWC) should urge Congress to require federal water resource agencies to include "Integrated Water Resources Planning and Assistance" as one of their primary missions, with the goal of:*
>
> *(a) changing the way water planning is conducted by encouraging more comprehensive plans developed under state leadership with federal assistance; and*
>
> *(b) reducing inefficiencies caused by the present mode of project-specific responses to competing demands, contradictory actions by multiple state, local and federal water agencies, and hastily conceived reactions to the latest real or perceived crisis.*

Table 19. States doctrines compatible for conjunctively administering hydrologically interconnected surface-water and groundwater resources.

Unified[1] Systems	Selective[2] Implementation	Bifurcated[3] Systems	Other
Alabama[4]	Alaska[5]	Arizona[7,8]	California[9]
Connecticut[4]	Colorado[6]	Arkansas[10]	Louisiana[11]
Delaware[4]	Idaho[6]	Georgia[10]	Missouri[11]
Florida[4]	Kansas[5]	Illinois[7]	New York[11]
Hawaii[4]	Montana[6]	Indiana[12]	Ohio[11]
Iowa[4]	New Mexico[6]	Maine[12]	Rhode Island[11]
Kentucky[4]	North Dakota[5]	Nebraska[7]	Tennessee[11]
Maryland[4]	Oregon[6]	New Hampshire[7]	West Virginia[11]
Massachusetts[4]	Pennsylvania[13]	Oklahoma[16]	
Michigan[4]	South Dakota[5]	South Carolina[10]	
Minnesota[4]	Washington[6]	Texas[12]	
Mississippi[4]	Wyoming[6]	Vermont[14]	
Nevada[15]		Virginia[10]	
New Jersey[4]		Wisconsin[10]	
North Carolina[4]			
Utah[15]			

1. Water is managed under a single, uniform system with no legal distinction between groundwater and surface water
2. State can conjunctively manage surface water and groundwater in designated management areas or basins (Hazard and Shively 2011).
3. Bifurcated system – surface water and groundwater legal systems are incompatible, so it is difficult if not impossible to conjunctively manage surface water and groundwater resources.
4. State has a single regulated riparian statute that addressed both surface water and groundwater (Dellapenna 2013)
5. States have not been reviewed here individually; however, based on their classification in Tables 8 and 9, it is presumed that they potentially could conjunctively manage surface water and groundwater resources.
6. State can conjunctively manage surface water and groundwater selected management areas or basins based on a decision made by the State Engineer or equivalent Director of water/natural resources (Hazard and Shively 2011).
7. State has regulated riparian system for groundwater but not for surface waters. The differences between the legal regimes make it difficult if not impossible to conjunctively manage surface water and groundwater resources (Dellapenna 2013).
8. Arizona use appropriative rights for surface water, and regulated riparian for groundwater in management areas and absolute dominion outside of management areas.
9. California manages surface water rights using both the appropriative and riparian rights, depending on location. Groundwater is managed using correlative rights. Then state only manages surface water rights; groundwater allocation is generally controlled locally. However, the state water plan advocates and incentivizes conjunctive management and many localities do so.
10. State has separate reasonable use riparian statutes for surface water and regulated riparian statues for groundwater. These are different systems, but surface water and groundwater are administered by the same agency, so conjunctive management is possible (Dellapenna 2013).
11. State law is not clear enough to determine (e.g., New York, Dellapenna 2013) or its laws not compatible with potential conjunctive administration (e.g., surface water and groundwater are both managed using reasonable use).
12. States manages groundwater using Absolute Dominion.
13. Pennsylvania does not have regulated riparian system for either surface waters or groundwater under state law; however, parts of the state are subject to regulated riparian for both surface water and groundwater under the Delaware River Basin and Susquehanna River Basin Compacts (Dellapenna 2013).
14. Vermont seems to be going to a regulated riparian system for groundwater, but not for surface waters (Dellapenna 2013).
15. State manages surface waters and groundwater under a single appropriative rights system which requires full integration of surface water and groundwater resources (Hazard and Shively 2011).
16. Oklahoma's surface water allocation system (prior appropriation) does not recognize groundwater/surface water interactions (OWRB 2011).

Both the WGA and the WSWC have indicated that they endorse the development of IWRM-like programs for the management of federal projects by federal agencies and the development of a national IWRM framework; however, they are very resistant to the development of a federal IWRM program that dictates to the states how to manage waters under the state's purview. To date, only three states are known to have developed IWRM-based water management programs. California (CADWR 2013), Nebraska (Nebraska Revised Statue 46-715) and Oregon (OWRD 2012) have developed state water plans that explicitly develop statewide or local/regional IWRM or IWRM-like water resources management strategies and plans.

Tribal Water Development and Allocation

Historically, the federal government has managed overall water-allocation and water-quality decisions for Indian tribes on most Indian reservations. Therefore, how water and water-related resources are managed on various Indian reservations by the tribes themselves is not well documented or well vetted in the literature; hence, it is unclear how these resources are managed on most Indian reservations.

To the extent that Indian tribes have the authority to manage atmospheric waters and depending on whether they manage diffuse waters on their reservations, they should also develop tribal policies and laws follow similar principles as discussed above for the states. Tribal councils should consider developing explicit polices and laws requiring that all tribal land and water development projects and activities authorized and/or funded under their jurisdictions be planned for, assessed, monitored, and managed in a more integrated and holistic manner using the best available science.

As part of the Federal Reserved Water Right settlement process described above, it is recommended that the federal government assist all federally recognized Indian tribes with reservations that do not already actively manage their own water and water-related resources to develop reservation-specific water allocation, water quality, and water-related policies and laws. Such a framework could help each Indian tribe develop its own sustainable water resources programs that meet their specific needs and it could allow them to interface appropriately and on equal terms with their adjacent state(s).

Those tribes that have the necessary financial and technical capacities should consider developing IWRM programs for managing the water resources associated with their reservations. Ideas for developing such a comprehensive, integrated reservation-specific approach to water management that is appropriate for their area, conditions, and needs could be obtained through the selective use of one or more of the comprehensive model water codes that have been developed recently (Eheart 2002; ASCE 2013; ASCE 1997; EWRI 2007; and Muys, Sherk, and O'Leary 2007).

Because of Indian tribe's special status as sovereign entities, such programs would not necessarily need to comport with adjacent state's water policies and laws. However, because of the ubiquitous nature of atmospheric water and the flowing properties of both surface water and groundwater, the availability and the quality of water on many Indian reservations can be negatively impacted by off-reservation decisions and actions by the federal and state governments and vice-a-versa. Therefore, state and Indian water policies and laws would at least need to be compatible with each other relative to all waters that flow onto or off Indian reservations.

Federal Water Quality Policies and Laws

It is well established scientifically that within a given basin or watershed surface water and groundwater bodies are generally hydrologically interconnected and that surface water quality affects and is affected by hydrologically interconnected groundwater systems (e.g., EPA 2015a, GWP 2007, GWPC 2007, and Winter et al. 1998). As was demonstrated in the Ground Water Protection Council's recent report (GWPC 2014) and others, it will be difficult at the least and near impossible at worst, to develop a comprehensive, integrated watershed approach to managing water quality in the U.S. using the current patchwork of policies and laws. Therefore, it is recommended that Congress provide the appropriate policies, laws, and direction to the EPA, the Corps, and other water-quality-related agencies to actually protect the health of all federally regulated water resources in the U.S., in a more holistic, systematic, and integrated manner.

The SDWA was promulgated to protect all "public drinking water supplies" throughout the U.S. (EPA 2012b). The Act is comprehensive in that it provides for the monitoring and protection of all public drinking water supplies, be they supplied by surface water or groundwater. However, the Act does not regulate drinking water systems not defined as a public drinking water supplies (e.g., private household wells) (EPA 2014). The SDWA can provide some protections to known and potential sources of drinking water supplies. However, the Act can only protect drinking water sources from a limited number of potential contaminant sources (e.g., regulating underground injection wells), through the voluntary development and implementation of wellhead and source water protection programs, and through mostly voluntary sole-source aquifer designations. This leaves many aquifers or portions of aquifer systems in the U.S. unprotected and vulnerable to becoming polluted.

For example, the USGS estimates that the water used by about 44.5 million people in 2010 is self-supplied and that about 98% of these withdrawals are from fresh groundwater sources (Maupin et al. 2014). These wells are likely untested for water quality on a regular basis and unprotected from contaminants in their source waters because they are unregulated/protected by the SDWA.

The CWA was promulgated to establish a national framework "…to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." In many aspects this law has been very successful, especially in the reduction of "point source" pollutants. However, its implementation relative to surface-water quality is limited to "waters of the U.S." (e.g., traditionally navigable waters, interstate waters, and territorial seas) that is relatively narrowly defined (e.g., GWPC 2007).

This approach has been marginally successful relative to protecting surface-water quality from non-point sources of pollution. For example, according to EPA's most recent "National Water Quality Inventory Report to Congress" (305(b) report), summarized in EPA's ATTAINS database (EPA 2015b), 70.4% of rivers and streams in the U.S. have not been assessed recently. However, of those water bodies that have been assessed recently, 53.7% are water quality impaired. This is largely due to the lack of funding and resources to fully implement the Act and the fact that numerous common sources of non-point pollution in the U.S. are exempt from either the CWA itself or from various CWA permitting requirements (e.g., 40 CFR 122.2(b) and others). In addition, there is constantly immense political and legal pressure by businesses, industry, and states lobbying Congress and suing EPA to further narrow the scope and to reduce the capacity of the Act to protect the surface water quality in the U.S. (e.g., U.S. Supreme Court cases in U.S. v. Riverside Bayview, Rapanos v. United States, and Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers, and Rapanos v. United States). This can be seen in the number of exemptions contained within the CWA also.

For example, the definition of the "waters of the U.S." is utilized in 33 CFR Part 328, and in 40 CFR Parts 110, 112, 116, 117, 122, 230, 232, 300, 302, and 401 of the CWA to define the activities that are not regulated under the Act. In the recent rewriting of the definition, the agencies emphasized numerous times that (Federal Register, Vol. 80, No. 124):

Congress has exempted certain discharges, and the rule does not affect any of the exemptions from CWA section 404 permitting requirements provided by CWA section 404(f), including those for normal farming, ranching, and silviculture activities… This rule not only maintains current statutory exemptions, it expands regulatory exclusions from the definition of ''waters of the United States'' to make it clear that this rule does not add any additional permitting requirements on agriculture. The rule also does not regulate shallow subsurface connections or any type of groundwater, erosional features, or land use, nor does it affect either the existing statutory or regulatory exemptions from NPDES permitting requirements, such as for agricultural storm water discharges and return flows from irrigated agriculture, or the status of water transfers.

If Congress does not find a better approach to regulating these activities, there is little probability that the U.S. will improve from having 53.7% of the water bodies monitored in the U.S. be water quality impaired, let alone meet the stated national goal "…to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." If Americans truly desire safe, clean water resources in the U.S., these laws should be restructured and integrated such that they can actually protect all of the nation's waters, be they surface waters or groundwater. To do so would require a number of actions by Congress.

First, it is recommended that Congress consider reducing the number and scope of the regulatory and permitting exclusions currently contained in the CWA. Farming, silviculture, ranching are clearly important activities relative to feeding the U.S. population and providing food to many other areas of the world. However, they are also the primary causes of non-point source pollution in many parts of the U.S. Therefore, Congress could review these exemptions and modify the Act as appropriate to find a better balance which allows traditional resource management practices to continue to thrive within the U.S., but reduce these exemptions such that the nation's waters are protected from the non-point pollution produced by these activities. This may include such activities as making NRCS' voluntary conservation practices mandatory for lands adjacent to waters of the U.S. that are water quality limited (hence requiring a TMDL) or other such activities.

Second, relative to groundwater quality, federal water quality laws have had provisions to protect groundwater resources in the U.S. at least since the 1948 Federal Water Pollution Control Act (see section 2(a), FWPCA 1948). Section §102(a) of the CWA states (U.S. Senate 2002):

> *The Administrator shall… prepare or develop comprehensive programs for preventing, reducing, or eliminating the pollution of the navigable waters* ***and ground waters*** *and improving the sanitary condition of surface* ***and underground waters****... to conserve such waters for the protection and propagation of fish and aquatic life and wildlife, recreational purposes, and the withdrawal of such waters for public water supply, agricultural, industrial, and other purposes. [Emphasis added]*

In addition, groundwater is addressed in §104 (Research, Investigations, Training, and Information), §106 (Grants for Pollution Control Programs) and §319 (Nonpoint Source Management Programs) of the Act.

Despite the clear intent of the CWA, EPA, the Corps, and most states have ignored the groundwater protection aspect of the Act and the nexus between surface water and groundwater quality relative to implementing the Act. In fact, during recent rule making, the EPA and Corps stated that as a matter of policy they have never implemented the Act to address groundwater quality (Federal Register, Vol. 80, No. 124):

> *The agencies have never interpreted ‘‘waters of the United States’’ to include groundwater and the proposed rule explicitly excludes groundwater, including groundwater drained through subsurface drainage systems.*

This statement is made despite clear statutory direction to the contrary in the CWA and the fact that the agencies 400-plus page scientific synthesis of more than 1,200 peer-reviewed papers (EPA 2015a) and their 400-plus page technical support guidance (EPA 2015d) make abundantly clear the importance of the hydrologic connectivity between surface water and groundwater sources relative to the health and maintenance of downstream surface waters, including wetlands, and stream and riparian ecologies. Therefore, it is recommended that Congress consider amending the CWA to be explicit that that all aquifers that are hydrologically interconnected to the waters of the U.S. (e.g., so-called “tributary” groundwater) are also waters of the U.S. Congress could be explicit that all surface water and tributary groundwater resources should be protected under the CWA. A less satisfying but more simple and expedient approach would be EPA and the Corps modifying their current policy decision and include groundwater in the definition of waters of the U.S. (Federal Register, Vol. 80, No. 124).

Third, §319 requires state and authorized tribes to evaluate water quality within their jurisdiction, to develop a management program to control non-point pollution and to report annually waters that do not meet their water quality standards per §303(d) of the Act. Section 303(d) requires states and authorized tribes to develop lists of “impaired waters” and to establish priority rankings for waters on the lists and develop TMDLs for these waters. EPA and most states largely ignored and/or failed to implement this requirement until forced to do so by the courts (EPA 2013b). TMDLs have now been developed for most water quality limited waters (EPA 2013b); however, there are no requirements under the Act for EPA, the states or tribes to actually implement the TMDLs they developed. Hence, there are no consequences for not implementing TMDLs. Therefore, it is recommended that Congress consider amending the CWA to explicitly require the actual implementation of TMDLs and it should consider developing the appropriate funding to assist the states and tribes in implementing them.

Hence, the SDWA doesn't protect all public drinking water systems or sources in the U.S., and the CWA doesn't protect the nation's waters. This disconnect is made very clear in an recent assessment by the Groundwater Protection Council relative to developing a comprehensive, integrated watershed approach to water quality management in the U.S. using the existing authorities provided in the SDWA and CWA (GWPC 2014). This assessment clearly demonstrates the tortured pathways that would need to be taken to navigate the current patchwork of regulations, the out-of-the-box thinking and the levels of cooperation that would be necessary to implement a comprehensive, integrated watershed approach to water quality management in the U.S. It is unlikely that such an approach could be implemented widely in the U.S. However, even if it could be fully implemented throughout the U.S., it would still only provide protection for water bodies regulated under the SDWA and CWA, leaving water bodies in many parts of country without uniform standards to protect human health and the environment.

Therefore, these actions are only a partial solution relative to addressing the disconnection between the SDWA and CWA relative to protecting water quality in the U.S. To help bridge the gap between these laws, Congress could also reassign the water resources protection programs currently residing in the SDWA (§§1421 et seq., 1424, 1428 and 1453) and the other water quality related environmental laws (see Table 6) to the CWA to provide a single, holistic, systematic, and integrated approach to protecting the nation's waters (see Table 7). This could include updating and directly integrating or at least harmonizing the current SDWA resource protection programs and water quality related aspects of the other environmental laws (e.g., water resources protection under RCRA and TSCA and cleanup standards under RCRA and CERCLA) with the point and non-point source protection programs in the CWA (§§303, 303(d), 319, 401, 403, and 404) to provide a single, integrated body of policies and laws that are capable of protecting both surface water and groundwater quality on a sub-basin or watershed scale.

Integrating the critical resource protection programs from both the SDWA and CWA would make the CWA the primary law in the U.S. for comprehensively assessing, monitoring, and protecting all federally regulated waters in the U.S. It would allow for the development of a comprehensive, integrated sub-basin/watershed approach to water quality management in the U.S. In addition, by reducing the number of independent water quality related policies and laws that need to be implemented and by streamlining the requirements, this consolidation would likely reduce the regulatory burden, the complexity and the confusion associated with implementing the patchwork of policies and laws currently regulating the water community. Overall, it would likely make regulation of water quality in the U.S. more effective and robust, and less costly and less burdensome to the both regulated community and taxpayers.

State and Tribal Water Quality Policies and Laws

Both the SDWA and the CWA require the development and implementation of water quality programs, as appropriate for all federally regulated waters (i.e., sources for public drinking water supplies and waters of the U.S.). While these requirements are contained in two separate laws, they are both, in part, actually addressing the same issues (water resource protection) associated with one resource (federally regulated waters within a given sub-basin or watershed). Rather than duplicating the funding and resources necessary to implement two laws (e.g., having separate SDWA and CWA groups within an agency addressing each set of requirements independently), states should explore options to address surface water/groundwater pollution holistically to integrate their water quality programs and activities (e.g., modeling and evaluating potential sources of pollution and their impacts) and to streamline their technical and administrative processes.

It is recommended that each state and Indian tribe in the U.S. obtain full authority allowable to them to design and administer the SDWA and CWA within their jurisdiction to the extent that they have the financial, technical and administrative capacities to do so. Since both the SDWA and CWA allow some flexibility relative to their implementation, the states and tribes should customize their programs using a holistic, systematic, and integrated approach to implement state-/reservation-wide water quality programs that are protective of both their surface water and groundwater resources on a sub-basin or watershed scale.

If Congress accepts the challenge to integrate the resource protection programs under the SDWA with the CWA for protecting surface-water and groundwater resources (see above), this process could be relatively straight forward. However, if Congress chooses to not enact such changes, the states and tribes should develop an integrated water quality program for the surface water and groundwater within their jurisdiction to the extent they can by law in order to simultaneously meet the requirements of both Acts. The Groundwater Protection Council’s recent publication provides a number of ideas on how state and tribal programs can do so using the existing authorities provided in the SDWA and CWA (GWPC 2014).

Relative to implementing such an approach, EPA should support the development of pilot projects that allow states and tribes to experiment with developing such integrated programs, even if they do not meet all of the established procedural requirements of the SDWA and CWA; as long as they meet the intent and the water quality standards under each Act. Such an approach is in line with EPA's Long-Term Vision for Assessment, Restoration, and Protection under the Clean Water Act Section 303(d) Program (Stoner 2013):

> *By 2016, EPA and the States identify and coordinate implementation of key point source and nonpoint source control actions that foster effective integration across CWA programs, other statutory programs (e.g., CERCLA, RCRA, SDWA, CAA), and the water quality efforts of other federal departments and agencies (e.g., Agriculture, Interior, Commerce) to achieve the water quality goals of each state.*

In addition, states and tribes have full jurisdiction over the protection of all waters within their borders that are not under federal jurisdiction (i.e., surface waters not meeting the definition of waters of the U.S. and surface waters and groundwater not regulated as drinking water sources under the SDWA). It is recommended that each state and Indian tribe develop water quality protection programs for the waters under their jurisdiction that are analogous to the programs they administer under the federal programs to ensure consistent, high quality programs throughout their state or reservation, as applicable.

Specific to Indian tribes, it is recommended that EPA make it a high priority to develop the necessary programmatic processes and criteria to allow Indian tribes with federally-recognized reservations to apply for TAS authorization for all SDWA and CWA programs that the states currently have authorization to implement, such that they can fully participate in administering the SDWA and CWA on their reservations, on an equal basis with the states. In addition, Congress could provide the necessary financial and technical assistance to help Indian tribes to be successful in developing and implementing holistic, systematic, and integrated water resource protection programs.

Finally, it is recommended that EPA, other federal water and land agencies and the states located adjacent to Indian reservations collaborate and cooperate with Indian tribes to develop transboundary SDWA and CWA programs such that the goals of the SDWA and CWA can be met by both the states and the tribes relative to adjacent waters and waters that flow between the states and Indian reservations. A logical approach initially may be for EPA and BIA to support the tribes in developing a model water code(s) (e.g., see ASCE 2013; ASCE 1997; Draper 2013; EWRI 2007; INBO and GWP 2012; and Muys, Sherk, and O'Leary 2007) specifically designed to incorporate the Indian tribes' traditional knowledge and unique cultural values on Indian reservations, but also provides the appropriate regulatory framework to allow the reservation-based water polices and laws to interface properly with the water policies and laws governing the adjacent states and federal reservations.

Federal Land Management Policies and Laws

It is well established that any significant land disturbance within a basin, sub-basin or watershed has some, often significant impact(s) on the partitioning of water resources (e.g., the amount of evaporation and whether water flows overland or infiltrates into the ground), and the quantity, quality and timing of surface water and groundwater flows (Foley et al. 2005 and Lenat and Crawford 1994). Therefore, land and water resources planning and management should be more closely integrated in the U.S. However, fully integrating land and water resources planning has been proven difficult in much of the U.S. because of the complexities of differing authorities (e.g., federal, state, and tribal), ownership (e.g., private versus public lands), pushback by private property owners and the various stakeholders, constituencies associated with federal, state and tribal lands, and other factors.

There is a well-established body of federal resource management and environmental policies and laws for managing federal properties and resources (e.g., ESA, FLPMA, NEPA, NFMA, NPS Organic Act, NWPS, NWRSAA, and Wilderness Act). However, many of these laws do not provide a sufficient framework for holistically managing water and water-related resources on federal lands and some of these laws provide none (e.g., the NPS Organic Act, see above). It is recommended that Congress reevaluate each of these policies and laws and amend them to include clear and consistent policy and legal frameworks for managing water and water-related resources on federal lands in a more holistic, systematic, and integrated manner. Ideally, these policies and laws would foster the use of an IWRM or IWRM-like framework to ensure that water resources management on federal lands in federal water projects implements a scientifically-based, integrated management framework for the managing water allocations and quality, and for land development and use to meet their established management goals while reducing their impacts on water availability and quality, and riparian and aquatic habitats on all federal lands.

Development of more holistic, systematic, and integrated water policies and laws for federal lands would help improve the management of water and water-related resources on approximately 609 million acres of land under direct federal control. This constitutes approximately 27% of the lands in the U.S. In addition, by doing so, it would allow federal agencies to develop and test various approaches to improving the management of water and water-related resources and then make the knowledge, methods, and tools available for use by other federal, state and tribal agencies.

State and Tribal Land Management Policies and Laws

Legislatures in each state and tribal councils on each federally-recognized Indian reservation should consider utilizing an IWRM or IWRM-like framework, as discussed above, for managing water resources within their respective jurisdictions. Fortunately, it appears that most states have a well-established body of policies and laws for regulating and managing state lands and their associated natural resources (see above). Federal and tribal agencies also have well established policies and laws for managing lands and their associated natural resources on federally recognized Indian reservations. It is recommended that state legislatures and tribal councils review their polities and laws to determine if they include the appropriate criteria and guidance for managing water and water-related resource development and use in an integrated and sustainable manner within their jurisdictions. If they do not, it is recommended that they amend their existing or developing new water and water-related policies and laws to do so.

For example, most western states and a growing number of eastern states already have the requirement or at least the ability to manage surface-water and groundwater resources conjunctively (see above). However, most states have chosen not to do so, or they have chosen to do so only on a limited scale, to date. The development and implementation of water allocation policies and laws, outside of the Winters Doctrine and a few select court cases has not been well documented or vetted in the literature. Therefore, it is not clear at this time whether many or most Indian tribes on reservations have similar internal policies and laws.

In addition, most states already have the ability to integrate their water allocation policies and laws with water quality and ecosystem protection policies and laws, as likely do a selected number of Indian tribes on reservations. However, none are known to have established such policies and laws to date. Some authors suggest that it will be difficult to develop integrated approaches on Indian reservations (Royster 2011). That said, it is still recommended that each state and Indian tribe with federally-recognized reservation assess the potential costs and benefits associated with developing comprehensive, integrated land, and water policies for managing water and water-related resources within their jurisdictions, using an IWRM or IWRM-like framework. Such an integrated framework could be developed and tested on select state-owned lands, and on Indian reservations in collaboration with the BIA and the applicable states to the extent necessary and/or desired prior to being implemented more broadly.

Finally, surely all federal, state, and tribal agencies could benefit by working more cooperatively with each other when developing their integrated approaches to managing their water and water-related resources. In addition, they could all benefit by developing such policies in harmony with each other, prior to their water and water-related resources becoming stressed by severe droughts, over-appropriation, or water quality issues.

Associated Environmental Policies and Laws

The ESA, NEPA and the Wild and Scenic Rivers Act, and the Principles and Requirements are very important policies and laws relative to protecting water and water-related resources in the U.S. Each of them require extensive planning and analyses prior to implementing a federal water resources development project or activity, or designating a river as a wild and scenic river. The ESA, NEPA and the Wild and Scenic Rivers Act could be amended to require the use of an IWRM or IWRM-like framework when assessing water and water-related projects, activities or designations associated with federal lands and water projects. At a minimum, they could refocused to assess the potential impacts of federal projects and activities on the full extent of the surface waters, their hydrologically interconnected groundwater resources water and water-related resources that may be impacted by federal development activities, at the appropriate sub-basin or watershed scale (e.g., potential impacts on critical habitats, listed species or free flowing rivers, and their surrounding environment).

In addition, the Principles and Requirements could be revised to require the use of the IWRM framework and principles during both the planning and analysis phase of all major federal water projects and activities.

Water Treaties and Compacts

The U.S. has freshwater treaties with both of its international neighbors Canada and Mexico (Table 12). In addition, there are 45 water-related interstate compacts and/or commissions designed to improve cooperation and coordination between two or more states (Table 17).

Despite recent efforts by the IJC and the IBWC (Campana, Neir, and Klise 2007), for the most part, there is insufficient information about groundwater resources along the U.S.'s borders to manage water and water-related resources in a holistic, systematic, and integrated manner. Only recently has the IJC begun to develop integrated transboundary surface water maps (hydrologic unit maps) for the border between the U.S. and Canada (Monday 2010). In addition, the IJC recently began developing integrated groundwater maps for selected portions of the border area (Long et al. 2014, Nastev et al. 2006, Thamke et al. 2014, and Williams et al. 2010). However, many of the groundwater resources along the U.S./Canadian border remain poorly characterized and understood.

Historically there has been even less groundwater-related data and information collected along the U.S.-Mexico border. However, in 2006, Congress passed the U.S. – Mexico Transboundary Aquifer Assessment Act (Public Law 109-448) to authorize and fund a bi-national study to systematically assess priority transboundary aquifers and to meet the water information needs of border communities (Alley 2013). However, these studies will only address a small portion of the sub-basins/watersheds/ aquifers associated with the U.S./Mexico border.

Despite these recent efforts, there is not a comprehensive transboundary approach for collecting the data and information necessary to fully understand the water and water-related resources along either U.S. border. In addition, the three countries have not developed the policies and laws that would be necessary for managing water and water-related resources within all of the transboundary sub-basins/watersheds they share in common. The U.S., Canada, and Mexico should work together through their respective commissions (i.e., the IJC and the IBWC) to develop a more holistic, systematic, and integrated approach to understanding and managing the water and water-related resources within each of the transboundary sub-basins or watersheds they share in common to the extent allowable under their respective treaties.

Interstate compacts with few exceptions are single issue agreements between states (e.g., water quality, water quantity, or flood control), that are mostly focused on surface water issues (Table 17). Generally, interstate compacts have sufficient data and information available to implement the specific management aspects they are designed to implement. However, there is generally insufficient information available to comprehensively understand and/or manage interstate or state/tribal sub-basins/watersheds. A few (e.g., the Delaware River Basin, and Susquehanna River Basin Compacts) are comprehensive for surface water and groundwater resources and they address both quantity and quality. A few others at least include both surface water and groundwater resources (e.g., Republican River Compact between Kansas and Nebraska); however, they are in the vast minority.

Draper (2013, 2006, and 2002) points out the growing need for comprehensive water sharing agreements between countries (e.g., international treaties or agreements). However, these needs are not limited to agreements between countries. Many states and Indian tribes are also facing increasing demands within transboundary sub-basins/watersheds because of increasing impacts by upstream countries, states, and reservations on downstream entities. Draper (2013) emphasizes that effective and robust transboundary water sharing should be based on four guiding principles; coordination and cooperation, interdisciplinary analysis, watershed and river basin planning, and adaptive management. Finally, he emphasizes that in order to be effective, basin managers need a full understanding of the atmospheric, surface water, groundwater resources, water supply demands, and other environmental and resource issues. Many similar recommendations can be seen in the *Utton Transboundary Resources Center Model Interstate Water Compact* (Muys, Sherk, and O'Leary 2007).

It is recommended that the U.S. State Department, for treaties, and the applicable states, for interstate compacts, review the rather recent transboundary model water codes relative to their respective treaties and compacts to determine if they could benefit from developing a more holistic, systematic, and integrated approach to assessing and managing their transboundary water and water-related resources. In addition, it is recommended that those states and Indian tribes that share water resources with other riparians, but do not currently have water sharing agreements with their neighboring states and/or Indian reservations also review the transboundary model water codes to determine if they could benefit from developing transboundary water agreements with their neighbors. Hopefully, both the applicable states and tribes will develop more effective and robust transboundary water and water-related agreements well in advance of crises developing, which would force them to develop such agreements under duress.

Federal Executive Orders and Others

Under the U.S. Constitution, Congress is responsible for establishing federal policies and laws and the President is responsible for implementing those policies and laws through the various agencies within in the Executive Branch. In general, Congress passes laws setting general requirements and goals with some level of specificity. In order to implement those laws, the Executive Branch agencies generally develop and implement detailed regulations. In addition, the President can and often does establish executive orders to establish consistency and direction within the Executive Branch relative to implementing various policies and laws.

Relative to resource management, it is generally preferable that Congress develop long-term, holistic and sustainable policies and laws for managing natural resources (e.g., managing water and water-related resources associated with federal lands and federal water projects). To date, the body of federal resource management and environmental policies and laws for managing federal properties and resources do not provide a sufficient framework for holistically managing water and water-related resources on federal lands or in federal water development projects. Therefore, it is recommended above that Congress consider assessing and modifying the appropriate federal water and water-related policies and laws associated with all federal lands and water development projects. It is hoped that Congress will do so. However, if Congress is unwilling or unable to do so, then the President could consider using his/her executive authority to implement such policies for the Executive Branch agencies via the use of an executive order to the extent that it can be implemented within the applicable federal policies and laws.

If the President is directed by Congress to develop a more holistic, systematic, and integrated approach to managing water and water-related resources on federal public lands and reserves, and/or within federal water projects, or the President chooses implement it under his/her executive authority, it is recommended that it be implemented broadly throughout the Executive Branch. For example, the Council on Environmental Quality, the Office of Management and Budget, and the Office of Science and Technology Policy could be directed to work in cooperation with the appropriate agencies to develop the interagency policies and methodologies based on the best available science. This effort could include the participation of the water agencies (Corps and BOR) and other water-related agencies governed by the Principles (e.g., NRCS), land management agencies (e.g., USFS, NPS, F&WS, and BLM), DOD, science agencies (e.g., DOE, NASA, and USGS), atmospheric science agencies (e.g., NOAA and NWS), and other agencies (e.g., BIA and EPA), as appropriate.

This program could include developing interagency guidance for implementing a more holistic, systematic, and integrated approach on all federal lands and in federal water development projects, based on the best available science. The Technical Guide to Managing Ground Water Resources (Glasser et al. 2007) and other related federal agency guidance documents may provide an excellent starting point for developing an interagency IWRM guidance document. Based on the final interagency guidance document(s), federal land and water agencies could test, using an adaptive management approach, the implementation of an IWRM or IWRM-like framework for managing water resources on the federal lands and in federal water projects. In addition, they could establish an interagency scientific program for developing and evaluating the methods, tools, data, and other information necessary to help facilitate the implementation of the framework at the appropriate sub-basin or watershed scales (Corps 2015b; Omernik 2004; Omernik and Griffith 2014; and Wolock, Winter, and McMahon 2004).

The federal government owns approximately 629 million acres of land that are directly under its control (Gorte et al. 2012). It could use those lands for conducting pilot studies for evaluating the effectiveness, robustness and desirability of the various policies and laws, and for evaluating and testing various interagency guidelines, methods and tools to improve our understanding and management of water and water-related resources. These studies could be designed, implemented, and evaluated using an adaptive management framework on various water and water-related management options using a phased or tiered approach (e.g., initially using select forests, grazing lands, and wildlife units and then expanding as appropriately to additional lands and projects) on a wide variety of federal lands that reflect a large range of physiographic provinces, hydrologic landscapes, and ecosystems.

The results of the pilot programs could be used to evaluate whether an IWRM or IWRM-like framework can provide a solid basis for developing and refining federal water and water-related policies and laws, and for developing the scientific tools and methods necessary to better understand and manage land and water resource associated with federal lands and water development projects. Based on the results of the pilot studies, Congress and the President could determine whether federal water and water-related resources can be better understood and more effectively and robustly managed using an IWRM or IWRM-like framework and then either implement the framework or not, as is appropriate.

If the pilot programs are successful, the federal government could then transfer such knowledge and tools to states and Indian tribes to allow them to conduct similar pilot studies towards managing water and water-related resources within their states and on their reservations, as appropriate and desired, to determine for themselves whether an IWRM or IWRM-like framework is the most appropriate approach for managing their water and water-related resources. Hopefully, these studies would be conducted in collaboration with other federal agencies, states, and Indian tribes such that each could learn from and support each other.

Conclusions

The management of water, land, and environmental resources in the U.S. are based on a mix of federal, state, tribal and local policies, laws, regulations and ordinances, and treaties and compacts. Some of these legal instruments have been well thought out, are comprehensive and have stood the test of time; others have not. However, as the demands for water and the conflicts over water continue to increase, it may be time for the U.S. water community to develop more holistic, systematic, and integrated management policies and laws, and the methods and tools necessary to meet those growing demands and address those conflicts. IWRM may be the most logical and appropriate next logical step for managing water resources needs in the U.S. (AWRA 2011; ASCE 2001, 1998a, 1998b, 1997; EWRI 2007; and USACE 2013 and 2010).

The U.S. has a significant body of water and water-related policies and laws. However, it may be possible to improve these by viewing them as a body of polices and laws and assessing them as a whole. In the end, IWRM as it is described by Agenda 21 (UNCED 1992) may or may not prove to be the appropriate approach for managing water and water-related resources in the U.S. However, at a minimum, given the existing and expected challenges facing the U.S. water community and some of the obvious weaknesses existing in U.S. water policy and law, it appears to be a logical model for at least testing and evaluating potential new opportunities and approaches for improving water and water-related management in the U.S. It appears that IWRM can provide a model framework that can be modified for evaluating existing water and water-related policies and laws in the U.S. In addition, it can provide a model framework for developing new or modifying existing policies and laws to produce more holistic, systematic, and integrated system for managing water and water related resources in the U.S. Therefore, carefully crafted, IWRM or an IWRM-like framework may indeed be the most appropriate approach to managing U.S. water and water-related resources in the future.

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CHAPTER 5: SUMMARY AND CONCLUSIONS

Introduction

The United States (U.S.) is a resource-rich nation and the development of water and water-related resources has helped to create enormous socioeconomic prosperity and stability in the U.S. for more than 200 years. However, development of these resources has not been without its attendant costs. Global change (Steffen et al. 2004) has impacted virtually every river basin in the U.S., often degrading the quality and availability of water and water-related resources (Bates et al. 2008, Georgakakos et al. 2014, Glennon 2009, and Reisner 1993). For example, it has significantly altered the quality of most freshwater, resources (e.g., surface water and groundwater) to the extent that water-quality in more than 54% of the surface water bodies monitored in the U.S. is threatened or impaired (EPA 2015). In addition, global change has significantly altered the vast majority of ecosystems (e.g., forests, prairies, freshwater bodies, and territorial seas) in the U.S. (Georgakakos et al. 2014) to the extent that a large number of aquatic and riparian species are listed as "threatened" or "endangered" (e.g., 164 species of fish and 35 species of amphibian) under the Endangered Species Act (USFWS 2013).

Based on recent population (Colby and Ortman 2014) and climate change (Bates et al. 2008) projections, it is likely that these impacts will increase in many parts of the U.S. in the future. In addition, it is likely that such changes will increase the number and the intensity of conflicts over water and water-related resources in the U.S. as more people compete for the remaining available water supplies and as ecosystems continue to be degraded by anthropogenic water use (Gleick 2013, Greenberg 2009, Hunton and Williams 2009, and Wines 2014). Therefore, the question is whether the U.S. water community should adapt more effective, robust and sustainable policies, laws, practices and technologies to improve the management and use of water and water-related resources in the U.S. in advance of such impacts or should it wait and address those impacts as they arrive in an *ad hoc* manner?

The overall purpose of this dissertation is to evaluate if Integrated Water Resources Management (IWRM) or an IWRM-like approach could be a useful for improving the management of water resources the U.S. and if it appears to be a useful approach, then to provide a conceptual framework and recommendations concerning utilizing it for the management of water and water-related resources in the U.S. This research provides an overview of the evolution of IWRM and its connection to the evolution of water resources management in the U.S. In addition, it evaluates the basic principles and concepts of IWRM, as provided in Agenda 21 (UNCED 1992) versus a comprehensive conceptual hydrologic model to provide a better understanding of the interrelationship and the interdependence of the physical, socioeconomic, legal, and environmental constraints associated with the management of water and water-related resources on a watershed and/or sub-basin scale. Finally, it evaluates existing U.S. water and water-related policies and laws to determine if an IWRM framework can provide a more holistic, systematic, and integrated national framework for developing and managing water and water-related resources in the U.S. to provide a more sustainable approach to meet the U.S.' increasingly demanding water resources challenges.

Development and Implementation of Integrated Water Resources Management

Chapter 2 provides an overview of the development and implementation of IWRM in the international community and concepts and efforts in the U.S. to develop more holistic, systematic, and integrated approach to the development and management water and water-related resources in the U.S. (e.g., IWRM or IWRM-like programs).

The most broadly accepted definition of IWRM is (GWP 2000);

> *A process, which promotes the coordinated development and 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.*

The concept of IWRM was primarily developed through the United Nations (UN) and it was formally accepted internationally as part of Agenda 21 in 1992 (UNCED 1992a). According to one UN review (UNDESA 2012):

> *Primarily the intention [of developing IWRM] was to shift the common approach from the supply-oriented mindset to a more holistic catchment conscious approach, integrating all stakeholders, users, polluters and regulators to inform governance processes and develop compatible monitoring systems to inform those processes.*

IWRM has been formally approved and documented in Chapter 18 of Agenda 21, "Protection of the Quality and Supply of Freshwater Resources: Application of Integrated Approaches to the Development, Management and Use of Water Resources" (UNCED 1992). Specifically, IWRM is discussed in Sections 18.6–18.22. These sections provide the original "basis for action" (18.6), objectives (18.7–18.11), activities (18.12), and means of implementation (18.13–18.22) for developing IWRM programs.

IWRM provides a holistic, systematic, and integrated framework that promotes the sustainable development and management of water and water-related resources in order to maximize the economic and social welfare of humans without compromising the sustainability of the environment (GWP 2000 and GWP 2009). It is intended to be implemented using a comprehensive, interdisciplinary, stakeholder-driven approach to developing and implementing efficient, equitable, and sustainable solutions to water and water-related development challenges. It promotes the objectives of sustainable freshwater management, which include: "…to make certain that adequate supplies of water of good quality are maintained [for humans]…while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature, and combating vectors of water-related diseases" (UNCED 1992). It advocates the need for understanding and managing all water resources within a sub-basin or watershed as a unitary source from a hydrologic cycle perspective; including consideration of both water quantity and quality. In addition, it advocates the need for understanding and managing all water-related resources (e.g., land and ecological resources) that impact the availability and the quality of water within a sub-basin or watershed.

Finally, IWRM advocates for the consideration of the multi-sectoral nature of water resources development (e.g., water supply for domestic, commercial, municipal, industrial, sanitation, agricultural, power generation, freshwater fisheries, transportation, and recreation), the implementation of water conservation and waste minimization measures, flood prevention and control measures, and sedimentation control, where it is needed.

In summary, IWRM is intended to be a framework that promotes the sustainable development and management of water and water-related resources in order to maximize the economic and social welfare of humans without compromising the sustainability of the environment (GWP 2000 and UNCED 1992).

IWRM was designed for world-wide applicability; it has been largely embraced by the international water resources community (GWP 2005, GWP 2000, UNCED 1992b, and UNEP 2012), but to date has not be well accepted by the U.S. water community. Some have debated whether IWRM can be or has ever been successfully implemented anywhere (e.g., Biswas 2008, 2004, and 2001) or whether IWRM is significantly different or any better than well-established and well-run water resources management programs in the U.S. (AWRA 2005). However, a growing number of organizations believe that IWRM may be a significant improvement for managing water resources in the U.S. (AWRA 2011, AwwaRF 1998, and USACE 2010). For example, while many aspects water resources management in the U.S. are very advanced, in general the "mindset" of the U.S. water community remains primarily supply-oriented rather than a holistic, systematic, and integrated approach that balances human needs with the needs of the environment in a sustainable manner. In addition, many U.S. water and water-resource related policies and laws are not physically based, and water policies, laws, and governance (e.g., the roles, responsibilities and goals of agencies) in the U.S. are highly decentralized and fragmented.

The question at hand is whether an IWRM framework can be utilized to develop a more holistic, systematic, and integrated approach for developing and managing water and water-related resources in the U.S.? That is, can this framework be used to find and fill existing gaps, find and remove inconsistencies, and refine existing U.S. policies and laws within the bounds of the traditions and expectations of the U.S. water community and its stakeholders to more sustainably develop and manage water and water resources in the U.S.?

Conceptual Model

One way to improve water development and use in the U.S. is to better understand the hydrologic cycle and anthropogenic impacts on water and water-related resources within each watershed and/or sub-basin and then develop policies and laws that can foster a sustainable balance between the protection and use of those resources. Chapter 3 provides a conceptual model (modified from Scanlon et al. 2002) which looks at each of the critical "pieces and parts" of a watershed or sub-basin. It discusses the physical socioeconomic, legal and environmental constraints within a "competent hydrologic unit" and the links between each of these aspects. By developing a better understanding of each of these aspects and the interrelationship between them, we can develop more holistic, systematic, and integrated water policies and laws. In addition, if these policies and laws are properly grounded and developed holistically, they can link with other connected resources and with other overarching or affected policies, laws at the appropriate scale (e.g., federal, state and tribal policies and laws).

In his influential book "The Closing Circle" Barry Commoner provides four "Laws of Ecology" (Commoner 1972),

- Everything is connected to everything else
- Everything must go somewhere
- Nature knows best
- There is no such thing as a free lunch.

As can be seen in Chapter 3, these concepts are analogous to water resources in a given competent hydrologic unit (e.g., watershed or sub-basin). For example, "everything is connected to everything else." Atmospheric water is directly connected to surface water resources and it is directly and/or indirectly connected to groundwater resources. Likewise, groundwater discharges to surface water bodies or seepage into shallow soils reconnects it with the surface water supply and the atmosphere. Water within a given competent hydrologic unit flows through or is temporarily stored, but eventually all water resources will eventually flow out of most if not all watersheds and/or sub-basins (even if that movement is on a geological time scale).

"Nature knows best" in that the storage and flow of water will conform to the physical laws of nature and follow the most energetically efficient pathway within and through a given watershed and/or basin some external energetic input is applied to change its pathway. Humans can and do modify the natural storage and flow of water; however, any such changes have costs associated with them. From a physical perspective, it will require the input of energy (e.g., manpower, from beasts of burden or the use of electricity/fuels); from a socioeconomic perspective, it will require the input of social and/or monetary capital. Finally, there are no "free lunches" in nature. If the natural storage and flow of water is modified by humans, it will directly impact the quality, quantity, timing and/or location of the water available to other water users and the environment throughout a given competent hydrologic unit or between connected competent hydrologic units.

These concepts are not necessarily new or likely a surprise to anyone in the water community or even an educated member of the general public. However, actually considering each of these parts as a whole from a watershed and/or basin perspective, developing an understanding the causes and effects of our modification and use of these resources and trying to find a sustainable approach to balancing the needs and desires of humans and the environment would be new for much if not most of the U.S.

Holistic, Systematic, and Integrated Policies and Laws

Water policies and laws (legal constraints) are important. They establish what activities are legal and illegal, what types of activities the government will promote or try to prevent, and what government resources and finances will be authorized and allocated to promote or to prevent those activities. Therefore, in order to have effective, robust and sustainable water programs, the U.S. needs to have well designed and well integrated water and water-related policies and laws that consider each of the critical aspects which effects water and water-related resource development and management.

Chapter 4 provides an overview of the key federal, state, and Indian policies and laws that govern water and water-related development, allocation, and protection. These include major water federal development policies and laws (e.g., the Reclamation Act, and various Rivers and Harbor Acts, Water

Resources Development Acts, and Flood Protection Acts); water quality policies and laws (e.g., the Safe Drinking Water Act and the Clean Water Act); other key water and water-related policies and laws (e.g., the Endangered Species Act, National Environmental Policy Act, and the Wild and Scenic Rivers Act); various treaties and interstate compacts; executive orders; and key federal land management policies and laws that govern water and water-related resources for about 27% of the U.S. (Gorte et al. 2012). In addition, Chapter 4 provides an overview of state and Indian water allocation and water quality policies and laws. These policies and laws combined with judicial decisions and executive orders comprise the federal, state, and tribal policies and laws that govern water and water-related resources in the U.S. (Grigg 2011).

Chapter 4 recommends that each of the policies and laws discussed be reviewed as a whole and that the U.S. water community considers how they can be modified and/or integrated to develop a more holistic, systematic, and integrated approach to governing our water and water-related resources in the U.S. In addition, it provides a select number of recommendations relative to improving water and water-related resource development in the U.S. These include developing physically-based water policies and laws; the management and disposition of Federal Reserved Water Rights; establishing a more holistic, systematic, and integrated approach for managing federal, state, and tribal water development, water quality and land management programs; recommendations for improving water treaties and interstate water compacts; and recommendations for using executive orders for developing pilot studies for developing and testing more holistic, systematic, and integrated water policies, laws, methods and guidance for managing federal, state, and tribal water and water-related resources in the U.S.

As was stated above, policies and laws are important because they establish the “tone” and the “tenor” and they provide the opportunities and the constraints relative to how water and water-related resources are currently developed and managed in the U.S. and how they will be managed in the future. Water, land, and environmental resource management in the U.S. are based on a mix of federal, state, tribal, and local policies, laws, regulations and ordinances, and treaties and compacts that cumulatively impact the final outcome of how we manage these resources. Therefore, they must be considered as a whole within a given competent hydrologic unit and wherever they affect or are affected by other connected resources and/or policies and laws, including those at other scales. As demands for and conflicts over water and water-related resources continue to increase, it may be time for the U.S. water community to develop more holistic, systematic, and integrated management policies, laws, methods, and tools to meet those growing demands and changing needs. IWRM may be the most logical and appropriate next logical step for managing water resources needs in the U.S.

Conclusions

As is discussed in Chapter 2 of this dissertation, numerous international and U.S. organizations have recognized the need for establishing a more sustainable and integrated approach to water and water-related resources to balance socioeconomic and environmental needs. Focusing on the U.S. programs, many organizations have discussed the need to better align and integrate water policy and law

Many water resources professionals and organizations in the U.S. have called for better integration of economic, environmental, ecological, physical, and social aspects into natural resources management (ASCE 2010a, ASCE 1998a, ASCE 1998b, AWRA 2012, AWRA 2011, AwwRF 1986, CEQ 2013, EPA 2013, Grigg 2008, Naiman 1992, NDWAC 2010, NEPA 1969, NRC 1999, NWC 1973, WRC 1973, WRC 1983, and WWPRAC 1988). Some have called for more scientifically based approaches (ASCE 1997, EWRI 2007, CEQ 2013, and NRC 1999); using such approaches as adaptive management (NRC 1999 and WWPRAC 1988), conjunctive management (USACE 2010b), integrating water quality and water quantity management (EPA 2012b), and recognizing the impacts of various the various policies and laws on water users and the environment (NRC 1999 and WWPRAC 1988). Others have called for evaluating and integrating resources management on a watershed/sub-basin scale (USACE 2010b and NRC 1999), including both human and environmental needs and impacts (CEQ 2013 and NRC 1999). And a few have even recommended better interagency coordination (CEQ 2013 and WWPRAC 1988). Despite the clear recognition of the many shortcomings of water resources management in the U.S., there have been relatively few calls by water resources professionals and organizations to actually develop and implement a systematic, integrated, and holistic approach to managing water resources in the U.S.

Some professionals and organizations have specifically called for the implementation of IWRM or IWRM-like programs in the U.S. at the state (ASCE 1997, AwwaRF 1996, CADWR 2013, EWRI 2007, and OWRD 2012) or federal level (AWRA 2012, AWRA 2011, EPA 2013, EPA 2012c, Shabman and Scodari 2012, and USACE 2010b). However, most of these offerings are quite general in nature; providing little specificity as to what a systematic, integrated, and holistic approach water resources management in the U.S. would include or how these programs would be framed (AWRA 2012, AWRA 2011, AwwaRF 1996, EPA 2013, and EPA 2012c). Most of the specific details have been provided by the Corps, which provides a big more complete details on the concept of IWRM (USACE 2010b) and even a relatively robust framework for implementing IWRM (Shabman and Scodari 2012). However, Shabman and Scodari's framework is limited to the discussing implementation of water resources planning within the Corps' established project-planning process, although at a watershed scale.

Using the IWRM framework developed via Agenda 21 as a starting point, this dissertation summarizes the key concepts and activities that appear to be pertinent to implementing a more systematic, integrated and holistic approach to managing water resources in the U.S. In addition, this dissertation highlights the key criticisms and potential shortcomings of implementing the contemporary approach to IWRM provided in Agenda 21, as provided in the literature (Biswas 2008, 2004, and 2001). A similar, though less rigorous review of the key concepts, activities and criticisms was provided by the authors of AWRA (2012), but such a review was not provided by the others reviewed by this research.

This dissertation also provides a conceptual hydrologic model that should be useful for evaluating and developing a better understanding watersheds and sub-basins, for establishing systematic, integrated and holistic data/information and water management programs, and for establishing more systematic, integrated and holistic policy and legal frameworks in the U.S. The USGS has developed a similar approach for characterizing basins under its National Water Quality Assessment Program (USGS 2013b) and a select number of its National Research Programs (e.g., bibliography at USGS 2015a). However, these programs are generally focused on understanding the scientific aspects of the basin during a snapshot in time. They are not designed to provide an integrated and holistic framework for managing water resources or for developing a policy framework. No other agencies reviewed have established such a systematic, integrated, and holistic approach to either characterizing or managing water resources or for developing a water resources policy framework.

Finally, this dissertation evaluates state, tribal and federal water polices and laws that seem amenable to developing IWRM and/or IWRM-like programs, as deemed appropriate and desired by the appropriate state, tribal and/or federal policy- and decision-makers. No other literature reviewed as part of this research provided a comprehensive review of these policies and laws.

It should be noted that the recommendations and criticisms provided in this dissertation likely have some validity, but each one should be considered and implemented with caution depending on the given program(s) being developed and implemented, the given purpose(s) for implementing such a program, and the local/regional requirements, conditions, and constraints. Both the recommendations and criticisms should be evaluated within the context of the appropriate legal and policy goals, requirements, and constraints and within the applicable physiographic and hydrologic contexts of the watershed(s) or sub-basin(s) being considered.

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APPENDIX A. SUMMARY OF WATER DOCTRINES IN THE U.S. INCLUDING CONJUNCTIVE MANAGEMENT[1]

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Eastern Water Law					
Alabama		Regulated Riparian[2,11,12]	Regulated Riparian[12], Reasonable Use[4]/ Absolute Ownership[9] (due to lack of implementation of statutes)	Alabama Water Resources Act (Ala. Code §§ 9-10B-1-30 (2008) Declarations of Beneficial Use (Ala. Admin. Code. r. 305-7-10-.01-.07 (1994)	Withdrawals are administered by the Department of Economic and Community Affairs, Office of Water Resources. All uses must file a Declaration of Beneficial Use with the Office of Water Resources. Registration and reporting is required for uses above 100,000 gpd. Conjunctive Management – Unclear. Alabama has unified SW/GW laws in place, but does not appear to be implementing them in practice.
Arkansas		Reasonable Use[11,12], Regulated Riparian[2]	Reasonable Use[9,12], Correlative Rights[4]	Power of Commission Regarding Waters (Ark. Stat. Ann. § 15-22-205 (1985)) Rules Governing Water Development Project Compliance with the Arkansas Water Plan (6 Ark. Code R. §§ 601.1–607.3 (2007))	Withdrawals are administered by the Arkansas Natural Resource Commission. All water withdrawals are registered and non-riparian surface water withdrawals are permitted. Annual water reports are used to allocate water during times of shortage. Permits are transferable. Conjunctive Management – No. SW/GW are regulated separately.[3] Permits are only required for surface water diversions.[9]
Connecticut	Modified Common Enemy Law[10]	Regulated Riparian[2,11,12]	Regulated Riparian[12], Absolute Ownership[4]/ Regulated Riparian[9]	Water Diversion Policy Act (Conn. Gen. Stat. §§ 22a-365–379 (2005)) Water Diversions (Conn. Agencies Regs. §§ 22a-372-1 to -377(c)-2 (1990))	Withdrawals are administered by the Department of Environmental Protection. Permits are required for withdrawals or transfers greater than 50,000 gpd, diffused water collected from areas greater than 100 acres. Selected withdrawals must be reported. Conjunctive Management - Yes. Connecticut has unified SW/GW laws.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Delaware	Natural Flow[10]	Regulated Riparian[2,11,12]	Regulated Riparian[12], Correlative Rights[4]/ Regulated Riparian[9]	Delaware Revised Code (Del. Code Ann. tit. 7, § 6003(a)(3)(1953)) Regulations Governing the Allocation of Water (1987) Title 7,Natural Resources and Environmental Control, 7500 Wetlands and Subaqueous Lands	Withdrawals are administered by the Department of Natural Resources and Environmental Control. Transfers to non-riparian water users are permitted. Water withdrawals greater than 50,000 gpd are permitted and selected withdrawals must be reported. Additional permits are required in Delaware River Basin for withdrawals greater than 100,000 gpd. Conjunctive Management - Yes. Permits large surface- and ground-water withdrawals and regulates impacts on hydrologically interconnected SW/GW systems.[3]
District of Columbia	Modified Common Enemy Law[10]	Riparian	Absolute Ownership[1]		Withdrawals are administrated by D.C. Water and Sewer Authority. Virtually all water use now goes through the municipal utility. Conjunctive Management – Unclear.
Florida	Natural Flow[10]	Regulated Riparian[2,11,12]	Regulated Riparian[9,12], Reasonable Use[4]	Permitting of Consumptive Uses of Water (Fla. Stat. §§ 373.219–245 (2008)) Water Management Administrative Code (Fla. Admin. Code Ann. r. 40A–E (2008))	Withdrawals are administered by five independent water districts. Water withdrawal permitting and reporting requirements are established independently by each water management districts Conjunctive Management - Yes. Permits large surface- and ground-water withdrawals[3] and regulates impacts on hydrologically interconnected SW/GW systems.[3,9]
Georgia	Natural Flow[10]	Regulated Riparian[2,11,12]	Reasonable Use[12], Absolute Ownership[1,4] /Regulated Riparian[9]/ Absolute Ownership[9] (due to exemption of most withdrawals)	Surface Water Use Act & Groundwater Use Act (Ga. Code Ann. §§ 12-5-31, -96 (2008)) Groundwater Use (Ga. Comp. R. & Regs. 391-3-2 (1990))	Withdrawals are administered by the Environmental Protection Division. Large non-agricultural water uses, greater than 100,000 gpd, require permits and monitoring. Georgia exempts virtually all agricultural water use (about 80% of the water withdrawals in the state).[9] Conjunctive Management - No. SW/GW are regulated separately.[3, 9]

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Illinois	Riparian	Riparian[11,12]	Regulated Riparian[12], Reasonable Use[4]/ Absolute Ownership[9] (due to lack of implementation of statutes)	Level of Lake Michigan Act (615 Ill. Comp. Stat. 50/1 (1996)) Illinois Water Use Act (525 Ill. Comp. Stat. 45/1 (1983)) Illinois Groundwater Protection Act (415 Ill. Comp. Stat. 55/1 (2006)) Illinois Environmental Protection Act (415 Ill. Comp. Stat. 5-14 (2002))	Surface water withdrawals are administered by the Illinois Department of Natural Resources. Groundwater rights are registered with the Illinois Department of Agriculture and disputes settled by Soil and Water Conservation Districts. Select surface water withdrawals are permitted and groundwater withdrawals greater than 100,000 gpd are registered. Generally, surface water withdrawals are governed by riparian rights and groundwater withdrawals are governed by reasonable use. Surface water withdrawals from Lake Michigan are governed by the Level of Lake Michigan Act. Conjunctive Management - No. SW/GW are regulated separately.[3, 9]
Indiana	Common Enemy Law[10]	Riparian[11,12]	Absolute Dominion, Absolute Ownership[1,4]	Water Resource Management Act (Ind. Code §§ 14-25-7 (1995)) Navigable Water Rights Act (Ind. Code §§ 14-29-1 (1995))	Withdrawals are administered by the Indiana Department of Natural Resources, Water Division. Significant water withdrawals, greater than 100,000 gpd, must be registered and reported. Permits are required for withdrawals from navigable waters. Selected permit may be required. Conjunctive Management - No. SW/GW are regulated separately[3] Permits are only required for significant withdrawals in “critical areas.[9]
Iowa	Reasonab le Use	Regulated Riparian[2,11,12]	Regulated Riparian[2,12]	Permits for Beneficial Use (Iowa Code §§ 455B.261–.278 (1996)) Water Permit or Registration, when Required (Iowa Admin. Code r. 567-50–52 (1996))	Withdrawals are administered by the Department of Natural Resources. Water withdrawals greater than 25,000 gpd require permits and must report water use. Conjunctive Management - Yes. Regulates impacts on hydrologically interconnected SW/GW systems.[9]

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Kentucky	Not Regulated	Regulated Riparian[11,12]	Regulated Riparian[9,12], Reasonable Use[4]	Kentucky Revised Statutes (Ky. Rev. Stat. Ann. §§ 151.00.140–.210 (1978)) Kentucky Administrative Regulations–Water Resources (401 Ky. Admin. Regs. 4:010 –300 (2005))	Withdrawals are administered by the Department of Environmental Protection, Division of Water. Water withdrawals greater than 10,000 gpd are permitted and reported except domestic, agricultural, PSC seam-powered generation plants, and underground injection for gas and oil production. Conjunctive Management - Yes. Permits large surface- and ground-water withdrawals and regulates impacts on hydrologically interconnected SW/GW systems.[3]
Louisiana	Natural Flow[10]	Reasonable Use[11,12] (based on French Civil Code)	Reasonable Use[12], Absolute Ownership[1,4]	Louisiana Revised Statutes (La. Rev. Stat. Ann. §§ 38.3091–3097) Water Wells (La. Admin. Code tit. 56, § 101)	Groundwater withdrawals are registered with the Department of Transportation and Development, Water Resources Division in cooperation with U.S. Geological Survey. Groundwater withdrawals are registered except gas and oil production. Water withdrawals greater than 50,000 gpd are permitted. Facilities using greater than 1,000,000 gpd report quarterly, around Baton Rouge report monthly and others quadrannually. Conjunctive Management – Unclear.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Maine	Common Enemy Law[10]	Reasonable Use[11,12]	Absolute Dominion, Absolute Ownership[4]	Water Withdrawal Reporting Program (Me. Rev. Stat. Ann. tit. 38, §§ 470-A–H (2001)) Sustainable Use of and Planning for Water Resources (Me. Rev. Stat. Ann. tit. 5, §3331-8 (2007)) Act to Clarify and Harmonize State Policy on Groundwater Management (Me. Rev. Stat. Ann. tit. 12, §685-B-4 (2007)) Natural Resources Protection Act (Me. Rev. Stat. Ann. tit. 38 §§ 480-A to 480-BB (2008)) Wetlands and Waterbodies Protection (06-096-310 Me. Code R. 11,120 (2006)) In-stream Flows and Lake and Pond Water Levels (06-096-587 Me. Code R. 11,124 (2006))	Withdrawals are administered by the Department of Environmental Protection, Bureau of Land and Water Quality. The department establishes minimum stream flows and lake levels where significant surface water withdrawals are allowed. All agricultural uses are reported to the Department of Environmental Protection or the Department of Agriculture, Food and Rural Resources Division. Significant groundwater withdrawals are permitted and agricultural withdrawals are reported. Conjunctive Management – No. Main manages GW using Absolute Dominion.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Maryland		Regulated Riparian[2,11,12]	Regulated Riparian[9,12], Reasonable Use[4]	Appropriation or Use of Waters (Md. Code Ann., Envir. §5-501–516 (2000)) Maryland Water Conservation (Md. Code Ann., Envir. §5-5B-01–05 (2000)) Water Management (Md. Code Regs. 26.17.06–.9999 (1988))	Withdrawals are administered by the Department of the Environment. Water withdrawals are permitted, additional permitting requirements for withdrawals greater than 10,000 gpd Conjunctive Management - Yes. Permits large surface- and ground-water withdrawals and regulates impacts on hydrologically interconnected SW/GW systems.[3]
Massachusetts		Regulated Riparian[2,11,12]	Regulated Riparian[9,12], Absolute Ownership[4]	Massachusetts Water Management Act (Mass. Gen. Laws Ann. ch. 21G, § 1–19 (1986)) The Water Management Act Regulations (310 Mass. Code Regs. 36.00 (2005))	Withdrawals are administered by the Department of Environmental Protection Water withdrawals are registered. Withdrawals greater than 100,000 gpd are permitted. Conjunctive Management - Yes. Regulates impacts on hydrologically interconnected SW/GW systems.[9] Conjunctive Management – Yes, Massachusetts has unified SW/GW laws.
Michigan	Natural Flow[10]	Regulated Riparian[9,11,12]	Regulated Riparian[12], Reasonable Use[9] / Restatement of Torts, Section 858[10]	Natural Resources and Environmental Protection Act (Mich. Comp. Laws § 324.32701– .32730 (2008)) Inland Lakes and Streams–Permit Applications (Mich. Admin. Code r. 281.812 (2000))	Withdrawals are administered by the Department of Environmental Quality, except agricultural withdrawals which are administered by the Department of Agriculture. Water withdrawals are registered, withdrawals greater than 100,000 gpd are reported, and withdrawals great than 2,000,000 gpd are permitted. Conjunctive Management - Yes, Michigan has unified SW/GW laws.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Minnesota	Reasonable Use[1]	Regulated Riparian[2,11,12]	Regulated Riparian[9, 12], Correlative Rights[4]	Water Conservation–Regulatory Policy (Minn. Stat. §103A.20 (2008)) Appropriation and Use of Waters (Minn. Stat. § 103G.271 (2008)) Minnesota Administrative Rules (Minn. R. 611,125.0600–.0810 (2009))	Withdrawals are administered by the Department of Natural Resources. Water withdrawals are above 10,000 gpd/1,000,000 gpy are permitted and reported, small domestic withdrawals are exempt. Permits can be transferred. Conjunctive Management - Yes. Permits large surface- and ground-water withdrawals[3] and regulates impacts on hydrologically interconnected SW/GW systems.[3,9]
Mississippi	Natural Flow[10]	Regulated Riparian[2,11,12]	Regulated Riparian[9, 12], Absolute Ownership	Mississippi Code (Miss. Code Ann. §§ 51-3-1 106 (1985)) Mississippi Commission on Environmental Quality Surface Water and Groundwater Use and Protection (Miss. Code R. § LW-2 (2006))	Withdrawals are administered by the Department of Environmental Quality. Water withdrawals are permitted except domestic use, isolated surface water impoundments, withdrawals from most wells smaller than 6-in diameter. All withdrawals greater than 20,000 gpd may require a permit despite exemptions. Reporting is voluntary. Conjunctive Management - Yes, Mississippi has unified SW/GW laws.
Missouri		Reasonable Use[11,12]	Reasonable Use[9,12], Correlative Rights[4]	Missouri Statute-Major Water Withdrawal (Mo. Rev. Stat. § 256.410 (2008))	Withdrawals are administered by the Department of Natural Resources. Water withdrawals greater than 100,000 gpd are required to register and all withdrawals are required to report annually. Conjunctive Management – Unclear.
New Hampshire	Reasonable Use[1]	Reasonable Use[11,12]	Regulated Riparian[12], Reasonable Use[9]	New Hampshire Groundwater Protection Act (N.H. Rev. Stat. Ann. § 485-C:21 (2007)) Major Groundwater Withdrawal (N.H. Code R. 388.01–.28 (2001))	Withdrawals are administered by the Department of Environmental Services. The department evaluates potential water quantity and quality impacts of new groundwater applications. Groundwater withdrawals greater than 57,600 gpd are permitted. Conjunctive Management – No. New Hampshire has bifurcated SW/GW laws.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
New Jersey		Regulated Riparian[2,11,12]	Regulated Riparian[9, 12], Correlative Rights[4]	Water Supply Management Act (N.J. Stat. Ann. § 58:1A-1 17 (2007)) Water Supply Allocation Rules (N.J. Admin. Code § 7:19-1.1 18.6 (2008))	Withdrawals are administered by the Department of Environmental Protection, Bureau of Water Allocation. Withdrawals or dewatering processes equal or greater than 100,000 gpd and pumps with a combined capacity of 70 gpm are permitted, except agriculture, aquaculture or horticulture uses. Permitting/registration/ certification depending upon use Conjunctive Management - Yes. Permits large surface- and ground-water withdrawals[3] and regulates impacts on hydrologically interconnected SW/GW systems.[3,9]
New York		Regulated Riparian[2,11,12]	Reasonable Use[4]	Environmental Conservation Laws Water Supply (N.Y. Envtl. Conserv. Law §§ 15-1501-1529 (2008)) Water Supply Applications−Exclusive Of Long Island Wells (6 N.Y. Comp. Codes R. & Regs. tit. V, § 601 (1995))	Withdrawals are administered by the Department of Environmental Conservation. Withdrawals are permitted in Long Island counties if greater than 45 gpm and they are registered in the Great Lakes Basin if greater than 100,000 gpd averaged over a 30-day period or 3,000,000 gallons during any 30-day period. Conjunctive Management - Unclear.
North Carolina		Regulated Riparian[2,11,12]	Regulated Riparian[9, 12], Reasonable Use[4]	Registration of Water Withdrawals and Transfers Required (N.C. Gen. Stat. § 143-215.22H (2009)) Water Use During Droughts And Water Supply Emergencies (15A N.C. Admin. Code 02E.0600 (2007))	Withdrawals are administered by the Department of Environment and Natural Resources. Agricultural withdrawals greater than 1,000,000 gpd, non-agricultural water withdrawals equal or greater than 100,000 gpd are registered. Groundwater withdrawals in the Central Coastal Plain Capacity Use Area greater than 100,000 gpd are permitted and surface and groundwater withdrawals equal or great than 100,000 gpd are registered and must report annually. Conjunctive Management – No. North Carolina only permits high volume water uses in the Central Coastal Plain Capacity Use Area.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Ohio		Regulated Riparian[11,12]	Reasonable Use[9]/ Absolute Ownership[4]/ Restatement of Torts, Section 858[10]	Applying for permit for major increase in withdrawal of waters of state (Ohio Rev. Code Ann. §1501.33 (1988)) Registering facilities capable of withdrawing more than 100,000 gallons a day - rules for ground water stress areas (Ohio Rev. Code Ann § 1521.16 (1994)) Water Diversion Permit Applications (Ohio Admin. Code 1501-2-05-11,12 (2000))	Withdrawals are administered by the Department of Natural Resources. Withdrawals greater than 100,000 gpd are registered and greater than 2,000,000 gpd over a 30 day period are permitted and reported. Conjunctive Management – Unclear.
Pennsylvania		Reasonable Use[11]	Reasonable Use[9]	State Water Plan (Pa. Cons. Stat. tit. 27 § 3111-20 (2007)) Water Resource Planning Act (H.B. 2302, 2002 Leg. (Pa. 2002) Water Resource Planning (25 Pa. Code § 110 (2008))	Withdrawals are administered by the Department of Environmental Protection. Commercial, industrial, agricultural or individual withdraws equal or greater than 10,000 gdp, averaged over any 30-day period, must register and report. Withdrawals governed by the Delaware River Basin or the Susquehanna River Basin Compacts exceeding 100,000 gpd and consumptive uses governed by the Susquehanna River Basin Compact exceeding 20,000 gpd must be approved. Withdrawals exceeding 20,000 gpd in the Southeastern Pennsylvania Groundwater Protected Area must be permitted. Conjunctive Management - No. SW and GW are not permitted by state law. However, SW/GW are subjected to regulated riparian water law under the Delaware and Susquehanna River Basin Compacts.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Rhode Island		Reasonable Use[11,12]	Reasonable Use[9], Absolute Ownership[1,4]	Management of the Withdrawal and Use of the Waters of the State (R.I. Gen. Laws § 46-15.7 (2007)) Public Drinking Water Supply System Protection (R.I. Gen. Laws § 46-15.3-5.1 (2007)) Rules and Procedures for Water Supply System Management Planning	Withdrawals are administered by the Water Board. Withdrawals great than 50,000,000 gpy must develop Water Supply System Management Plans. Conjunctive Management – Unclear.
South Carolina	Modified Common Enemy Law[10]	Regulated Riparian[2,11,12]	Reasonable Use[12], Regulated Riparian[9]	Groundwater Use and Reporting Act (S.C. Code Ann. § 49-5-10-150 (2008)) Surface Water Withdrawal and Reporting Act (49-4-10–80 (2008)) Groundwater Use and Reporting (S.C. Code Ann. Regs. 61-113 (2006))	Withdrawals are administered by the Department of Health and Environmental Control. Surface withdraw must register and report. All withdrawals greater than 3,000,000 gpm must register and report use annually. Ground Water withdrawals in a designated Capacity Use Areas greater or equal to 3,000,000 gpm are permitted and groundwater withdrawals in the Coastal Plain but outside Capacity Use Areas must provide a public notice. Conjunctive Management - No. SW/GW are regulated separately.[3] Permits are only required for groundwater diversions.[9]

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Tennessee	Natural Flow[10]	Reasonable Use[11,12]	Reasonable Use[4]	Tennessee Water Resources Information Act (Tenn. Code Ann. §§ 69-7-301-309 (2002)) Division of Water Resources Repealed (Tenn. Comp. R. & REGS. 0400-04-01–02 (Repealed)	Withdrawals are administered by the Department of Environment and Conservation, Division of Water Supply. Withdrawals greater than 10,000 gpd must register except agriculture, nonrecurring and water withdrawn for emergency uses. Some withdrawals are required submit an annual Water Withdrawal Registration their use, others are encouraged to do so voluntarily. Conjunctive Management – Unclear.
Vermont	Natural Flow[10]	Reasonable Use[11,12]	Reasonable Use[9, 12], Absolute Ownership[4]/ Reasonable Use[9]	Groundwater Protection (Vt. Stat. Ann. tit. 10, §§ 1390-1419 (2008)) Interim Groundwater Withdrawal Permit (Vt. Stat. Ann. Tit. 10 § 1415 (2006)) Policy on water withdrawal for snowmaking (Vt. Stat. Ann. Tit. 10 § 1031 (1995)) Water Withdrawals for Snowmaking (Vt. Code R.§ 16-01 (1996))	Withdrawals are administered by the Department of Environmental Conservation, Water Supply Division. Commercial and industrial withdrawals greater or equal to 20,000 gpd averaged monthly must register, and agricultural, commercial and industrial withdrawals greater or equal to 57,600 gpd are permitted. Withdrawals, greater than 340,000 gpd must also comply with additional public notice requirements. Surface water withdrawals for snow making are permitted. Conjunctive Management – No. Vermont has bifurcated SW/GW laws.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Virginia		Reasonable Use[11,12], Regulated Riparian[2]	Reasonable Use[9,12], Regulated Riparian/ Absolute Ownership[9] (due to lack of implementation of statutes)	Ground Water Management Act of 1992, (Va. Code Ann. §§ 62.1-254-270 (1992)) Virginia Water Protection Permit Program (9 Va. Admin. Code § 25-210 (2008)) Surface Water Management Area Regulation (9 Va. Admin. Code §§ 25-220 (2008)) Declaration of Ground Water Management Areas (9 Va. Admin. Code § 25-610 (1993))	Withdrawals are administered by the Department of Environmental Quality, Division of Water Programs. Groundwater withdrawals in Ground Water Management Areas (currently the Eastern Virginia and Eastern Shore Ground Water Management Areas) greater or equal to 300,000 gpm are permitted. Surface water withdrawals are permitted under the Virginia Water Protection Permit Program. Conjunctive Management - No. Permits only required for selected uses and/or areas; SW and GW uses are permitted as separate resources. Permits are only required for groundwater diversions.[9]
West Virginia	Natural Flow[10]	Reasonable Use[11,12]	Reasonable Use	(None)	Withdrawals are administered by the Department of Environmental Protection, Division of Water and Waste Management. Conjunctive Management – Unclear.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Wisconsin		Regulated Riparian[2,11,12]	Reasonable Use[12], Regulated Riparian/ Restatement of Torts, Section 858[10]	Withdrawal of Water from Lakes and Streams (Wis. Stat. § 30.18 (2008)) Water Quality and Quantity; Specific Regulations (Wis. Stat. § 281.17 (2001)) Well Construction and Pump Installation (Wis. Admin. Code NR § 812.07 (1994)) Groundwater Quantity Protection (Wis. Admin. Code NR § 820 (2007))	Withdrawals are administered by the Department of Natural Resources, Division of Water. Withdrawals are registered. Groundwater withdrawals great than 100,000 gpd are permitted and reported annually. Surface water withdrawals greater than 2,000,000 gpd require a permit, except withdrawals for maintaining a navigable waterbody or waterway, or for agricultural or irrigation purposes. Separate permits are required for withdrawals from lakes or stream results in loss over 2,000,000 gallons of water over a person's base amount in any 30-day period. Withdrawals over 5,000,000 gpd require consultation with other Great Lakes states. Conjunctive Management - No. SW/GW are regulated separately.[3] Permits are only required for surface water diversions.[9]
Western Water Law					
Alaska	Hybrid	Hybrid[11,12], Prior Appropriation, Riparian	Appropriative Rights, Prior Appropriation	Water Use Act (Alaska Stat. §§ 46.15.010–.270 (2009)) Water Permitting Fees (Alaska Admin. Code tit. 11 05.010(8) (2006))	Withdrawals are administered by the Department of Natural Resources, Division of Mining Land and Water. Permits are required for surface and groundwater withdrawals. Conjunctive management - Yes. AK requires All SW and GW systems are regulated as a unified resource without distinguishing between water above or beneath the ground

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Arizona	Absolute Right[1]	Appropriative Rights[11,12]	Regulated Riparian[9, 12], Reasonable Use (outside of groundwater management areas)	Appropriation of Water (Ariz. Rev. Stat. Ann. §§ 45-151–166 (2007)) Public Nature and Use of Surface Water (Ariz. Rev. Stat. Ann. §45-141 (2007)) Groundwater Withdrawal Permits (Ariz. Rev. Stat. Ann. §§ 45-511–528 (2007)) Department of Water Resources-Fees (Ariz. Admin. Code. § 12-15-151 (2007))	Withdrawals are administered by the Department of Water Resources (ADWR). All surface water and selected groundwater withdrawals are permitted. However, surface water and groundwater withdrawals are administered separately. Pueblo water rights for some municipalities (similar to federal reserved water rights).[1] Conjunctive management - No. Surface water and groundwater are managed as separate hydrologic systems
California		Hybrid[11,12], Prior Appropriation, Riparian and Prescriptive Rights	Correlative Rights[1,4]/Prior Appropriation[4]	Water Code–Permits (Cal. Water Code §§ 6-1375–6.5-1410.2 (2009)) Appropriation of Water (Cal. Code Regs. tit. 23 §§ 650–874 (2009))	Surface water withdrawals are administered by the California Water Resources Control Board. Ground water rights are administered by counties. Three categories are recognized; subterranean streams, underflow of surface waters, and percolating groundwater. Subterranean streams and underflow of surface waters are regulated as surface waters. All surface water and selected groundwater withdrawals are permitted by the state. Prior Appropriation for surplus groundwater over what is needed by overlying land owner. Pueblo water rights for some municipalities (similar to federal reserved water rights).[1] Conjunctive Management - Not state-wide. Surface water rights are administered by the state, groundwater resources are managed by the counties. They are managed as separate resources except in some local areas, especially in areas where imported surface water and groundwater are management conjunctively.[10]

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Colorado	Prior Appropriation[1]	Appropriative Rights[11,12], Prior Appropriation	Appropriative Rights, Prior Appropriation[4]	Water Rights Determination and Administration (Colo. Rev. Stat. §§ 37-92-101–602 (1969))	Withdrawals are administered by state water courts. CO utilizes “judicial permitting.” Critical areas may limit new/existing or prohibit new groundwater withdrawals[4]. Pueblo water rights for some municipalities (similar to federal reserved water rights)[1] Conjunctive Management - Yes. SW and GW resources are regulated as separate systems, but integrated through permit reviews relative to their impacts on other SW and GW resources in certain areas.
Hawaii		Regulated Riparian[2,11,12]	Regulated Riparian[9,12]	Statute Permit Required (Haw. Rev. Stat. §174C-48 (1987)) Hawaii Administrative Code (Haw. Code R. §§13-168-1 –171-63 (1988))	Withdrawals are administered by the Commission on Water Resource Management. Water withdrawals are permitted. Conjunctive Management – Yes. Hawaii has unified SW/GW laws.
Idaho	Natural Flow[10]	Appropriative Rights[11,12], Prior Appropriation	Appropriative Rights, Prior Appropriation[4]	Irrigation and Drainage Water Rights and Reclamation (Idaho Code Ann. §§ 42-101–114 (2008)) Department of Water Resources Administrative Rules (Idaho Admin. Code r. 37.03.08 (2008))	Withdrawals are administered by the Idaho Department of Water Resources. Water withdrawals are permitted with the exception of domestic and in-stream stock watering. Conjunctive Management - Yes. SW and GW resources are regulated as separate systems, but integrated through permit reviews relative to their impacts on other SW and GW resources in certain areas.
Kansas	Natural Flow[10]	Hybrid[11,12], Prior Appropriation, Riparian	Appropriative Rights, Prior Appropriation[4]	Kansas Statutes Appropriation of Water for Beneficial Use (Kan. Stat. Ann. §§ 82a-701 773 (2004)) Kansas Water Appropriation Act (Kan. Admin. Regs. § 5-130 (2006))	Withdrawals are administered by the Department of Agriculture, Division of Water Resources. Groundwater withdrawals in Groundwater districts are reviewed by the district. Water withdrawals are permitted and reported except domestic withdrawals. Critical areas may limit new/existing or prohibit new groundwater withdrawals.[4] Conjunctive Management - Yes. Requires all SW and GW systems are regulated as a unified resource without distinguishing between water above or beneath the ground.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Montana	Common Enemy Law[10]	Appropriative Rights[11,12], Prior Appropriation	Appropriative Rights, Prior Appropriation[4]	Montana Water Use Act of 1973 (Mont. Code Ann. §§ 85-2-10 117 (1997)) Water Resources Bureau New Appropriation Rules (Mont. Admin. R. 36.12.101.2001 (2005))	Withdrawals are administered by the Department of Natural Resources, Water Resources Bureau. The bureau evaluates applications for potential water and environmental impacts. Water withdrawals are permitted except small livestock pits and groundwater withdrawals less than 35 gpm. Critical areas may limit new/existing or prohibit new groundwater withdrawals.[4] Conjunctive Management - Yes. Requires all SW and GW systems are regulated as a unified resource without distinguishing between water above or beneath the ground.
Nebraska	Modified Common Enemy Law[10]	Hybrid[11,12], Prior Appropriation, Riparian	Correlative Rights[4], Reasonable Use	Nebraska Statutes Surface Water (Neb. Rev. Stat. § 46-201 299 (1980)) Nebraska Statutes Groundwater (Neb. Rev. Stat. §§ 46-601 692 (2007)) Nebraska Statutes Water Data Collection (Neb. Rev. Stat. § 61-209 (2000)) Rules for Surface Water (457 Neb. Admin. Code § 1-001 024 (2005))	Withdrawals are administered by the Department of Natural Resources. Withdrawals are administered using a bifurcated system; surface water withdrawals are permitted. Groundwater withdrawals must be registered and a permit may be required. Permits are required for wells constructed after 1993, and located within 50 feet of the bank of any stream, within a Water Management Area or for geothermal resource development. Critical areas may limit new/existing or prohibit new groundwater withdrawals.[4] Conjunctive Management - No. Surface water and groundwater resources are managed as separate resources.[9]
Nevada	Natural Flow[10]	Appropriative Rights[11,12], Prior Appropriation but not necessarily implemented[1]	Appropriative Rights, Prior Appropriation[4]	Application, Permits and Certificates (Nev. Rev. Stat. §§ 533.324 .435 (2008)) Practice and Procedure in Protest Hearings Before the State Engineer (Nev. Admin. Code §§ 533.010 .380 (1995))	Withdrawals are administered by the State Engineer. The State Engineer may consider water quality impacts of new water rights. Permits are also required for percolating water. New withdrawals are permitted, vested water rights are exempted. Critical areas may limit new/existing or prohibit new groundwater withdrawals.[4] Conjunctive Management - Yes. Requires all SW and GW systems are regulated as a unified resource without distinguishing between water above or beneath the ground.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
New Mexico	Absolute Right[1]/ Natural Flow[10]	Appropriative Rights[11,12], Prior Appropriation	Appropriative Rights, Prior Appropriation[4]	Water Rights In General (N.M. Stat. Ann. §§ 72-1-1-4 (2008)) Appropriation and Use of Surface Water (N.M. Stat. Ann. §§ 72-5-1-39 (2008)) Underground Waters (N.M. Stat. Ann. §§ 72-12-1–28 (2008)) Administration and Use of Water (N.M. Code R. § 19.25.13.1-50 (2004))	Withdrawals are administered by the State Engineer's Water Resources Allocation Program. Withdrawals are permitted except vested water rights and small stock watering. Critical areas may limit new/existing or prohibit new groundwater withdrawals[4]. Pueblo water rights for some municipalities (similar to federal reserved water rights).[1] Conjunctive Management - Yes. SW and GW resources are regulated as separate systems, but integrated through permit reviews relative to their impacts on other SW and GW resources in certain areas.[10]
North Dakota	Absolute Right[1]	Hybrid[11,12], Prior Appropriation, Riparian	Appropriative Rights, Prior Appropriation[4]	Appropriation of Water (N.D. Cent. Code § 61-04 (2007)) Water Appropriations Water Permits (N.D. Admin. Code 89-03-01-03 (1994))	Withdrawals are administered by the Water Commission. Withdrawals are permitted except domestic, livestock, fish, wildlife, or recreation withdrawals less than 12.5 acre-feet per year and reported annually. Conjunctive Management - Yes. All SW and GW systems are regulated as a unified resource without distinguishing between water above or beneath the ground.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Oklahoma	Absolute Right[1]	Hybrid[11,12], Prior Appropriation, Riparian	Reasonable Use	Waters and Water Rights Surface Water (Okla. Stat. tit. 82, §§ 105.1-19 (1993)) Waters and Water Rights Groundwater (Okla. Stat. tit. 82, §§ 1020.1-11 (1993)) Appropriation and Use of Stream Water (Okla. Admin. Code § 785:20 (2008)) Taking and Use of Groundwater (Okla. Admin. Code § 785:30 (2008))	Withdrawals are administered by the Oklahoma Water Resources Board. Surface water permits may be transferred or assigned except irrigation permits. Groundwater permits may be either transferred or assigned. Withdrawals are permitted except domestic uses. Conjunctive Management - No. SW and GW resources are managed as separate resources.
Oregon	Prior Appropriation but not necessarily implemented[1]	Hybrid[11,12], Prior Appropriation, Riparian	Appropriative Rights, Prior Appropriation[4]	Oregon Water Laws (Or. Rev. Stat. §§ 536 541 (2007)) Water Appropriations Application, Permits and Certificates (Or. Admin. R. 690-300 340)	Withdrawals are administered by the Department of Water Resources. Withdrawals are permitted. Various agencies, municipalities and districts, and select new water users are required to report. Critical areas may limit new/existing or prohibit new groundwater withdrawals.[4] Conjunctive Management - Yes. SW and GW resources are regulated as separate systems, but integrated through permit reviews relative to the impacts new GW users on other SW and GW resources.
South Dakota	Absolute Right[1]	Hybrid[11,12], Prior Appropriation, Riparian	Appropriative Rights, Prior Appropriation[4]	Administrative Procedure for Appropriation of Water (S.D. Codified Laws § 46-2A-1-23 (2001) Regulation of Groundwater Use (S.D. Admin. R. 74:02:05:01-08 (1987))	Withdrawals are administered by the Department of Environment and Natural Resources. Withdrawals are permitting except for domestic uses and distribution systems that pump less than 18 gpm. Conjunctive Management - Yes. SW and GW resources are regulated as separate systems, but it explicitly unifies criteria and priorities for allocation.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Texas	Absolute ownership for vested rights; regulated as Prior Appropriation, Riparian, Equitable Rights for all others[1], Natural Flow[10]	Hybrid[11,12], Prior Appropriation, Riparian, Equitable Rights	Absolute Dominion. Absolute Ownership[1,4]	Texas Water Rights (2 Tex. Water Code Ann. §§ 11.121.146 (2005)) Groundwater Management Areas (2 Tex. Water Code Ann. §§ 35.001.020 (2007)) Groundwater Conservation Districts(2 Tex. Water Code Ann. §§ 36.001.418 (2005)) Texas Water Development Board Rules (31 Tex. Admin. Code §§ 356-358 (2008)) Water Rights, Substantive (30 Tex. Admin. Code § 297 (2002))	Withdrawals are administered by the Texas Commission on Environmental Quality. Texas authorizes the creation of water conservation districts and groundwater management areas preserve, protect, and conserve groundwater resources which can regulate well spacing, enjoining wasteful water practices, and conducting educational programs about water conservation methods. Surface water withdrawals are permitted. Groundwater is a private property right of the owner of the land. Water conservation districts can require permits for new wells. Pueblo water rights for some municipalities (similar to federal reserved water rights).[1] Conjunctive Management - No. Surface water and groundwater resources are managed as separate resources. Groundwater is managed via Absolute Dominion Doctrine.
Utah	Prior Appropriation[1]	Appropriative Rights[11,12], Prior Appropriation	Appropriative Rights, Prior Appropriation[4]	Water Appropriation (Utah Code Ann. §§ 73-3-1-31 (2008) Groundwater Management Plan (Utah Code Ann. §§ 73-5-15 (2008)) Department of Natural Resources Water Rights (Utah Admin. Code r. R655 (2009))	Withdrawals are administered by the Department of Natural Resources, Division of Water Resources. Withdrawals are permitted. Conjunctive Management - Yes. All SW and GW systems are regulated as a unified resource without distinguishing between water above or beneath the ground.

State	Diffused Water	Surface Water[2]	Groundwater[2]	Water Law & Codes[7]	Summary[7]
Washington		Hybrid[11,12], Prior Appropriation, Riparian	Appropriative Rights, Prior Appropriation[4]	Washington Water Code (Wash. Rev. Code § 90.03.005.605 (2003)) Regulation of Public Groundwaters (Wash. Rev. Code § 90.44.020–.520 (2000)) Water Right Administration Procedures (Wash. Admin. Code § 1000 (1990))	Withdrawals are administered by the Department of Ecology, Water Resources Program. Non-vested withdrawals require a permit or certificate, except livestock watering, non-commercial lawns or gardens one-half acre in size or less, single home or groups of homes less than or equal to 5,000 gpd), and industrial and irrigation uses less than or equal to 5,000 gpd. Critical areas may limit new/existing or prohibit new groundwater withdrawals.[4] Conjunctive Management - Yes. SW and GW resources are regulated conjunctively, under the presumption that they are related.
Wyoming		Appropriative Rights[11,12], Prior Appropriation	Reasonable Use[12], Prior Appropriation[4]	Water General Provisions (Wyo. Stat. Ann. § 41-1-101 (2005)) Obtaining a Surface Water Right (03-05-1974 Wyo. Code R. §1792 (1974)) Obtaining a Groundwater Right (03-05-1974 Wyo. Code R. § 1804 (1974))	Withdrawals are administered by the State Engineer. Withdrawals are permitted except stock and domestic uses. Groundwater withdrawals greater than 25 gpm within a groundwater control area must be approved by the control area's advisory board. Conjunctive Management - Yes. SW and GW resources are regulated as separate systems, but they are explicitly integrated in the allocation process. It is presumed that they are not connected unless proven otherwise.

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