6 Wild and Scenic Rivers

Authors

Lead Author
Margaret A. Palmer, University of Maryland

Contributing Authors
Dennis Lettenmaier, University of Washington
N. LeRoy Poff, Colorado State University
Sandra Postel, Global Water Policy Project
Brian Richter, The Nature Conservancy
Richard “Omar” Warner, Kinni Consulting

NOTE: This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the U.S. Environmental Protection Agency. It does not represent and should not be construed to represent any agency determination or policy.

Chapter Contents

Chapter Structure

6.1 Background and History
Describes the origins of the National System of Wild and Scenic Rivers (WSR System) and the formative factors that shaped its mission and goals

6.2 Current Status of Management System
Reviews existing system stressors, the multi-agency management structure and management practices currently used to address the WSR System goals, and how those goals may be affected by climate change

6.3 Adapting to Climate Change
Discusses approaches to adaptation for planning and management in the context of climate change

6.4 Case Studies
Explores methods for and challenges to incorporating climate change into specific management activities and plans for three WSRs
- **Wekiva River**
- **Rio Grande**
- **Upper Delaware River**

6.5 Conclusions

6.1 Background and History

In the late summer of 1958, the greatest anadromous fish disaster in history was unfolding on the Snake River near the small town of Oxbow, Idaho. Once known for its booming copper mines and rowdy saloons, this small town would soon be known as the site of the "Oxbow Incident." Chinook salmon and steelhead had started their fall spawning run but became stranded in stagnant, un-aerated pools of water just below the 205-foot Oxbow Dam. Plans to trap the fish and transport them around the dam were failing. By the end of the season, 10,000 fish had perished before spawning (Barker, 1999).

Oxbow is situated just below Hell's Canyon—North America's deepest river gorge—which was carved by the Snake River and remains one of the largest wilderness areas in the West. In the 1950s, this gorge contained one of the last free-flowing stretches of the Snake River (Fig. 6.1) and became the focus of a major fight that spanned two decades. Idaho Senator Frank Church played a pivotal role in deciding who would build dams and where they would be built (Ewert, 2001). As a New Deal Democrat, Church had supported development and dam construction that he felt were keys to the growth and prosperity of Idaho. However, the Oxbow Incident had a profound effect on Church. He witnessed the severe effect of dams on fisheries, and even began to ponder the value of riverine corridors to wildlife and their growing value to tourism and recreation.

Fig. 6.1. Photo of Snake River below Hell's Canyon Dam. Photograph compliments of Marshall McComb, Fox Creek Land Trust.

Frank Church's efforts in the U.S. Senate resulted in passage of the national Wild and Scenic Rivers Act in 1968. While it was not until 1975 that the Hell's Canyon of the Snake River was designated as wild and scenic, two of the eight rivers originally designated as wild and scenic were in Idaho.

Fundamental to the Act was the desire to preserve select rivers with "outstandingly remarkable values" in a "free-flowing condition." The Act defines free-flowing as "existing or flowing in natural condition without impoundment," and the term generally has been interpreted to mean that water quality is high and there are no major dams or obstructions within the stretch of river to be designated, although there can be impoundments upstream. The "outstandingly remarkable values" encompass a range of scenic, biological, and cultural characteristics that are valued by society. The management goals for Wild and Scenic Rivers (WSRs) center on the preservation and protection of these conditions and values (Box 6.1).

There are currently 165 WSRs across the country, representing more than 11,000 stream miles (Fig. 6.2). Oregon ranks highest with 46 designations, most of which were designated in 1988 when a large number of forest management plans were developed to deal with concerns over salmonids. Alaska follows with 25 WSRs that became designated as a result of the Alaska National Interests Land Conservation Act in 1980. This act created nearly 80 million acres of wildlife refuge land in Alaska, much of which is wilderness. Michigan and California are the only other states with a significant number of rivers that have the wild and scenic designation (16 and 13, respectively); however, most states have at least one designated river or river segment. Selected milestones in the evolution of the Wild and Scenic Rivers system are shown in Fig. 6.3.

Fig. 6.2. Wild and Scenic Rivers in the United States. Data from USGS, National Atlas of the United States (2005).

Figure 6.3. Selected milestones in the evolution of the Wild and Scenic Rivers system. Adapted from National Wild and Scenic Rivers System website (2007a).

As severe as the dam effects were on fisheries in Oxbow, Idaho, there is equal or greater concern today about the potential future impacts of climate change on WSRs. Climate change is expected to alter regional patterns in precipitation and temperature, and this has the potential to change natural flow regimes at regional scales. The ecological consequences of climate change and the required management responses for any given river will depend on how extensively the magnitude, frequency, timing, and duration of key runoff events change relative to the historical pattern of the natural flow regime for that river, and how adaptable the aquatic and riparian species are to different degrees of alteration.

6.2 Current Status of Management System

With the exception of the state of Alaska, most WSRs are within watersheds affected by human activities including development (agricultural, urban, or suburban land use) or dams. In fact, many WSR segments lie downstream of these impacts, meaning their management for scenic or free-flowing condition is difficult. Thus in many ways, WSRs are like rivers all over the United States—they are not fully protected from human impacts. However, because many of the WSRs are on federal lands, it is the responsibility of the relevant federal agency—the Forest Service, the National Park Service, the Bureau of Land Management, or the Fish and Wildlife Service—in conjunction with some state and local authorities, to manage them in ways to best protect and enhance the values that led to the designation as wild and scenic.

Because the original intent of the Wild and Scenic Rivers Act was to protect rivers from the harmful effects of water resource projects, the Federal Energy Regulatory Commission is prohibited from licensing new dams or diversions that would alter the free-flowing character of designated rivers or diminish their outstanding character. However, because the Act allows existing uses of a river to continue, today there are actually a number of segments designated wild and scenic that are within dammed watersheds.

6.2.1 Framework for Assessing Present and Future Status

Climate change is expected to have a significant impact on running waters throughout the world, not only in terms of changes in flow magnitude and timing, but in terms of thermal regimes and the flora and fauna that currently inhabit these waters (Sala *et al.*, 2000). The focus in this chapter is not only on identifying the likely impacts of climate change, but also identifying management options for protecting riverine ecosystems and their values against these impacts. However, rivers across the United States have been designated as wild and scenic for diverse reasons, and they exist in diverse settings. Thus climate change is not the only risk they face.

Anticipating the future condition of a river in the face of climate change requires explicit consideration not only of the current climatic, hydrogeologic, and ecological conditions (the *hydrogeomorphic context*), but also of how it is currently management and how human behavior will affect the river (the *human context*) (Fig. 6.4). Even if impacts are small at present, consideration of the human context is critical to a river's future unless it is within a fully protected basin. If it is not, then impacts associated with activities such as development and water withdrawals are likely to become issues in the future. Stress associated with the *future human context* will interact with climate change, often exacerbating problems and intensifying management challenges (Fig. 6.4)

Figure 6.4. Conditions and factors affecting the future conditions of Wild and Scenic Rivers.

The ability of a WSR to provide the ecosystem goods and services in the future that originally prompted its designation will largely depend on how it is managed. Without deliberate management actions that anticipate future stress, managers will be left "reacting" to problems (*reactive management)* that come along, and the provision of ecosystem services will not be guaranteed.

6.2.2 Hydrogeomorphic Context

6.2.2.1 Ecosystem Goods and Services

WSRs provide a special suite of goods and services valued highly by the public (Box 6.2) that are inextricably linked to their flow dynamics and the interaction of flow with the landscape. The ecological processes that support these goods and services are fueled by the movement of water as it crosses riparian corridors, floodplains, and the streambed transporting nutrients, sediment, organic matter, and organisms. Thus, water purification, biological productivity and diversity, as well as temperature and flood control are all mediated by interactions between the local hydrology and geologic setting. For this reason, the particular goods and services offered by WSRs vary greatly across the nation, reflecting the great variety of landscape settings and climates in which WSRs occur.

The Rogue River in Oregon supports whitewater rafting through dramatic gorges, while the Loxahatchee River in Florida supports highly productive cypress swamp. The goods and services provided by any river depend in no small measure on how "healthy" it is, *i.e.*, the degree to which the fundamental riverine processes that define and maintain the river's normal ecological functioning are working properly. One of the main threats of climate change to WSRs is that it may modify these critical underlying riverine processes and thus diminish the health of the system, with potentially great ecological consequences. Of particular concern is the possibility that climate-induced changes can exacerbate human-caused stresses, such as depletion of water flows, already affecting these rivers. The likelihood of this happening will depend on the current conditions in the river and the extent to which future changes in precipitation and temperature differ from present conditions.

Although every river is arguably unique in terms of the specific values it provides and the wildlife it supports, an important scientific perspective is to identify the general underlying processes that dictate how a river functions, so that researchers may consider the vulnerabilities of these systems to climate change. This report uses the phrase “hydrogeomorphic context” to mean the combination of fundamental riverine processes that interact with the particular landscape setting of a river to define its fundamental character and potential for ecological resilience in the face of natural variation and future climate change.

From a physical perspective, rivers function to move water and sediment off the landscape and downhill toward the sea. The regime of rainfall and the geology of a river’s watershed control landscape soil erosion rates and influence how fast precipitation falling on a watershed is moved to the river channel, as well as the likelihood that the channel will develop an active floodplain (Knighton, 1998). Thus, a river’s hydrogeomorphic context is largely defined by the nature of the flow regime and the river’s channel features. For example, rivers flowing through steep mountains with bedrock canyons and boulder-strewn beds, such as Colorado’s Cache la Poudre River, represent very different environments than rivers flowing slowly across flat land where channels can be wide and meandering due to sandy banks, such as Mississippi’s Black Creek. Likewise, rivers draining watersheds with porous soils and high groundwater levels respond very sluggishly to rainfall storm events, compared with those that drain impervious soils and show a rapid flood response to heavy rains (Paul and Meyer, 2001). Such differences exert strong control over the temporal dynamics of critical low and high flow events and thus directly influence many ecological processes and populations of aquatic and riparian species (Poff *et al.*, 1997; Bunn and Arthington, 2002).

But the hydrogeomorphic context can also be extended beyond precipitation and geology. Specifically, the thermal regime of a river is also a critical component of its fundamental nature, because water temperature directly controls animal and plant metabolism and thus influences the kinds of species that can flourish in a particular environment and the rates of biogeochemical processes within the river ecosystem (Ward, 1992; Allan, 1995). This thermal response explains the categorization of fishes as being either cold-water species (*e.g.*, trout, salmon) or warm-water species (*e.g.*, largemouth bass) (Eaton and Scheller, 1996; Beitinger, Bennett, and McCauley, 2000). Regional climate largely determines air temperature, and hence water temperature (Nelson and Palmer, 2007), and this factor also influences whether precipitation falls as rain or snow. When it falls as snow, regional climate also influences the time and rate of melt to provide the receiving river with a prolonged pulse of runoff.

At a broad, national scale, it is important to appreciate the differences in hydrogeomorphic context of WSRs. Not only do these differences influence the kind and quality of human interactions with WSRs, they also serve to generate and maintain ecological variation. For example, the cold and steep mountain rivers of the West, such as Montana’s Flathead River, support different species of fish and wildlife compared with the warmer rivers in the South, such as the Lumber River in the south-central coastal plains of North Carolina. Aquatic and riparian species are adapted to these local and regional differences (Lytle and Poff, 2004; Naiman, Décamps, and McClain, 2005), thereby generating great biodiversity across the full range of river types across the United States. The wide geographic distribution of WSRs is important not only in ensuring large-scale biodiversity but also the concomitant ecosystem processes associated with different river systems. This is particularly true for "wild" rivers, *i.e.*, those that are not dammed or heavily modified by human activities and that are protected over the long term due to their WSR status. Thus, wild rivers across the United States can serve as a valuable natural repository of the nation's biological heritage (*e.g.*, Poff *et al.*, 2007; Moyle and Mount, 2007), and the threats of climate change to this ecological potential is of great national concern.

6.2.2.2 What it Means to be Wild

One of the key defining features of a "wild" river is its natural flow regime; *i.e.*, the day-to-day and year-to-year variation in the amount of water flowing through the channel. Research over the last 10 years has clearly demonstrated that human modification of the natural flow regime of streams and rivers degrades the ecological integrity and health of streams and rivers in the United States and around the world (Poff *et al.*, 1997; Richter *et al.*, 1997; Bunn and Arthington, 2002; Postel and Richter, 2003; Poff *et al.*, 2007).

From an ecological perspective, some of the key features of a natural flow regime are the occurrence of high flood flows and natural drought flows. These flows act as natural disturbances that exert strong forces of natural selection on species, which have adapted to these critical events over time (Lytle and Poff, 2004). But it's not just the magnitude of these critical flows that is ecologically important; it's also their frequency, duration, timing, seasonal predictability, and year-to-year variation (Poff *et al.*, 1997; Richter *et al.*, 1997; Lytle and Poff, 2004), because various combinations of these features can dictate the success or failure of aquatic and riparian species in riverine ecosystems. Thus, for example, a river that has frequent high flows that occur unpredictably at any time of the year provides a very different natural environment than one that typically has only one high flow event predictably year-in and year-out.

Across the United States there are large differences in climate and geology, and thus there is a geographic pattern to the kinds of natural flow regimes across the nation. This is illustrated in Fig. 6.5. from Poff and Ward (1990). For example, in the Rocky Mountain states and in the northern tier of states, most annual precipitation falls in the winter in the form of snow, which is stored on the land until the spring, when it melts and enters the rivers as an annual pulse (Fig. 6.5a). In more southerly regions where there is frequent rainfall, floods can occur unpredictably and flow regimes are much more variable over days to weeks (Fig 6.5b). In watersheds with highly permeable soils, such as those in Michigan, falling rain infiltrates into the ground and is delivered slowly to the stream as groundwater (Fig. 6.5c). The frequency of floods and river low flows depends on precipitation patterns and specific hydrologic conditions within a given watershed. Yet other streams may be seasonally predictable but present harsh environments because they cease to flow in some seasons (Fig. 6.5d).

Figure 6.5. Illustration of natural flow regimes from four unregulated streams in the United States, (a) the upper Colorado River (CO), (b) Satilla Creek (GA), (c) Augusta Creek (MI), and (d) Sycamore Creek (AZ). For each the year of record is given on the x-axis, the day of the water year (October 1–September 30) on the y-axis, and the 24-hour average daily streamflow on the z-axis (Poff and Ward, 1990).

These different flow regime types result in very different hydrogeomorphic contexts, which in turn support very different ecological communities. For example, Montana’s Upper Missouri River supports extensive stands of native cottonwood trees along the riverbanks. These trees become established during annual peak flows that jump the banks and create favorable establishment conditions during the annual snowmelt runoff event. Arkansas’ Buffalo River is nestled in the Ozark Mountains and supports a tremendous diversity of fish and other aquatic life such as native mussels, as well as diverse riparian tree species. This near-pristine river is seasonally very dynamic, due to the steep mountain topography and rapid runoff from frequent rainfall events. Florida’s Wekiva River is a flatwater system that is heavily influenced by groundwater and streamside wetlands that store and release water to the river over the year. This creates a highly stable flow regime and stable wetland complexes that support a great diversity of plant species and community types.

These natural flow regime types occur across the nation and reflect the interaction of precipitation, temperature, soils, geology, and land cover. For every region of the country there can be a natural flow regime representative of the unaltered landscape; *i.e.*, with native vegetation and minimally altered by human activities such as point- or non-point source pollution (Poff *et al.*, 2006).

6.2.3 Present Human Context

To the American public, the designation of a river as “Wild and Scenic” conjures an image of a river protected in pristine condition, largely unchanged by human development. However, as mentioned above, in reality many of the rivers in the WSR system have experienced considerable ecological degradation from a variety of human activities.

Due to their vulnerable position as the lowermost features of landscapes, rivers are the recipients of myriad pollutants that flush from the land, the bearers of sediment loads washed from disturbed areas of their watersheds, and the accumulators of changes in the hydrologic cycle that modify the volume and timing of surface runoff and groundwater discharge. As Aldo Leopold once said, “It is now generally understood that when soil loses fertility, or washes away faster than it forms, and when water systems exhibit abnormal floods and shortages, the land is sick" (Leopold, 1978). Because rivers are integrators of changes in a watershed, they are also often indicators of ecological degradation beyond their banks.

WSR managers have limited authority or control over human activities occurring outside of formally designated WSR corridors, thus many rivers in the WSR system are afflicted by human impacts in their watersheds. The vulnerability of rivers generally increases in relation to the area of contributing watershed lying outside and upstream of the WSR corridor; designated headwater reaches are considerably less vulnerable to human impacts than reaches situated downstream of cities and agricultural areas. This reality makes the Middle Fork of the Salmon River in Idaho, a headwater river embedded in a federal wilderness area, far less susceptible to human influences than the Rio Grande in Texas.

To prepare a foundation for understanding the potential consequences of climate change, this report summarizes current influences and historic trends in water use and dam operations that affect the ecological condition of WSRs.

6.2.3.1 Water Use

Excessive withdrawals of water from rivers can cause great ecological harm. The nature and extent of this ecological damage will depend upon the manner in which water is being withdrawn. The hydrologic and ecological effects of surface water withdrawals may differ considerably from the impact of the same amount of water being withdrawn through groundwater extraction. When on-channel reservoirs are used to store water for later use, the placement and operation of dams can have considerably greater ecological impact than direct withdrawal of water using surface water intakes, as discussed below.

The depletion of river flows fundamentally alters aquatic habitats because it reduces the quantity of habitat available (Poff *et al.*, 1997; Richter *et al.*, 1997; Bunn and Arthington, 2002). Adequate water flows can also be important in maintaining proper water temperature and chemistry, particularly during low-flow periods. The depth of water can strongly influence the mobility of aquatic animals such as fish, and river levels can also influence water table levels in adjacent riparian areas, particularly in rivers with high degrees of hydraulic connectivity between the rivers and alluvial floodplain aquifers.

During the latter half of the 20th century, water withdrawals in the United States more than doubled (Hutson *et al.*, 2004) (Fig 6.6). Virtually all of this increase occurred during 1950–1980, and withdrawals leveled off in 1980–2000 even while the U.S. population grew by 24%. This flattening of water withdrawals resulted primarily from lessened demand for thermoelectric power and irrigation. Thermoelectric-power water withdrawals primarily were affected by federal legislation that required stricter water quality standards for return flow, and by limited water supplies in some areas of the United States (Hutson *et al.*, 2004). Consequently, since the 1970s, power plants increasingly were built with or converted to closed-loop cooling systems or air-cooled systems, instead of using once-through cooling systems. Declines in irrigation withdrawals are due to changes in climate, shifts in crop types, advances in irrigation efficiency, and higher energy costs that have made it more expensive to pump water from ground- and surface-water sources.

Figure 6.6. Trends in water withdrawals by water-use category. As the population has grown, water has been increasingly withdrawn for public use since 1950 as indicated by total withdrawals (blue line). Water withdrawn for power production and water for irrigation represent largest use followed by water for industrial uses then public supply. From Hutson *et al.* (2004).

An important exception to the recent nationwide declines in total water withdrawals has been a continuous increase in public water supply withdrawals (withdrawals for urban use) during the past 50+ years; withdrawals for public water supplies more than tripled during 1950–2000 (Hutson *et al.*, 2004) (Fig 6.6). These rises in urban water demand have been driven by overall population growth as well as the higher rate of urban population growth relative to rural population growth. Fifty U.S. cities with populations greater than 100,000 experienced growth rates of at least 25% during recent decades (Gibson, 1998).

Water withdrawals for urban and agricultural water supplies are having substantial impacts on the natural flow regimes of rivers across the United States, including WSRs. For example, upstream withdrawals for New York City's water supply have depleted average annual flows in the Upper Delaware Scenic and Recreational River by 20%, with flows in some months lowered as much as 40% (Fitzhugh and Richter, 2004; Fig. 6.7). Heavy agricultural and municipal withdrawals along the Rio Grande in Colorado, New Mexico, Texas, and Mexico have increasingly depleted river flows during the past century (Collier, Webb, and Schmidt, 1996).

While national trends in water use provide insight into large-scale factors influencing river flows in WSRs, the impact of water withdrawals on hydrologic systems varies greatly across the United States, as illustrated by Fig. 6.5. Ultimately, the consequences of water withdrawals on a specific WSR can best be understood by developing hydrologic simulation models for the local region of interest, or by examining changes or trends in river flows such as those presented in Fig. 6.7.

Figure 6.7. Changes in monthly average river flows on the Delaware River, in the Upper Delaware Scenic and Recreational River segment. Lowered flows in December–July result from upstream depletions for New York City water supply. Increased flows result from upstream reservoir releases during summer months for the purpose of controlling salinity levels in the lower Delaware. Figure based on data provided by USGS (2007).

6.2.3.2 Dam Operations

Nearly 77,000 dams are listed in the National Inventory of Dams for the United States (U.S. Army Corps of Engineers, 2000). At least one-third of these dams are publicly owned, with ownership divided among federal, state, local, and public utility entities. An estimated 272 of these dams are located within 100 miles upstream or downstream of WSRs (Fig. 6.8).

Figure 6.8. Location of dams and WSRs in the United States. Data from USGS, National Atlas of the United States.

Most dams provide substantial benefits to local or regional economies (World Commission on Dams, 2000). Hydroelectric power dams currently provide 7% of the U.S. electricity supply. By capturing and storing river flows for later use, dams and reservoirs have contributed to the national supply of water for urban, industrial, and agricultural uses. Storage of water in reservoirs helped to meet the steep growth in water use in the United States during the 20th century, particularly for agricultural water supply. Nearly 9,000 (12%) of the U.S. dams were built solely or primarily for irrigation.

However, damming of the country's rivers has come at great cost to their ecological health and ecosystem services valued by society (Ligon, Dietrich, and Trush, 1995; World Commission on Dams, 2000; Postel and Richter, 2003; World Wildlife Fund, 2004; Poff *et al.*, 2007). The most obvious change in river character results from the conversion of a flowing river into an impounded reservoir. Also obvious is the fact that dams create barriers for upstream-downstream movements of mobile aquatic species such as fish. A dam can artificially divide or isolate species populations, and prevent some species from completing anadromous or diadromous life cycles, such as by blocking access to upriver spawning areas (Silk and Ciruna, 2005). For example, Pacific salmon migrations through WSR segments on the Salmon and Snake rivers in Idaho, and pallid sturgeon migrations on the Missouri River are impeded by dams. The consequences of such population fragmentation have been documented for many fish species, including many local extirpations following damming. Hence, dams located downstream of WSRs likely have consequences for movements of aquatic animals, particularly widely ranging fish.

Dams have considerable influence on downstream river ecosystems as well, in some cases extending for hundreds of miles below a dam (Collier, Webb, and Schmidt, 1996; McCully, 1996; Willis and Griggs, 2003). Dam-induced changes affect water temperature (Clarkson and Childs, 2000; Todd *et al.*, 2005) and chemistry (Ahearn, Sheibley, and Dahlgren, 2005); sediment transport (Williams and Wolman, 1984; Vörösmarty *et al.*, 2003); floodplain vegetation communities (Shafroth, Stromberg, and Patten, 2002; Tockner and Stanford, 2002; Magilligan, Nislow, and Graber, 2003). Dams may even affect downstream estuaries, deltas, and coastal zones by modifying salinity patterns, nutrient delivery, disturbance regimes, and the transport of sediment that builds deltas, beaches, and sandbars (Olsen, Padma, and Richter, Undated). Of all the environmental changes wrought by dam construction and operation, the alteration of natural water flow regimes (Fig. 6.5) has had the most pervasive and damaging effects on river ecosystems (Poff *et al.*, 1997; Postel and Richter, 2003). Dams can heavily modify the magnitude (amount) of water flowing downstream, change the timing, frequency, and duration of high and low flows, and alter the natural rates at which rivers rise and fall during runoff events.

The location of a WSR relative to upstream dams can have great influence on the ecological health of the WSR. As a general rule, ecological conditions improve with distance downstream of dams due to the influence of tributaries, which moderate dam-induced changes in water flow, sediment transport, water temperature, and chemistry. For example, flow alterations associated with hydropower dams in the Skagit River are most pronounced immediately downstream of the dams, but lessen considerably by the time the river reaches its estuary. It is quite difficult to assess the dam-induced biophysical changes that have transpired in WSRs, because long-term measurements of sediment, temperature, water quality, and biological conditions are rarely available. However, for many rivers, dam-related changes to hydrologic regimes can be evaluated by examining streamflow changes before and after dams were built (see Fig. 6.7 for example).

6.2.3.3 Land-Use Changes

As humans have transformed natural landscapes into cities and farms, and increasingly utilized resources such as timber and metals, the consequences to river ecosystems have been quite severe. Beyond the impacts on water quantity and timing of river flows discussed above, landscape conversion has had substantial influence on water quality (Silk and Ciruna, 2005; U.S. Geological Survey, 2006b). The potential impact of land use on WSRs depends upon a number of factors, including proximity of the WSR to various land uses and the proportion of the contributing watershed that has been converted to high-intensity uses such as agriculture or urbanization.

Nearly half of the billion hectares of land in the United States has been cultivated for crops or grazed by livestock. As described above, agriculture accounts for approximately 70% of water withdrawals in the United States. While most of this water is consumed through evapotranspiration, the portion of irrigation water that returns to streams and rivers is commonly tainted with chemicals or laden with sediment (National Research Council, 1993; U.S. Geological Survey, 2001). Because much of the land converted to agricultural use in recent decades has been wetlands and riparian areas, this conversion has severely affected the natural abilities of landscapes to absorb and filter water flows. Major pollutants in freshwater ecosystems include excessive sediment, fertilizers, herbicides, and pesticides (Silk and Ciruna, 2005). Agriculture is the source of 60% of all pollution in U.S. lakes and rivers; nitrogen is the leading pollution problem for lakes and the third most important pollution source for rivers in the United States (U.S. Environmental Protection Agency, 2000). The U.S. Geologic Survey National Water Quality Assessment (NAWQA) found that most of the rivers sampled in agricultural areas contained at least five different pesticides (U.S. Geological Survey, 2001), including DDT, dieldrin, and chlordane. Intensive agriculture often leads to the eutrophication of freshwater ecosystems, resulting in deoxygenation of water, production of toxins, and a general decline in freshwater biodiversity. Agriculture is a major source of sedimentation problems as well, resulting from large-scale mechanical cultivation, channelization of streams, riparian clearing, and accentuated flood runoff.

After agriculture, the next three top sources of river ecosystem degradation include hydromodification, urban runoff/storm sewers, and municipal point sources—all associated with urban environments (Silk and Ciruna, 2005). Although urban areas occupy only a small fraction of the U.S. land base, the intensity of their impacts on local rivers can exceed that of agriculture (see Fig. 6.9 for an example). More than 85% of the U.S. population lives in cities, potentially concentrating the impacts from urban activities and exacerbating conditions affected by rainfall runoff events, such as water use, wastewater discharge, polluted surface runoff, and impervious surfaces. Industrial activities located in cities pose several threats to river ecosystems, including effluent discharge and risk of chemical spills, in addition to water withdrawals. The USGS NAWQA program reports the highest levels of phosphorus in urban rivers. Other highly problematic forms of pollution in urban areas include heavy metals, hormones and pharmaceutical chemicals, and synthetic organic chemicals from household uses (U.S. Geological Survey, 2001). Excellent reviews on the effects of urbanization on streams have been published (Paul and Meyer, 2001; Walsh *et al.*, 2005), but in brief the most obvious impacts are increases in impervious surface area resulting in increased runoff, higher peak discharges, higher sediment loads, and reduced invertebrate and fish biodiversity (Dunne and Leopold, 1978;

Arnold, Jr. and Gibbons, 1986; McMahon and Cuffney, 2000; Walsh, Fletcher, and Ladson, 2005).

Figure 6.9. Photo of scientists standing on the bed of an urban stream whose channel has been incised more than 5 m due inadequate storm water control. Incision occurred on the time scale of a decade but the bank sediments exposed near the bed are marine deposits laid down during the Miocene epoch. Photograph courtesy of Margaret Palmer.

6.2.4 The Policy Context: Present Management Framework Legal and Management Context

The creation of the National System of Wild and Scenic Rivers (the WSR System) under the Wild and Scenic Rivers Act of 1968 (Box 6.3) was an attempt by the U.S. Congress to proactively rebalance the nation's river management toward greater protection of its river assets. Every river or river segment included within the WSR System must be managed according to goals associated with preserving and protecting the values for which the river was designated for inclusion in the system (see Box 6.1). The degree of protection and enhancement afforded each river or river segment is a prerogative of the agency responsible for a particular river's management, but the values that made the river suitable for inclusion in the WSR System must be protected. (Throughout the remaining chapter, the term "river," in the context of a WSR, refers to the segment of river designated under the Act.)

When a river is admitted into the WSR System, it is designated under one of three categories: "wild," "scenic," or "recreational." These categories are defined largely by the intensity of development that exists along and within a particular river corridor, rather than by specific wild, scenic, or recreational criteria *per se*. For instance, "wild" river segments have no roads or railroads along them, nor do they have ongoing timber harvesting occurring near their banks. Accessible only by trail, they are intended to represent vestiges of primitive America. "Scenic" river segments are free of impoundments and have shorelines still largely undeveloped, but may be accessible in places by roads. Lastly, "recreational" river segments may have been affected by dams or diversions in the past, may have some development along their banks, and may be accessible by road or railroad. Despite the label, WSRs designated as "recreational" are *not* "river parks"—that is, they are not necessarily used or managed primarily for recreational pursuits. Even where recreational uses exist, management of the WSR emphasizes the protection of natural and cultural values. As with the "wild" and "scenic" categories, it is the degree of development within the river corridor that determines the designation as "recreational." So the existence of a road alongside a designated river, for instance, likely places that river segment in the "recreational" category, but the "outstandingly remarkable value" that qualifies the river for inclusion in the WSR System might be critical fish habitat and has nothing to do with recreational benefits (Interagency Wild and Scenic Rivers Coordinating Council, 2002).

Once placed under one of the three classifications, the river must be managed to maintain the standards of that classification. A river classified as wild, for instance, cannot be permitted to drop to the less-strict criteria of scenic. A non-degradation principle therefore guides river management.

6.2.4.1 Administering Agencies and Authorities

The management of WSRs is complex due to the overlapping and at times conflicting federal and state authorities that are responsible for managing these rivers, as well as to the mix of public and private ownership of lands within or adjacent to WSR corridors. Neither of the two major federal river management and dam-operating agencies—the Army Corps of Engineers or the Bureau of Reclamation—has significant oversight responsibility for WSRs, even though federal dams appear to influence at least 250 WSRs (Fig. 6.8). The four federal agencies administering WSRs are the Bureau of Land Management (BLM), the National Park Service (NPS), the U.S. Forest Service (USFS), and the U.S. Fish and Wildlife Service (USFWS) (Fig. 6.10). WSRs administered by the NPS and the USFWS are managed as part of the National Park System or the National Wildlife Refuge System, respectively. If a conflict arises between laws and regulations governing national parks or refuges and the WSR Act, the stricter of them—that is, the laws and regulations affording the greatest protection to the river—applies.

Figure 6.10. Organization of the WSR system. Adapted from National Wild and Scenic Rivers System website (2007a).

In addition to ensuring that the management of lands within the river corridor sufficiently protects WSR values, the administering agency must work to ensure that activities on lands adjacent to the river corridor do not degrade WSR values. Other (non-administering) federal agencies must also protect WSR values when exercising their oversight of activities within and adjacent to a WSR corridor. For rivers designated by states and added to the WSR System under Section 2 (a)(ii) of the Act, authorized state agencies have primary responsibility for river management. In all cases, a partnership among federal, state, and local entities is encouraged.

A number of environmental laws that are applicable to all federal resource agencies—including the Clean Water Act, the National Environmental Policy Act, the Endangered Species Act, and the National Historic Preservation Act—come into play in the management of WSRs. The four primary administering agencies therefore work collaboratively with agencies that administer these “cross-cutting acts,” such as the Army Corps of Engineers and the Environmental Protection Agency. The Act also encourages river-administering federal agencies to enter into cooperative agreements with state and local political entities where necessary or beneficial to protect river values. For example, state and local authorities implement zoning restrictions and pollution control measures that may be critical to protecting the river’s water quality or specific outstandingly remarkable values. Finally, where private landholdings abut WSRs, the administering agencies may need to negotiate arrangements with private landowners to ensure adequate protection of the river’s values (Interagency Wild and Scenic Rivers Coordinating Council, 2002).

6.2.4.2 Management Plans

For all WSRs designated by Congress, a Comprehensive River Management Plan (CRMP) must be developed within three full fiscal years of the river’s addition to the WSR System. CRMPs essentially amend the broader land management plans of the agency administering the river (the

BLM, for example, would amend its Resource Management Plans) in order to ensure that the designated river corridor's values are protected or enhanced. For rivers designated at the request of a state, a CRMP is not required, but the state's application for a river's inclusion in the WSR System must include a strategy to ensure that the river will be managed so as to meet the goals (see Box 6.1) associated with the purposes of the Act. In developing CRMPs, federal agencies will typically consult with state and local agencies and solicit intensive public involvement. Over the years, various parties have challenged the allowance of certain activities (*i.e.*, timber harvesting, livestock grazing, road-building) when a CRMP has not been prepared and the effects of the potentially harmful activities in question cannot be adequately assessed. CRMPs are an important vehicle for establishing the flow and quality objectives that will sustain the values for which the river was designated. They are also vehicles for setting forth adaptive strategies to mitigate the effects of future human stressors on WSRs, including potential climate change impacts.

The long-term protection of WSR values, including the maintenance of a designated river's "free-flowing condition," requires that the river managers identify objectives for both water flows and water quality. The Interagency Wild and Scenic Rivers Coordinating Council, a government body established to coordinate management of WSRs among the responsible agencies, has identified six steps to ensure that management strategies protect the river's outstandingly remarkable values and free-flowing condition: (1) clearly define the water-related values to be protected, (2) document baseline conditions against which to assess future changes or threats, (3) identify potential threats and protection opportunities, (4) identify an array of protection options in the management plan, (5) vet the plan through legal counsel, and (6) decide upon and implement the best protection strategies for achieving the management objectives for the river (Interagency Wild and Scenic Rivers Coordinating Council, 2003).

In order to fulfill the Act's intent to "protect and enhance" WSR values, the collection and documentation of adequate baseline information for each WSR, along with a detailed narrative description of the characteristics and values that qualified the river for the WSR designation, is critical to both river managers and stakeholders. For example, a long-term record of river flows is invaluable for developing a water rights claim (see water rights discussion below), and background data on water quality is often essential for pursuing action to stop some proposed activity that threatens a river's ecological services and outstandingly remarkable values. In a case decided in 1997, for instance, the Oregon Natural Desert Association claimed that the BLM's river management plan was failing to protect the riparian vegetation and aquatic habitat of the Donner and Blitzen WSR, which studies had shown were adversely affected by livestock grazing. The court ultimately determined that grazing could continue, but only in a manner that fulfilled BLM's obligation to "protect and enhance" the values that qualified the river as a WSR. Without adequate baseline information, it is difficult, if not impossible to implement a "protect and enhance" policy.

Since passage of the Act, scientific understanding of the ecological importance of the natural variability of a river's historic flow regime has expanded markedly (Poff *et al.*, 1997; Postel and Richter, 2003; Richter *et al.*, 2003). In particular, a prior emphasis on the maintenance of "minimum flows"—ensuring that some water flows in the channel—has been succeeded by the more sophisticated and scientifically based "natural flow paradigm," which calls on river managers to mimic, to some degree, the variable natural flows that created the habitats and ecological conditions that sustain the river's biodiversity and valuable goods and services. Especially in the face of climate change and the resulting likelihood of altered river flow patterns, an understanding of the importance of a river's historical natural flow pattern to the maintenance of its ecological services will be critical to the development of effective climate adaptation strategies.

6.2.4.3 Legal and Management Tools

The federal and state agencies administering Wild and Scenic Rivers have a number of tools and measures at their disposal to fulfill their obligations to "protect and enhance" the water flows, water quality, and outstandingly remarkable values that qualify a particular river for inclusion in the WSR System. This section describes a few of these tools. Later sections suggest how these and other tools can be used to more effectively adapt the management of WSRs to climate change impacts and related human stressors.

Water Rights Claims and Purchases

By virtue of two U.S. Supreme Court rulings, one in 1908 (Winters *v*. United States) and another in 1963 (Arizona *v*. California), national parks, forests, wildlife refuges, and other federal land reservations, as well as Indian reservations, may claim federal "reserved" water rights to the extent those rights are necessary to carry out the purposes for which the reservation was established. The WSR Act makes clear that such reserved rights apply to designated wild and scenic rivers, as well (Interagency Wild and Scenic Rivers Coordinating Council, 2002). The quantity of the right cannot exceed that necessary to protect the specific river values that qualified the river for inclusion in the WSR System. To date, there are approximately 15 WSRs with water rights adjudications completed or in progress.

Because most WSR designations are less than 30 years old, WSRs typically have very junior rights in the western system of "first-in-time, first-in-right" water allocations. In over-allocated western rivers, another way of ensuring flows for a WSR segment is often to purchase water rights from private entities willing to sell them. In any effort to secure more flow for a WSR, the CRMP developed for the river must demonstrate how the river's outstandingly remarkable values depend on a particular volume or pattern of flow, and include a strategy for protecting flow-dependent river values.

Environmental Flow Protections

An environmental flow study can assist river managers in establishing scientifically based limits on flow alterations that are needed to protect a WSR's habitat, biodiversity, fishery, and other values (Richter *et al.*, 1997; Postel and Richter, 2003). Where allowed by state laws, state agencies (often working in partnership with federal and local authorities) may secure more flows for designated rivers by legislating environmental flows, using permit systems to enforce limits on flow modifications, transferring water rights for instream purposes, and implementing water conservation and demand-management strategies to keep more water instream (Postel and Richter, 2003; Postel, 2007). The WSR study for Connecticut's Farmington River (pictured in Fig. 6.11), for example, resulted in state water allocation authorities and a water utility committing themselves to the protection of flows needed to safeguard fisheries and other flow-dependent outstandingly remarkable values (Interagency Wild and Scenic Rivers Coordinating Council, 1996).

Figure 6.11. Farmington WSR. Photo compliments of the Farmington River Watershed Association.

Land Protection Agreements with Landowners Adjacent to WSR Corridors

Protection of the land included in the designated river corridor is critical to the protection of the habitat, scenic, scientific, and other values of a WSR. The boundary of an WSR includes up to 320 acres per river mile (twice this for Alaskan rivers), measured from the ordinary high water mark (Interagency Wild and Scenic Rivers Coordinating Council, 1996). Under the WSR Act, the federal government may acquire non-federal lands, if necessary, to achieve adequate river protection, but only if less than 50% of the entire acreage within the WSR boundary is in public ownership. However, other options for land protection, besides acquisition, exist (Interagency Wild and Scenic Rivers Coordinating Council, 1996). For instance, the administering agency can work cooperatively with landowners and establish binding agreements that offer them technical assistance with measures to alleviate potentially adverse impacts on the river resulting from their land-use activities. The National Park Service proposes such cooperative agreements, for instance, in its management plan for the Rio Grande WSR in Texas (National Park Service, 2004). In addition, landowners may voluntarily donate or sell lands, or interests in lands (*i.e.*, easements) as part of a cooperative agreement. Local floodplain zoning and wetlands protection regulations can also be part of a land-protection strategy (Interagency Wild and Scenic Rivers Coordinating Council, 1996).

Limitations on Impacts of Federally Assisted Water Projects on WSRs

The WSR Act is clear that no dams, diversions, hydropower facilities, or other major infrastructure may be constructed within a designated WSR corridor. In addition, the Act states that no government agency may assist (through loans, grants, or licenses) in the construction of a water project that would have a “direct and adverse effect” on the river’s values. A grayer area exists, however, when projects upstream or downstream of a designated WSR would “invade” or “unreasonably diminish” the designated river’s outstandingly remarkable values. Legal decisions in a number of WSR cases suggest that proposed water projects above or below a designated stream segment, or on a tributary to a WSR, should be evaluated for their potential to “unreasonably diminish” the scenic, recreational, fish, or wildlife values of the designated river. For example, when the U.S. Army Corps of Engineers proposed to complete the Elk Creek Dam, located 57 miles upstream of the Rogue WSR, the two administering agencies— BLM and the USFS—issued a determination that the dam would result in “unreasonable diminishment to the anadromous fisheries resource [within the designated area] because of impediments to migration and some loss of spawning and rearing habitat.” While it was left to Congress to decide whether the dam should be built, the Rogue WSR’s administering agencies weighed in to protect the river’s values (Interagency Wild and Scenic Rivers Coordinating Council, 2002).

Cooperative Arrangements with Other Agencies to Mitigate Impacts on WSRs

The WSR administering agencies can work proactively with other federal or state agencies to secure their cooperation in protecting the natural flows and outstandingly remarkable values of designated rivers. For example, the NPS could establish an agreement with an upstream dam operator, such as the Army Corps of Engineers, to help ensure flows adequate to protect the WSR's habitat and other values. In addition, working with local governments and communities to secure zoning restrictions that protect a WSR's water quality or other values can be effective. For example, cooperative work on WSR studies for the Sudbury, Assabet, and Concord Rivers in Massachusetts (which received WSR designation in 1999) led to a "nutrient trading" program designed to reduce pollution loads and eutrophication problems within the river systems (Interagency Wild and Scenic Rivers Coordinating Council, 2003).

Establishment of Effective Baseline Information

Although there is sufficient authority for the administering agencies to acquire land interests and water rights, information is often lacking to answer the important detailed questions about where to acquire these interests and water rights, when to do so, for how much, and for what purposes. Baseline data that are needed to adequately implement authorities under the Act are often skimpy or lacking altogether. It is very difficult for a river manager to propose a change when it cannot be demonstrated what that change will do to the river's protection. Without baseline data as a reference point, it will also be impossible to detect climate-induced changes in flow regimes. Thus, it is critical to begin to develop baseline data.

Technical Assistance

The spirit of the WSR Act is one of cooperation and collaboration among all the entities involved—whether public or private, and including local, state, regional, and national political divisions. The provision of technical assistance to communities within or near a designated or potential WSR can be a powerful tool for implementing the Act. In some cases, for example, communities may see the value of zoning restrictions only when given assistance with GIS mapping that shows the potential for harmful flooding in the future.

6.3 Adapting to Climate Change

Climate change arises from human activity and, unlike climate variation resulting from natural forces operating at historical time scales, the rate of climate change expected over the next 100 years is extremely high (IPCC, 2007b). The magnitude and form of the changes will be variable across the United States—some regions may experience more frequent and intense droughts while others may have fewer or less severe dry periods. This regional variability will be pronounced among the WSRs because they already vary dramatically in terms of their local climates and in terms of the extent to which their watersheds are influenced by human activities that exacerbate climate change impacts. Because impacts due to human activities (*e.g.*, land use change, water extraction) will persist or grow in the future, this discussion focuses on climate change impacts and the interactive effects of climate change with other stressors on ecosystems and their services. This section finishes by presenting options for adaptation for WSRs.

6.3.1 Climate Change Impacts

Output from climate change models indicate that global temperature will increase, with the direction and magnitude varying regionally. Projections of changes in precipitation are less certain but include change in the amount or timing of rainfall as well as the frequency and magnitude of extreme rainfall events. The latest IPCC (2007a) assessment report states: [We are] "*virtually certain* to experience warmer and fewer cold days over most land areas as well as warmer and more frequent hot days; we are *very likely* to experience heat waves and heavy rainfall events more frequently; and we are *likely* to experience more drought in some regions." Thus, in general, much of the world can expect warmer conditions with more severe weather events.

6.3.1.1 Temperature

The average global surface temperature is projected to increase by 1.2–6.4°C during the 21st century (IPCC, 2007a), but increases may be greater in the western United States, thus more strongly affecting rivers such as those in Nevada, Utah, and Idaho in the summer, and rivers in parts of Colorado, Arizona, New Mexico, and Wyoming throughout the year (Fig. 6.12). Because streams and rivers are generally well mixed and turbulent, they respond to changes in atmospheric conditions fairly easily and thus they would become warmer under projected climate change (Eaton and Scheller, 1996). Rivers that are fed by groundwater, such as Michigan's Au Sable and Florida's Wekiva, should be somewhat buffered from atmospheric heating (Allan, 2004). Those that do warm could experience reductions in water quality due to increased growth of nuisance algae and to lower oxygen levels (Murdoch, Baron, and Miller, 2000).

Figure 6.12. Projected temperature changes for 2091-2100 (University of Arizona, Environmental Studies Laboratory, 2007).

6.3.1.2 Precipitation

Little to no change in precipitation is projected in southern Utah, southern Colorado, northeastern New Mexico, eastern Texas, and Louisiana, where only a few wild and scenic rivers are designated (the Saline Bayou, Louisiana; Upper Rio Grande and Pecos, New Mexico) (Fig. 6.13). Up to a 10% increase in rainfall may occur around the Great Lakes region where there are a number of designated rivers including the Indian, Sturgeon, Presques Isle, and St. Croix. As much as a 10% decrease in precipitation may occur in southern Arizona and southeastern California where the Verde, Kern, Tuolumne, and Merced rivers are designated as Wild and Scenic.

Figure 6.13. Projected annual precipitation changes for 2091-2100 (University of Arizona, Environmental Studies Laboratory, 2007).

In regions that receive most of their precipitation as snow, the increased temperatures may result in a shift from winter snow to rain or rain plus snow. A recent analysis of long-term USGS discharge gauge records showed that most rivers north of 44° North latitude—roughly from southern Minnesota and Michigan through northern New York and southern Maine—have had progressively earlier winter-spring streamflows over the last 50–90 years (Hodgkins and Dudley, 2006). Rivers in mountainous regions also may experience earlier snowmelt, and in some regions, less snowpack (Stewart, Cayan, and Dettinger, 2005; McCabe and Clark, 2005). Many parts of Oregon and southern Washington, which are states notable for their large number of WSRs, may experience earlier snowmelt and thus higher winter-spring discharges.

6.3.1.3 Discharge

Because of the projected changes in temperature and precipitation, river discharges are expected to change in many regions (Lettenmaier, Wood, and Wallis, 1994; Vörösmarty *et al.*, 2000; Alcamo *et al.*, 2003). The total volume of river runoff and the timing of peak flows and low flows are expected to shift significantly in some regions. In humic, vegetated regions of the world, the majority of runoff follows subsurface pathways and the majority of precipitation returns to the atmosphere as evapotranspiration (Allan, Palmer, and Poff, 2005). Since climate change will affect the distribution of vegetation (Bachelet *et al.*, 2001), the dominant flow paths to some rivers may shift, resulting in higher or flashier discharge regimes (Alcamo, Flörke, and Märker, 2007).

Milly, Dunne, and Vecchia (2005) evaluated global fields of relative (*i.e.*, percent) change in runoff from a 1900–1970 baseline (2006 IPCC 20C3M model runs) to a 2041–2060 period (2006 IPCC A1B model runs). They averaged the relative change across 24 pairs of model runs, obtained from 12 different models, some of which performed replicate runs. Fig. 4 in Milly, Dunne, and Vecchia (2005) shows projected changes in runoff globally in two ways: (1) as the mean, across 24 pairs of runs, of the relative changes in runoff, and (2) as the difference between the number of pairs of runs showing increases in runoff minus the number showing decreases in runoff. Fig. 6.14 shows similar results from the same analysis, but with (1) central estimates of change based on the more stable median instead of the mean, (2) equal weighting of the 12 models instead of the 24 pairs of model runs, and (3) relative changes of areal-averages of runoff over United States water regions instead of relative changes of point values of runoff.

Figure 6.14. Median, over 12 climate models, of the percent changes in runoff from United States water resources regions for 2041–2060 relative to 1901–1970. More than 66% of models agree on the sign of change for areas shown in color; diagonal hatching indicates greater than 90% agreement. Recomputed from data of Milly, Dunne, and Vecchia (2005) by Dr. P.C.D. Milly, USGS.

The median projections are for increased runoff over the United States Midwest and Middle-Atlantic, through slightly decreased runoff in the Missouri River Basin and the Texas Gulf drainage, to substantial change (median decreases in annual runoff approaching 20%) in the Southwest (Colorado River Basin, California and Great Basin). Median estimates of runoff changes in the Pacific Northwest are small. Large (greater than 20%) increases in runoff are projected for Alaska.

Figure 6.14 also contains information on the degree of agreement among models. Uncolored regions in the Southeast, New England, and around the Great Lakes indicate that fewer than two thirds of the models agreed on the direction of change in those regions. Elsewhere, the presence of color indicates that at least two thirds of the models agreed on the direction of change.

Diagonal stippling in Alaska and the Southwest indicate that more than 90% (*i.e.*, 11 or 12) of the 12 models agree on the direction of change.

It is important to note that and some of the regions in Fig. 6.14 are small and are not well resolved by the climate models, so important spatial characteristics—such as mountain ranges in the western United States—are only very approximately represented in these results. However, these regions are generally larger than many of the river basins for which Milly, Dunne, and Vecchia (2005) demonstrated substantial model skill in reproducing historical observations.

In regions in which snowmelt occurs earlier due to warmer temperatures, stream flows will increase early in the season and flooding may be pronounced (see Fig. 6.15 for a picture of river flooding) if high flows coincide with heavy rainfall events (“rain on snow events”). As evidenced by increases in discharge, a shift in the timing of springtime snowmelt toward earlier in the year is already being observed (1948–2000) in many western rivers (Fig. 6.16), particularly in the Pacific Northwest, Sierra Nevada, Rockies, and parts of Alaska (Stewart, Cayan, and Dettinger, 2004).

Figure 6.15. Photo of snowmelt in WSR during winter-spring flows. Photo courtesy of National Park Service, Lake Clark National Park & Preserve.

Figure 6.16. Earlier onset of spring snowmelt pulse in river runoff from 1948–2000. Shading indicates magnitude of the trend expressed as the change (days) in timing over the period. Larger symbols indicate statistically significant trends at the 90% confidence level. From Stewart, Cayan, and Dettinger (2005).

6.3.1.4 Channel and Network Morphology

Large changes in discharge that are not accompanied by changes in sediment inputs that offset the flow changes will have dramatic impacts on river geomorphology (Wolman, 1967). Rivers with increases in discharge will experience more mobilization of bed sediments (Pizzuto *et al.*, In Press), which may result in changes in the river’s width and depth (Bledsoe and Watson, 2001). Regions that lose vegetation under future climate may have increased runoff and erosion when it does rain (Poff, Brinson, and Day, Jr., 2002). The drier conditions for extended periods of time may result in some perennial streams becoming intermittent and many intermittent or ephemeral streams potentially disappearing entirely, thus simplifying the network.

6.3.2 Future Human Context: Interactive Effects of Multiple Stressors

The effects of multiple environmental stressors on ecosystems are still poorly understood, yet their impacts can be enormous. Any consideration of climate change is by definition a consideration of future conditions; *i.e.*, a look at what is expected over the next century. Many factors other than climate influence the health of ecosystems, and these factors certainly will not remain static while climate changes (see Box 6.5 for examples). The stressors most likely to intensify the negative effects of climate change include land use change - particularly the clearing of native vegetation for urban and suburban developments – and excessive extractions of river water or groundwater that feed WSRs (Allan, 2004; Nelson and Palmer, 2007).

WSRs in watersheds with a significant amount of urban development are expected to not only experience the greatest changes in temperature under future climates but also to experience temperature spikes during and immediately following rain storms (Nelson and Palmer, 2007) (Fig 6.17). Such changes may result in the extirpation of cool water species (Nelson and Palmer, 2004).

Figure 6.17. Very rapid increases (1–4 hours) in water temperature (temperature "spikes") in urban streams north of Washington D.C. have been found to follow local rain storms. *Top graph:* dark line shows stream discharge that spikes just after a rainfall in watersheds with large amounts of impervious cover; gray line shows temperature surges that increase 2–7ºC above pre-rain levels and above streams in undeveloped watersheds in the region. There is no temperature buffering effect that is typical in wildlands where rain soaks into soil, moves into groundwater, and laterally into streams. *Bottom graph:* shows that the number of temperature surges into a stream increases with the amount of impervious cover. From Nelson and Palmer (2007).

The number of extreme flow events would also increase more in WSRs in urbanized basins compared with those that are mostly wild. Large amounts of impervious cover are well known to cause an increase in flashiness in streams—both higher peak flows during the rainy season and lower base flows in the summer (Walsh *et al.*, 2005). Thus, flooding may be a very serious problem in regions of the United States that are expected to have more rainfall and more urbanization in the future(*e.g.*, the Northeast and portions of the mid-Atlantic) (Nowak and Walton, 2005) (see Fig. 6.13). Areas of the United States that will experience the greatest increase in population size are the South and West, with increases of more that 40% between the year 2000 and 2030 (U.S. Census Bureau, 2004). More specifically, significant growth is occurring in the following regions that have rivers designated as wild and scenic: most of Florida; central and southern California; western Arizona; around Portland, Oregon; much of the mid-Atlantic; and parts of Wisconsin, northern Illinois, and Michigan (Auch, Taylor, and Acevedo, 2004).

Excessive water extractions are already affecting some WSRs (*e.g.*, the Rio Grande) and this impact will be exacerbated in regions of the country expected to experience even more water stress under future climates. Alcamo, Flörke, and Märker (2007) used a global water model to analyze the combined impacts of climate change and future water stress due to socioeconomic driving forces (income, electricity production, water-use efficiency, etc) that influence water extractions. Their models indicate that for the 2050s, areas under severe water stress will include not only parts of Africa, Central Asia, and the Middle East, but also the western United States. (Fig. 6.18)

Figure 6.18. Water stress projected for the 2050s based on withdrawals-to-availability ratio, where availability corresponds to annual river discharge (combined surface runoff and groundwater recharge). From Alcamo, Flörke, and Märker (2007).

Water managers will need to adjust operating plans for storing, diverting, and releasing water as the timing and intensity of runoff changes due to climate change (Bergkamp, Orlando, and Burton, 2003). If these water management adjustments do not keep pace with climate change, water managers will face increasingly severe water and energy shortages due to lessened efficiency in capturing and storing water to supply cities and farms, or to generate electricity.

Dam building in the United States has slowed considerably relative to the past century, so river impacts related to the interactive effects of dams and climate change will result primarily from changes in management of the dams, particularly as water withdrawals for irrigation or urban water supplies increase in response to a changing climate. For basins expected to experience high water stress in the future (*e.g.*, in the southwestern United States), drawdown of reservoirs is expected, with less water available to sustain environmental flows in the downstream rivers. In regions expected to experience increased precipitation such as the Great Lakes, flooding problems may increase, particularly if climate change brings greater intensity of rainfall. Shifts in the timing of snowmelt runoff or ice break-up will force dam managers to adjust their operating plans to avoid catastrophic high releases of water into downstream areas. In general, WSRs in basins that are affected by dams or are highly developed will require more changes in management than free-flowing rivers in basins that are mostly wild (Palmer *et al.*, In Press). Ideally this will be done proactively to minimize the need to repair and restore damaged infrastructure and ecosystems.

6.3.3 Ecosystem Goods and Services Assuming Present Management

This chapter has outlined expectations given future climate projections that include warmer water temperatures for most rivers and changes in flow regimes, with extreme events (floods and droughts) increasing in frequency for many rivers. While the impacts will vary among the WSRs depending on their location, their ability to absorb change—which is largely related to the "wildness" of their watershed—also depends on the management response. If proactive measures to buffer ecosystems (such as those discussed in the next section) are taken, then the consequences may be reduced. The need for these proactive measures should be least for WSRs that are designated "wild" followed by those that are designated "scenic." Presumably wild rivers are the least affected by human activities that may exacerbate the impacts of climate change. However, as noted earlier, because many WSRs are in reality river *segments* within watershed that may be affected by development or even dams, each designated river must be evaluated to determine the management needs.

This section describes the impacts to ecosystems assuming "business as usual" in management—*i.e.*, no changes from current practices. The discussion focuses on species and ecological processes, because these two factors influence most of the attributes valued in WSRs: clean water and healthy ecosystems, with flow regimes that support diverse plant and animal assemblages. Even though recreational use of some WSRs is focused primarily on water sports, most users still have a strong preference for the other attributes listed above. Clean and beautiful waterways are only possible if materials entering that water—*e.g.*, nutrients, excess organic matter, etc.—do not interfere with natural biophysical processes or the health of flora and fauna.

For a given level of "wilderness," the impacts of climate change on WSRs will depend on how much the changes in thermal and flow regimes deviate from historical and recent regimes (Fig. 6.5). Changes outside the historical range of flow or temperature variability may have drastic consequences for ecosystem structure and function (Richter *et al.*, 1997; Poff, Brinson, and Day, Jr., 2002). The impacts will also depend on the rate of change in temperature or discharge relative to the adaptive capacity of species (amount of genetic diversity). Finally, the impacts will depend on the number and severity of other stressors. Thus, the warmer temperatures and drier conditions expected in southwestern rivers may lead to severe degradation of river ecosystems, which will be exacerbated if water withdrawals for consumptive uses increase (Xenopoulos *et al.*, 2005). For example, the Verde River north of Phoenix, Arizona is in a region of the United States that is experiencing increases in population size, and is expected to have reduced rainfall as well as higher winter and summer temperatures under future climates. The Verde is one of the few perennial rivers within Arizona, but its headwaters are an artificial reservoir (Sullivan Lake) and its flows are affected by groundwater pumping and diversions despite being largely in national forest land.

Some WSRs may experience more intense run-off following rain storms, particularly those that are in watersheds destined to become more urbanized. These are expected to lose sensitive taxa and experience serious water quality problems (Nelson and Palmer, 2007; Pizzuto *et al.*, In Press). The WSRs expected to be affected are those in regions projected to have more precipitation and increases in population size, such as the Upper Delaware, those in the Columbia River basin, and potentially the Chattooga.

6.3.3.1 Species-Level Impacts

As the water warms, individual growth and reproductive rates of fish are expected to increase so long as thermal tolerances of any life history stage are not exceeded; typically, eggs and young juveniles are the most sensitive to temperature extremes (Van der Kraak and Pankhurst, 1997; Beitinger, Bennett, and McCauley, 2000). Faster growth rates and time to maturation typically result in smaller adult size and, because size is closely related to reproductive output in many aquatic invertebrates (Vannote and Sweeney, 1980), population sizes may decline over time. The spawning time of fish may also shift earlier if river waters begin to warm earlier in the spring (Hilborn *et al.*, 2003). Further, some aquatic species require prolonged periods of low temperatures (Lehmkuhl, 1974); these species may move northward, with local extirpations. However, dispersal to more northern rivers may be restricted by habitat loss, and riverine insects with adult flying stages that depend on vegetated corridors for dispersal may not survive (Allan and Flecker, 1993). For fish, amphibians, and water-dispersed plants, habitat fragmentation due to dams or the isolation of tributaries due to drought conditions may result in local extirpations (Dynesius *et al.*, 2004; Palmer *et al.*, In Press).

Depending on their severity, climate-induced decreases in river discharge may reduce freshwater biodiversity, particularly if other stressors are at play. Xenopoulos et al. (2005) predict up to 75% of local fish biodiversity could be headed toward extinction by 2070 due to the combined effects of decreasing discharge and increasing water extractions. Even if streams do not dry up in the summer, those that experience reductions in baseflow (*e.g.*, in the Southwest) may have stressed biota and riparian vegetation (Allan, 2004). Dissolved oxygen levels may decline, as may critical habitat for current-dependent (rheophilic) species (Poff, 2002). Physiological stress and increased predation resulting from crowding (less depth means less habitat), combined with habitat fragmentation in stream networks (isolated pools), may dramatically reduce survival and constrain dispersal (Poff, 2002).

Rivers in which future discharge exceeds historical bounds will also experience a loss of species unless they are capable of moving to less-affected regions. Since species life histories are closely tied to flow regime, some species may not be able to find suitable flow environments for feeding, reproducing, or surviving major flood events. Further, with higher flows comes higher suspended sediment and bedload transport, which may interfere with feeding. If sediment deposition fills interstitial spaces, this will reduce hyporheic habitat availability for insects and spawning areas for lithophilic fish (Pizzuto *et al.*, In Press). Whether deposition or net export of these sediments occurs depends on the size of the sediment moving into channels in concert with peak flows (*i.e.*, the stream competency). Particle size and hydraulic forces are major determinants of stream biodiversity (both the numbers and composition of algae, invertebrates, and fish) and excessive bottom erosion is well known to decrease abundances and lead to dominance by a few taxa (Allan, 1995).

6.3.3.2 Impacts on Ecological Processes

Many of the ecological processes that ensure clean water for drinking and for supporting wildlife will be influenced by higher water temperatures and altered flows. Primary production in streams is very sensitive to temperature and flow levels (Lowe and Pan, 1996; Hill, 1996); climate change may thus result in an increase in food availability to herbivorous biota that could support higher abundances and also shift species composition. If riparian plants also grow at faster rates, inputs of leaves and other allochthonous material to rivers may increase. While this could be expected to provide more food for detritivores, this may not be the case if the rate of breakdown of those leaves is higher under future climates. This may occur with higher water temperatures and thus increased microbial growth, or with higher flows that contribute to the physical abrasion of leaves (Webster and Benfield, 1986). Further, allochthonous inputs may represent lower-quality food since plants growing under elevated CO_2 levels may have higher carbon-to-nitrogen ratios, and compounds such as lignin (Tuchman *et al.*, 2002) that reduce microbial productivity (Rier *et al.*, 2002). They also may experience higher leaf decay rates (Tuchman *et al.*, 2003) and detritivore growth rates in streams (Tuchman *et al.*, 2002).

There is a great deal of uncertainty about how rates of nutrient processing in streams will be influenced by climate change. Dissolved inorganic nitrogen (as NO_3) levels may decrease if rates of denitrification are increased (*e.g.*, by higher temperatures and lower oxygen), which could be important given increasing levels of nitrogen deposition (Baron *et al.*, 2000). On the other hand, if discharge and sediment transport increase, then the downstream movement of nitrogen (as NH_4) and phosphorus (as $P0_4$) may increase. In short, there is a high degree of uncertainty with respect to how climate change will affect ecological processes. This means that our present ability to predict changes in water quality, and food availability for aquatic biota is limited. To date, few studies have been conducted to simultaneously examine the many interacting factors that are both subject to change in the future and known to influence ecological processes.

6.3.4 Options for Protection Assuming New Management

Rivers are inherently dynamic systems—in their native state they are constantly “adjusting” to changes in sediment and water inputs by laterally migrating across the landscape and by changing the depth, width, and sinuosity of their channels. These changes are part of a healthy river’s response to changes in the landscape and the climate regime. However, the new temperature and precipitation regimes expected as a result of global climate change would occur much more quickly than historical climate shifts (IPCC, 2007b). Further, many WSRs are affected by development in their watershed, dams, and excessive water extractions. Thus, the ability to adjust to changes in the flux of water and material particularly on rapid time scales is impeded in many watersheds.

In general, WSRs that are in fairly pristine watersheds with no development and few human impacts will fare the best under future climates because their natural capacity to adjust is intact. Even in the face of climate change impacts, rivers surrounded by uninhabited and undeveloped land may experience shifts in channels—perhaps even a deepening and widening of those channels—but their provision of ecosystem services may remain intact. The access points for wildlife or river enthusiasts may need to be shifted and existing trails moved, but largely these rivers are expected to remain beautiful and healthy. In contrast, rivers in Illinois, which will also experience increased discharge, may experience serious problems because flooding and erosion may be exacerbated by development. That said, even some pristine rivers may be negatively affected. For example, the Noatak River in Alaska is already experiencing very large temperature shifts because of its fairly high latitude. This could have serious consequences for migrating salmon and other highly valued species (National Research Council, 2004) (Box 6.4).

The question becomes, what is the appropriate management response? Following Palmer et al. (In Press), we distinguish between *proactive* and *reactive* responses. The former includes management actions such as restoration, land purchases, and measures that can be taken now to maintain or increase the resilience of WSRs (*i.e.*, the ability of a WSR to return to its initial state and functioning despite major disturbances). Reactive measures involve responding to problems as they arise by repairing damage or mitigating ongoing impacts.

6.3.4.1 Reactive Management

Reactive management basically refers to what managers will be forced to do once impacts are felt if they have not prepared for them. When it comes to rivers, examples of reactive measures include rescuing stranded canoeists who are caught by unexpected floods in remote areas or demolishing Park Service buildings that are too close to eroding streambanks of a WSR. Reactive management in some WSRs in the Southwest may involve moving isolated populations of species of interest once they become stranded due to dropping water levels.

The most expensive and serious reactive measures will be needed for WSRs in basins that are heavily developed or whose water is managed for multiple uses. In areas with higher discharge, reactive measures may include river restoration projects to stabilize eroding banks or projects to repair in-stream habitat. Other measures such as creating off-channel storage basins or wetland creation may be a way to absorb high flow energy. Removing sediment from the bottom of reservoirs could be a short-term solution to allow for more water storage, perhaps averting dam breaches that could be disastrous. Water quality problems due to high sediment loads or contaminants may appear in WSR reaches downstream of developed (urbanized or agricultural) regions, and these problems are very difficult to cope with in a reactive manner.

In regions with higher temperatures and less precipitation, reactive projects might include fish passage projects to allow stranded fish to move between isolated river reaches during drought times, replanting of native riparian vegetation with drought resistant vegetation, or removal of undesirable non-native species that take hold. If dams are present upstream of the WSR, flow releases during the summer could be used to save flora and fauna in downstream river reaches that are drying up, and accentuated floods can be managed to avert potentially disastrous ecological consequences of extreme floods.

These are simply examples of reactive management that are discussed more fully in Palmer et al. (In Press), but the most important point is that a reactive approach is not the most desirable response strategy to climate change, because a high degree of ecosystem and infrastructure damage is likely to occur before reactive measures are taken. The best approach for reactive management is to continuously evaluate river health over time with rigorous monitoring and scientific research so that management begins as soon as problems are detected *i.e.*, before problems are severe. Further, this monitoring and research should help identify proactive needs, thus minimizing costs of repair and loss of ecological services.

6.3.4.2 Proactive Management

Many of the management actions that are needed to respond to the risks of climate change arise directly from changes in the frequency and magnitude of extreme events, in addition to changes in average conditions or baseflow. Anticipating how climate impacts will interact with other ongoing stressors is critical to developing strategies to protect the values of WSRs. Proactive measures that restore the natural capacity of rivers to buffer climate-change impacts are obviously the most desirable actions since they may also lead to other environmental benefits such as higher water quality and restored fish populations. Examples of such measures might include stormwater management in developed basins or, even better, land acquisition around the river or setting back existing levees to free the floodplain of infrastructure, absorb floods, and allow regrowth of riparian vegetation.

While shifting climate regimes may result in local shifts in species assemblage (Thuiller, 2004), if there are flora and fauna of special value associated with a WSR, then proactive responses to ensure the persistence of these species is needed. This will require detailed understanding of their life histories and ecology. For rivers in regions expected to experience hot, dry periods, planting or natural establishment of drought-tolerant varieties of plants may help protect the riparian corridor from erosion. A focus on increasing genetic diversity and population size through plantings or via stocking fish may increase the adaptive capacity of species. Aquatic fauna may benefit from an increase in physical habitat heterogeneity in the channel (Brown, 2003), and replanting or widening any degraded riparian buffers may protect river fauna by providing more shade and maintaining sources of allochthonous input (Palmer *et al.*, 2005).

Incorporating the potential impacts of climate change into water management strategies inevitably involves dealing constructively with uncertainty. Enough is now known about the likelihood of certain impacts of climate change on water availability and use that it is possible to design proactive management responses to reduce future risks and to protect important river assets. At the core of these strategies is the ability to *anticipate* change and to *adapt* river management to those changing circumstances. Water managers need to know, for example, when to take specific actions to ensure the maintenance of adequate flows to sustain river species. It is important that this adaptive capacity be built at the watershed scale, incorporating factors such as grazing, farming, forestry and other land-uses, reservoir management, water withdrawals, and other features. A new layer of cooperation and coordination among land and water managers will thus be essential to the successful implementation of these adaptive strategies for the management of WSRs.

Legal and institutional barriers exist in many river systems, and will need to be overcome for the adoption of effective management strategies. Water rights, interstate water compacts, property rights, and zoning patterns may all present constraints to effective adaptation strategies. Studies of the Colorado River basin, for example, have found that much of the potential economic damage that may result from climate change is attributable to the inflexibility of the Colorado River Compact (Loomis, Koteen, and Hurd, 2003). The new stressor of climate change, on top of the existing pressures of population growth, rising water demand, land-use intensification, and other stressors, may demand a re-evaluation of the institutional mechanisms governing water use and management, with an eye toward increasing flexibility.

Along with the management tools described above, a number of other categories of actions and measures can enhance the WSR System's ability to protect the nation's rivers under changing climatic regimes, as described below. Box 6.5 presents a summary list of specific actions WSR managers can take to promote adaptation.

Designate More River Corridors as Wild and Scenic

Rivers may be designated as Wild and Scenic by acts of Congress or by the Secretary of Interior upon a state's request. Designation of additional rivers to the WSR program may raise visibility and expand protection to river assets at a time when they are coming under increased human and climatic pressures. Possible candidates for designation include rivers in the Nationwide Rivers Inventory (NRI). The NRI, which is maintained by the National Park Service (updated last in the 1980s), includes more than 3,400 free-flowing river segments that are believed to possess at least one outstandingly remarkable value of national significance. By virtue of a 1979 Presidential directive, all federal agencies must seek to avoid or mitigate actions that would affect NRI segments. The WSR System would also benefit from hastening the review of rivers that have already been submitted for designation, but about which no decision has yet been made. For new designations, there is an opportunity to think strategically about climate change impacts when identifying and prioritizing rivers for designation. Climate change may affect the priority order and rationale for designation.

Rebalance the Priority of Values used for Designation of WSRs

In light of climate change impacts and their anticipated effects on habitat, biodiversity, and other ecological assets, it may be useful to emphasize such natural values when designating new WSRs. In addition, where two outstandingly remarkable values are in conflict within the same designated river—as sometimes happens, for example, between habitat and recreational values—

giving greater weight to natural assets most at risk from climate change may be an important instrument for adaptation to climatic impacts.

Claim, or Purchase, More Water Rights and/or Establish Effective Environmental Flow Programs to Secure Ecological Flows

The protection of river health and natural flows under a changing climatic regime will require more concerted efforts to secure environmental flows, namely flows that will support the ecosystem, for rivers. The purchase or leasing of water rights to enhance flow management options can be a valuable tool. For example, the establishment of dry-year option agreements with willing private partners can ensure that flows during droughts remain sufficient to protect critical habitats and maintain water quality. A strengthening of environmental flow programs and water use permit conditions to maintain natural flow conditions will also be critical.

Develop and Amend CRMPs to Allow for Adaptation to Climate Change

For river managers to fulfill their obligations to protect and enhance the values of WSRs, their management plans must be amended to take into account changing stressors and circumstances due to shifting climate (Poff, Brinson, and Day, Jr., 2002). For example, the severe drought in Australia in recent years has not only had serious short-term impacts on river flows, but—due to the effects of fires—may have severe long-term flow effects as well. Studies of the Murray River system by researchers at the University of New South Wales have found that large-scale forest regeneration following extensive bush fires will deplete already low flows further due to the higher evapotranspiration rates of the younger trees compared with the mature forests they are replacing. The 2003 fires, for example, may reduce flows by more than 20% for the next two decades in one of the major tributaries to the Murray (University of New South Wales, 2007). Similar flow alterations might be anticipated in the American Southwest, which can expect a significant increase in temperature, reduction in snowpack, and recurring droughts that may cause more frequent fires and related vegetation changes. Management of the Rio Grande Wild and Scenic corridors in both New Mexico and Texas will need to take such scenarios into account.

Develop Reservoir-Release Options with Dam Managers

With more than 270 dams located within 100 miles (upstream or downstream) of a designated WSR, collaborative arrangements with dam managers offer great potential to secure beneficial flows for WSRs under various climate change scenarios. Because the agencies administering WSRs have little or no authority over dam operations, a proactive collaboration among the agencies involved—at federal, state, and local levels—is critical.

Apply Climate Forecasting to Water Management Planning

Climate forecasts can enable water managers to minimize risk and avoid damage to WSR values. The development of scenarios that capture the spectrum of possible outcomes is an invaluable tool for anticipating the ramifications of climate-related hydrological and land-use changes, including reduced snowpacks, greater spring flooding, lower summer flows, and warmer stream temperatures. The utility of forecasting tools, however, depends on the ability to apply their results to water management planning. For instance, the possibility of severe drought occurring in three out of five years implies that river flows may be affected not only by lack of rainfall and runoff, but by increased evapotranspiration from vegetative regrowth after forest fires. Anticipating such flow depletion, and its potential magnitude, is critical to devising plans that mitigate the impacts. For example, warming trends across the Southwest exceed global averages by 50%, providing ample evidence of the importance of planning for reduced water availability and streamflows in the Rio Grande and other southwestern rivers (New Mexico Office of State Engineer and Interstate Stream Commission, 2006).

Improve Water Monitoring Capabilities

It is critical that river flow monitoring be supported adequately to detect and adapt to flow alterations due to climate change and other stressors. However, many stream gauges maintained by USGS have been discontinued due to resource limitations. Without sufficient monitoring capabilities, river managers simply cannot do their jobs adequately and researchers cannot gather the data needed to elucidate trends. For instance, if flooding is expected to increase as a consequence of more rapid melting in spring, river managers may need to know the acreage and location of additional land conservation easements to pursue, or where to encourage local zoning that limits development on floodplains. Without adequate monitoring to detect trends in flow, it is impossible to proceed confidently with such adaptation measures.

Build Capacity to Offer Technical Assistance

The ability to demonstrate to communities the importance of certain zoning restrictions, land conservation measures, land-use modifications, or floodplain restrictions may require user-friendly models or tools that exhibit potential climate change impacts within specific watersheds. While sophisticated tools may be feasible to use in reaches with ample resources to support management activities, there is a need for affordable tools that enable managers to offer technical assistance in areas with fewer resources.

6.4 Case Studies

As emphasized throughout this chapter, the effects of climate change on rivers will vary greatly throughout the United States depending on local geology, climate, land use, and a host of other factors. To illustrate the general “categories” of effects, we have selected three WSRs to highlight in the following case studies (Box 6.6). We selected these rivers because they span the range of some of the most obvious issues that managers will need to grapple with as they develop plans for protecting natural resources in the face of climate change. Rivers in the Southwest, such as the Rio Grande, will experience more severe droughts at a time when pressures for water extraction for growing populations are increasing. Rivers near coastal areas, such as the Wekiva, face potential impacts from sea level rise. A combination of groundwater withdrawals and sea level rise may lead to increases in salinity in the springs that feed this river. Rivers that are expected to experience both temperature increases and an increased frequency of flooding, such as the Upper Delaware, will need proactive management to prevent loss or damage to ecosystem services.

There are also key outstandingly remarkable values that the WSR program focuses on. One of those areas is anadromous fish. Box 6.7 provides an overview of potential climate change impacts to anadromous fish and offers management actions that may be taken to lessen those impacts.

6.4.1 Wekiva River Case Study

The Wekiva River Basin, located north of Orlando, in east-central Florida, is a complex ecological system of streams, springs, seepage areas, lakes, sinkholes, wetland prairies, swamps, hardwood hammocks, pine flatwoods, and sand pine scrub communities. Several streams in the basin run crystal clear due to being spring-fed by the Floridan aquifer. Others are "blackwater" streams that receive most of their flow from precipitation, resulting in annual rainy season over-bank flows. (Fig. 6.19)

Figure 6.19. The Wild and Scenic portions of the Wekiva River. Data from USGS, National Atlas of the United States (2005).

In 2000, portions of the Wekiva River and its tributaries of Rock Springs Run, Wekiwa[1] Springs Run, and Black Water Creek were added to the National Wild and Scenic Rivers System. The designated segments total 66.9 km, including 50.5 km designated as Wild, 3.4 miles as Scenic, and 13 km as Recreational. The National Park Service has overall coordinating responsibility for the Wekiva River WSR, but there are no federal lands in the protected river corridor. Approximately 60%–70% of the 0.8-km-wide WSR corridor is in public ownership, primarily managed by the State of Florida Department of Environmental Protection and the St. Johns River Water Management District (SJRWMD). The long-term protection, preservation, and enhancement are provided through cooperation among the State of Florida, local political jurisdictions, landowners, and private organizations. The designated waterways that flow through publicly owned lands are managed by the agencies that have jurisdiction over the lands. SJRWMD has significant regulatory authority to manage surface and ground water resources throughout the Wekiva Basin.

One of the main tributaries to the Wekiva River is the Little Wekiva River. Running through the highly developed Orlando area, the Little Wekiva is the most heavily urbanized stream in the Wekiva River Basin, and consequently the most heavily affected. The Orlando metropolitan area has experienced rapid growth in the last two decades, and an estimated 1.3 million people now live within a 20-mile radius of the Wekiva River.

The sections of the Wekiva River and its tributaries that are designated as WSR are generally in superb ecological condition. The basin supports plant and animal species that are endangered, threatened, or of special concern, including the American Alligator, the Bald Eagle, the Wood Stork, the West Indian Manatee, and two invertebrates endemic to the Wekiva River, the Wekiwa hydrobe and the Wekiwa siltsnail. At the location of the U.S. Geological Survey's gauging station on the Wekiva River near Sanford, the drainage area of the basin is 489 square km. Elevations for the basin range from 1.5–53 m above sea level. The climate is subtropical, with an average annual temperature of around 22°C. Mean annual rainfall over the Wekiva basin is 132 cm, most of which occurs during the June–October rainy season.

---

[1] The term "Wekiwa" refers to the spring itself, from the Creek/Seminole "spring of water" or "bubbling water." "Wekiva" refers to the river, from the Creek/Seminole "flowing water."

The WSR management plan is being prepared with the leadership of the National Park Service. Based on information from the pre-legislation WSR study report (National Park Service, 1999), and management plans for the state parks (Florida Department of Environmental Protection, 2005) and the SJRWMD (2006a), the priority management objectives for the WSR will likely include maintaining or improving: water quantity and quality in the springs, streams, and river; native aquatic and riparian ecosystems; viable populations of endangered and sensitive species; scenic values; and access and service for recreational users.

The Wekiva River was selected for a case study because it provides an example of a spring-fed WSR system, sub-tropical ecosystems, a coastal location with a history of tropical storms and hurricanes, and a system in a watershed dealing directly with large and expanding urban and suburban populations. In particular, the spring-fed systems combined with urban and suburban land uses require consideration of the relationship between groundwater and surface water and how they relate to management options in the context of climate change.

6.4.1.1 Current Stressors and Management Methods Used to Address Them

The primary stressors of the Wekiva WSR are:

- water extraction for public, recreational and agricultural uses;
- land conversion to urban and suburban development;
- pollution, particularly nitrates, via groundwater pathways and surface water runoff; and
- invasive species.

The Floridan aquifer has a naturally high potentiometric surface (*i.e.*, the level that water will rise in an artesian well), which sustains the natural springs that are critical to the water regime of the Wekiva WSR. McGurk & Presley (2002) cite numerous studies that show the long history of water extraction in East Central Florida and related these extractions to lowering of the potentiometric surface. Taking advantage of the high potentiometric surface, in the first half of the 20th century more than two thousands artesian (free-flowing) wells were drilled into the Upper Floridan aquifer, the water used to irrigate agriculture fields and the excess allowed to flow into the streams and rivers. Many of the artesian wells have since been plugged and otherwise regulated to reduce such squandering of the water resources.

Between 1970 and 1995, agricultural and recreational water use from the aquifer has increased nearly three fold to 958 million gallons per day (mgpd), with a significant part of the additional water supporting recreational uses (*i.e.*, golf courses). Over that same period, public (*e.g.*, city) use of water from the aquifer also increased threefold to 321 mgpd. Projections for the year 2020 are for water extraction for agricultural and recreational uses to barely increase, while extractions for public use will nearly double (McGurk and Presley, 2002). The St. Johns River, Southwest Florida, and South Florida Water Management Districts have jointly determined that the Floridan Aquifer will be at maximum sustainable yield by 2013, and by that date and into the future much of the water used by people will have to come from alternative sources.

Urban development prior to modern stormwater management controls is another stressor on aquatic systems in the Wekiva Basin. In particular, the Little Wekiva River exhibits extreme erosion and sedimentation caused by high flows and velocities during major storm events (St.

Johns River Water Management District, 2002). Approximately 479 drainage wells were completed in the Orlando area to control storm water and control lake levels (McGurk and Presley, 2002). These drainage wells recharge the Floridan aquifer.

Declines in spring flows in the Wekiva River Basin are strongly correlated with urban development and ground water extraction (Florida Department of Environmental Protection, 2005). Projections based on current practices predict that by 2020 water demand will surpass supply and recharge. By 2010, spring flows may decline to levels that will cause irreparable harm (Florida Department of Environmental Protection, 2005). In response to these projections, the St. Johns River Water Management District (SJRWMD) has declared the central Florida region, which includes the Wekiva River Watershed, a “Priority Water Resource Caution Area” where measures are needed to protect ground water supplies and spring-dependent ecosystems. SJRWMD has developed “Minimum Flows and Levels” (a.k.a., instream flow criteria) for the Wekiva River and Blackwater Creek, and the district has identified minimum spring flows in selected major springs feeding the Wekiva and Rock Springs Run. These are an important regulatory tool to set limits on ground water withdrawals to prevent adverse reductions in spring flow.

The water management district recommends the following strategies for improving water management (St. Johns River Water Management District, 2006b):

- water conservation;
- use of reclaimed water; and
- water resource development, including:
    - artificial aquifer recharge
    - aquifer storage and recovery
    - avoidance of impacts through hydration
    - interconnectivity of water systems.

The SJRWMD, counties, and cities in the watershed are working on local water resources plans and an integrated basin-wide water plan that will guide water use and conservation land use changes for the coming decades (Florida Department of Community Affairs, 2005).

Water pollution is another significant stressor of the Wekiva WSR. The causes of water pollution are closely related to the water quantity issues discussed above. In particular, unusually high concentrations of nitrates emanating from the springs of the basin are stressing the native ecosystems in the spring runs. Nitrates promote algal blooms that deplete oxygen, shade-out native species, and may negatively affect invertebrate and fish habitat. Nitrates in spring water now may reflect more distant past inputs from agricultural operations and septic systems. The sources of the nitrogen in the springs are animal waste, sewage, and fertilizers (Florida Department of Environmental Protection, 2005), which readily leach to groundwater due to the karstic geology of the basin. Future spring discharges may reflect a newer type of input from reclaimed water application for both landscape irrigation and for direct recharge via rapid infiltration basins that have increased significantly within the past 10–15 years and continue to increase. The management solutions to reduce nitrate pollution include educating the public to use fewer chemicals and apply these with greater care, development and application of agricultural best management practices, and increasing the use of central sewage treatment facilities in place of on-site systems such as septic tanks.

Recent data suggest that increases in dissolved chlorides in the springwaters may be related to sea level rise and groundwater withdrawals (Florida Department of Environmental Protection, 2005). To date, salinity changes in the Wekiva Basin springs are minor and the causes are unclear. Major increases in the salinity (increased chlorides) in the springwater would have significant impacts on the ecosystems of the WSR. Continued monitoring and further research are needed to determine the source of the chlorides (*e.g.*, recharge from polluted surface water or mixing with saltwater from below the Upper Floridan aquifer) and how to manage land and water to limit chlorides in the springflows.

Exotic plants are a major problem stressing ecosystems in the Wekiva WSR corridor. For example, wild taro (*Colocasia esculentum*) has infested Rock Springs Run and the lagoon area of Wekiwa Springs has hydrilla (*Hydrilla verticillata*), water hyacinth (*Eichhornia carssipes*), and water lettuce (*Pistia stratiotes*). The park managers use a combination of herbicides and manual labor to control invasive plant species (Florida Department of Environmental Protection, 2005).

Drought-related stress in upland areas has increased the vulnerability of trees to pest species, the Southern pine beetle (*Dendroctomus frontalis*) in particular. Infestations have prompted park managers to clear-cut infested stands and buffers to limit the spread of the beetles. Without these interventions, dead trees would contribute significant fuel, increasing the potential for destructive forest fires.

6.4.1.2 Potential Effects of Climate Change on Ecosystems and Current Management Practices

For Central Florida, climate change models project average temperatures rising by perhaps 2.2–2.8°C and annual rainfall to total about the same as it does today (University of Arizona, Environmental Studies Laboratory, 2007). However, the late summer and fall rainy season may see more frequent tropical storms and hurricanes, overwhelming the current storm water management infrastructure and resulting in periodic surges of surface water with significant pollution and sedimentation loads. More runoff also means less recharge of the aquifer.

At other times of the year, droughts may be more frequent and of longer duration, leading to water shortages and increased withdrawals from the aquifer, which may reduce spring flows.

While there is only moderate confidence in predictions of changes in patterns of precipitation, there is a high confidence that it will get warmer. Warmer temperatures over an extended period will change species composition in the WSR corridor. Some native species, particularly those with limited ranges, may no longer find suitable habitat, while invasive exotics, which often tolerate a broad range of conditions, would thrive. Current programs to control invasive species would face new challenges as some native species are lost and replaced by species that favor the warmer climate, particularly for terrestrial species. Where the cold spring waters can moderate water temperature in the streams and river, the current control programs for aquatic invasive species may still be successful in a moderately warmer climate.

Climate change scenarios project sea level rising between 0.18–0.59 m by 2099 (IPCC, 2007a). There are two issues related to potential sea level rise relative to the Wekiva WSR: 1) how would changes in the tidal reach of the St. Johns River affect the Wekiva, and 2) how might the rising sea level affect the aquifer that supports the springflows? There are too few data available to answer these questions.

Finally, projected population increases in the Wekiva Basin and associated aquifer recharge area will add to the burden of managing for climate change impacts on water resources. Suburban expansion increases impermeable surfaces, thereby adding to polluted surface water runoff and reducing aquifer recharge. And groundwater will continue to be extracted for the public and recreational uses.

6.4.1.3 Potential for Altering/Supplementing Current Management to Enable Adaptation to Climate Change

Future management adaptations for meeting ecosystem goals in the Wekiva WSR should include monitoring ecosystem health, including water quantity and quality; basin-wide modeling to protect future management needs; and implementation of management programs in advance of climatic changes. The water management district and other land management agencies have robust monitoring programs, though they may not be adequate to understand the complexity of applying reclaimed surface water in a the karst uplands. Current groundwater monitoring, which focuses on salinity, may need to be expanded to better understand how nitrates and other nutrients are transported to the springflows. Increasingly refined models are needed to understand how water and ecosystems in the Wekiva Basin respond to management.

In many ways, it appears that the SJRWMD and local government agencies are beginning to implement management programs that would be needed to maintain ecological processes in the Wekiva WSR in a climate change scenario. Aquifer management is widely recognized as among the most critical tools for ensuring public water supplies and ecological integrity of the Wekiva WSR. Most of the drinking water in and around the Wekiva Basin is extracted from the Floridan aquifer—the same water source for the springflows that are essential to ecosystems of the Wekiva WSR. The Floridan aquifer is a water reservoir that can be managed in ways analogous to a reservoir behind a dam. Like a dam, with each rain event, to the extent permitted by surface conditions, the aquifer is recharged; water otherwise runs into streams and rivers, effectively lost for most public uses and often negatively affecting riverine ecosystems. Different from a dam, aquifer recharge and replenishment operate in a delayed time frame. This characteristic makes reversal of any mitigation measures a slow process, and should be considered in adaptation planning for global climate changes. Recognizing these conditions, programs and plans are in place to minimize surface runoff and maximize groundwater recharge. Programs include, for example, minimizing impermeable surfaces (*e.g.*, roofs, driveways, and roads), and holding surface water in water gardens and artificial ponds.

Recharge water must be of sufficiently good quality in order to not adversely affect the WSR system. Current stormwater management programs, while quite good, are focused on capturing surface water runoff to prevent it from degrading water quality, but this then “re-routes” poor-quality water from a surface water load to a ground water load. The sandy soils and karst geology of the area may result in nitrate-loaded water recharged to the aquifer and then to the springs. There is a great deal to learn about the ultimate effects on groundwater quality of applying reclaimed water to land surface in the karstic uplands.

While the human population in the Wekiva Basin is expected to grow, climate change models suggest that annual rainfall will remain about the same over the next 100 years, presenting a challenge for meeting water demand. In response, programs in the basin are under development to conserve water (reduce water use per person) and to develop “new” water sources (hold and use more surface water). Similarly, programs are also being planned and implemented to reduce pollution, including educating the public and commercial users about what, when, and how to apply chemicals, including nitrate-based fertilizers.

Management adaptations to more intense rain events under climate change conditions would require more aggressive implementation of all these programs, to: maximize recharge of the aquifer during rain events, minimize withdrawals at all times and particularly during droughts, minimize pollution of surface water and groundwater, and monitor and prevent salt water intrusion in the surface water-groundwater-seawater balance system. Considering the importance of water to local residents and as a factor driving economic development, there is considerable political will to invest in water management technologies and programs in the Wekiva Basin. Through this century, current and emerging technologies will likely be adequate for meeting the water needs for human consumption and ecosystem services in the Wekiva Basin, if people are willing to make the investment in technologies and engineering and to allocate enough water to maintain ecosystems.

6.4.2 Rio Grande Case Study

The Rio Grande, the second largest river in the American Southwest, rises in the snow-capped mountains of southern Colorado, flows south through the San Luis Valley, crosses into New Mexico and then flows south through Albuquerque and Las Cruces to El Paso, Texas, on the U.S.-Mexican border (see Figs. 6.20 and 6.21). A major tributary, the Rio Conchos, flows out of Mexico to join the Rio Grande below El Paso at Presidio and supplies most of the river’s flow for the 1,254 miles of river corridor along the Texas-Mexico border. Since 1845, the Rio Grande has marked the boundary between Mexico and the United States from the twin border cities of Ciudad Juárez and El Paso to the Gulf of Mexico.

Figure 6.20. The Wild and Scenic portions of the Rio Grande WSR in New Mexico. Data from USGS, National Atlas of the United States (2005).

Figure 6.21. The Wild and Scenic portions of the Rio Grande WSR in Texas. Data from USGS, National Atlas of the United States (2005).

Three different segments of the Rio Grande that total 259.6 miles of stream have been designated as Wild, Scenic, and Recreational. Part of the 68.2-mile segment of the river south of the Colorado-New Mexico border was among the original eight river corridors designated as wild and scenic at the time of the system's creation in 1968. A total of 53.2 miles of this reach are designated as wild, passing through 800-foot chasms of the Rio Grande Gorge with limited development. This segment is administered by the Bureau of Land Management and the U.S. Forest Service (National Wild and Scenic Rivers System, 2007b). About 97% of the land in the New Mexico WSR management zones is owned and managed by BLM or the USFS.

The longest segment of the Rio Grande WSR comprises 195.7 river miles in Texas (National Park Service, 2004) along the U.S.-Mexico border, with about half of this stretch classified as wild and half as scenic. This stretch, which was added to the system in 1978, is administered by the National Park Service at Big Bend National Park for the purpose of protecting the "outstanding remarkable" scenic, geologic, fish and wildlife, and recreational values (National Park Service, 2004). Land ownership is evenly divided between private and public (federal and state) owners on the United States side of the designated river segment.

In New Mexico, objectives for managing the WSR include (Bureau of Land Management, 2000):

- maintain water quality objectives designated by the New Mexico Environment Department
- conserve or enhance riparian vegetation
- preserve scenic qualities
- provide for recreational access, including boating and fishing
- protect habitat for native species, particular federally listed species

In Texas, the resource management goals for the wild and scenic river include (National Park Service, 2004):

- preserve the river in its natural, free-flowing character
- conserve or restore wildlife, scenery, natural sights and sounds
- achieve protection of cultural resources
- prevent adverse impacts on natural and cultural resources
- advocate for scientifically determined suitable instream flow levels to support fish and wildlife populations, riparian communities and recreational opportunities
- maintain or improve water quality to federal and state standards

The Rio Grande WSR was selected for a case study because the distinct segments of the designated river provide examples of features typical of many rivers in the mountainous and arid SW. Attributes important to this paper include: significant federal and state ownership of the streamside in designated segments; an important influence of snowpack on river flow; complex water rights issues with a great deal of water being extracted upstream of the WSR; primary competition for water by agriculture; and an international component.

6.4.2.1 Current Stressors and Management Methods Used to Address Them

The primary stressors of the Rio Grande WSR include (Bureau of Land Management, 2000; National Park Service, 2004; New Mexico Department of Game and Fish, 2006):

- Altered Hydrology: Impoundment, reservoir management and water extraction have led to flow reductions and changes in flow regime (loss of natural flood and drought cycle) and concomitant changes in the sediment regime and channel narrowing;

- Altered Land Use: Land and water use for agriculture, mining operations, and cities is leading to declines in water quality due to pollution and sedimentations;
- Invasive Species: Non-native fish and vegetation are altering ecosystems, displacing native species and reducing biodiversity, giant reed and saltcedar are particularly problematic in the Texas WSR segment; and
- Recreational Users: Visitors and associated infrastructure impact the riparian vegetation and protected species; subdivision and building on private lands along the Texas and Mexico segments threatens scenic values and may increase recreational users' impacts.

All segments of the Rio Grande that are designated as WSR face complex management challenges and multiple stressors on river health, most notably from dams, diversions and other water projects that dot the river and its tributaries, reducing and altering natural flows for much of the river's length. (Fig. 6.22) Although there are no dams on the main stem of the river upstream of the New Mexico WSR corridor, dams and other water projects on major tributaries affect flows downstream. For example, two Bureau of Reclamation projects in Colorado—the Closed Basin (groundwater) Project and the Platoro Dam and Reservoir on the Conejos River—influence downstream flows into New Mexico. Flow regime of the WSR in New Mexico is largely managed by the Bureau of Reclamation, which manages upstream dam and diversion projects based on a century of water rights claims and seasonal fluctuations in available water. The water rights and dams are considered integral to the baseline condition for the WSR, as they were in place prior to the river's designation.

Figure 6.22. Dams and diversions along the Rio Grande (Middle Rio Grande Bosque Initiative, 2007).

Downstream from El Paso, Texas, the channel of the Rio Grande is effectively dry from diversion for about 80 miles. Because of this "lost reach," the river is more like two separate rivers than one, with management of the Colorado and New Mexico portion having little effect on flows downstream of El Paso. In the past, the river in Colorado and New Mexico normally received annual spring floods from the melting snowpack while the river below Presidio, Texas received additional flood events in the summer through fall from rains in the Rio Conchos Basin, Mexico. However, throughout the Rio Grande these natural cycles of annual floods have been severely disrupted by dams and water extraction.

Management of the Texas Rio Grande WSR still depends on flows entering from Mexico—including the Rio Conchos, which provides 85% of the water to this WSR segment—and which is managed by the International Boundary and Water Commission according to the Rio Grande Compact. Instream flows in Texas segments of the WSR have decreased 50% in the past 20 years (National Park Service, 2004). During drought years of the late 1990s and into 2004, Mexico did not meet its obligations to the United States under the compact and water levels reached critical lows (Woodhouse, 2005). In 2003, the combination of dams, water extraction and drought were particularly hard on the river, flow essentially ceased, the river became a series of pools in Texas WSR segments and the river failed to reach the ocean (Garrett and Edwards, In Press).

Inefficient regulation of groundwater contributes to these impacts on the river's flow. The primary source of household water in central New Mexico is groundwater, for which the rate of extraction currently exceeds recharge (New Mexico Office of State Engineer and Interstate Stream Commission, 2006). Aquifers in the region may not be able to meet demand in twenty years, which will further stress an overburdened surface water resource.

Changes in the flow regime of the river are affecting the channel, the floodplain, and the associated aquatic and riparian ecosystems. In the past 90 years, overall stream flow has been reduced more than 50%, and periodic flooding below Presidio has been reduced by 49% (Schmidt, Everitt, and Richard, 2003). Dams in the lower Rio Grande prevent fish migrations so that Atlantic Sturgeon and American Eel no longer reach the WSR (National Park Service, 2007). Where native species were dependent on or tolerant of the periodic floods, the new flow regime is apparently giving an edge to invasive, non-native species (National Park Service, 1996). Garrett and Edwards (In Press) suggest that changes in flow and sedimentation, pollution, simplification of channel morphology and substrates, and increased dominance of non-native plant species can explain recent changes in fish diversity and critical reductions and local extinctions of fish species. Giant reed *(Arundo donax*) and salt cedar *(Tamarix* sp.) are particularly problematic as these exotic species invade the channelized river and further disrupt normal sedimentation, thereby reducing habitats critical to fish diversity (Garrett and Edwards, In Press). The problems of dams and irregular flows are complicated by local and international water rights issues, and the ecological health of WSR is only one of the many competing needs for limited water resources.

To address pollution issues, BLM, USFS, and NPS managers have reduced pollution to the river from their operations by reducing or eliminating grazing and mining near the river, improving management of recreation sites, and increasing education and outreach. However, as with flow regime, most of the water quality problems are tied to decreases in water quantity and discharge from large-scale agricultural, industrial and urban upstream users.

Federal land managers are making a difference where they can with site-level management. For example, riparian zones are being withdrawn from grazing and mineral leases and are being protected via limited access to sensitive sites and education of backcountry visitors about the values of protected streamside vegetation. Programs are also underway to control erosion in recreation areas and river access points and to improve habitat for protected species (Bureau of Land Management, 2000).

6.4.2.2 Potential Effects of Climate Change on Ecosystems and Current Management Practices

According to Schmidt et al. (2003) the primary drivers of ecosystem change of the Rio Grande are:

- Climatic changes that change runoff and influx of sedimentation
- Dam management and water extraction that lead to changes in flow regime (loss of natural flood and drought cycle) and sedimentation
- Changes to the physical structure of the channel and floodplain
- Introduction of exotic species
- Ecosystem dynamics that cause species to replace other species over time

The American Southwest in general, including the Rio Grande watershed, seems likely to experience climate extremes in the form of higher temperature, reduced precipitation (including reduced snowpacks), earlier spring melts, and recurring droughts on top of population growth and other existing stressors (New Mexico Office of State Engineer and Interstate Stream Commission, 2006). While global climate models are inconclusive regarding changes in precipitation for this region, and for the Upper Rio Grande Basin in particular, it seems likely that the projected increase in temperature will result in evaporation rates that more than offsets any possible increase in precipitation (New Mexico Office of State Engineer and Interstate Stream Commission, 2006). In this scenario, the New Mexico WSR segment of the Rio Grande might experience earlier spring floods, with reduced volume and more erratic summer rains (New Mexico Office of State Engineer and Interstate Stream Commission, 2006). Projections of perhaps 5% decrease in annual precipitation for the middle and lower Rio Grande (see Fig. 6.13) combined with higher temperatures (see Fig. 6.12) suggest that annual flows in the Texas WSR segment may be further reduced, and during severe droughts the water levels may decline to critical levels as has been the case in recent years (National Park Service, 2004). Water quality may be further reduced as the shallower water is susceptible to increased warming due to higher temperatures driven by climate change (Poff, Brinson, and Day, Jr., 2002). These conditions would negatively affect many native species and may favor invasive non-native species, further complicating existing programs to manage for native riparian vegetation and riverine ecosystems (National Park Service, 2004; New Mexico Office of State Engineer and Interstate Stream Commission, 2006).

6.4.2.3 Potential for Altering / Supplementing Current Management to Enable Adaptation to Climate Change

The incorporation of climate change impacts into the planning and management of the WSR corridors of the Rio Grande is complicated by the river's international character, the numerous dams, diversions, and groundwater schemes that already affect its flow regime, and the multiple agencies involved in the river's management within the WSR corridors as well as upstream and downstream. Sustaining the Rio Grande's wild and scenic values under these circumstances will require planning, coordination, monitoring of hydrological trends, and scenario-based forecasting to help river managers anticipate trends and their ramifications. For example, given the probability of reduced snowpack in the headwaters of the Rio Grande, sustaining flows through the New Mexico WSR corridor will likely depend on coordination among the USFS and BLM, which administer this WSR stretch, the Bureau of Reclamation, which manages upstream water projects (both groundwater and surface water) that influence downstream flows, and owners of local and international water rights. Long standing water rights complication any predictions of water releases to mimic natural flow regime. In this region, required water deliveries might be met by transferring water rights between watersheds or through credits for future water delivery.

Similarly, the NPS, which administers the Rio Grande WSR corridor in Texas, needs to coordinate with the International Boundary and Water Commission to extract ecological services from regulated flows. This may prove more difficult than securing water for the river in New Mexico. During recent years of drought, Mexico did not meet its obligations to the United States under the compact. With droughts of greater duration expected as temperatures warm, more years of difficulty meeting treaty obligations may arise.

Economic incentives are another approach to securing sufficient clean water needed to meet management objectives of the WSR. Recognizing the value of ecological services, one potential measure, for instance, is to purchase or lease water rights for the river. Additionally, technical assistance and incentives could also be provided to users who improve water efficiency, reduce pollution, and release surplus clean water to the river. Water deliveries could mimic natural flows, including scouring floods to build the channel.

Improving efficiency of agricultural and urban water use and increasing re-use to conserve water and reduce pollution are probably the most cost-effective strategies to make more clean water available in the Rio Grande. If improved water efficiency results in "new" water, the challenge for WSR managers will be to negotiate, purchase or lease water for the river when it is most needed for ecological flows.

6.4.3 Upper Delaware River Case Study

The Delaware River runs 330 miles from the confluence of its East and West branches at Hancock, N.Y. to the mouth of the Delaware Bay. Established by Congress in 1978, the Upper Delaware Scenic and Recreational River consists of 73.4 miles (32.1 miles designated as scenic and 50.3 miles as recreational) of the Delaware River between Hancock and Sparrow Bush, New York, along the Pennsylvania-New York border. Although this case study focuses on the Upper Delaware, there are also 35 miles designated as scenic in the Middle Delaware River in the Delaware Water Gap National Recreational Area and 67.3 miles of Delaware River and tributaries (25.4 scenic and 41.9 recreational) in the Lower Delaware Scenic and Recreational River (Fig. 6.23).

Figure 6.23. Map of Wild and Scenic stretches in the Delaware River basin. Courtesy of Delaware River Basin Commission (Delaware River Basin Commission, 2007).

The Upper Delaware Scenic and Recreational River boasts hardwood forests covering over 50% of the river corridor (Conference of the Upper Delaware Townships, 1986). These forests provide lush habitat for diverse fauna including at least 40 species of mammals, such as many of Pennsylvania's remaining river otters and one of the largest populations of black bear in the state. It is one of the most important inland bald eagle wintering habitats in the northeastern United States. Water quality in the Upper Delaware is exceptional and supports abundant cold- and warm-water fish. As the last major river on the Atlantic coast undammed throughout the entire length of its mainstem, the Delaware provides important habitat for migratory fish such as American eel and America shad. In the upper reaches of the Delaware system, rainbow and brown trout are highly sought by anglers. The river and its surrounding ecosystems provide a beautiful setting for recreation including fishing, boating, kayaking, sightseeing and hiking.

The Upper Delaware Scenic and Recreational River includes a 55,575 acre ridge-top-to- ridge-top (approx. ½ mile wide) corridor, nearly all privately held. The National Park Service (NPS) has jurisdiction over 73.4 miles of the river, including a "strand" area along its banks (up to the mean high water mark), but owns only 31 acres within the corridor (Conference of the Upper

Delaware Townships, 1986). While the Delaware's main stem remains free flowing, New York City has constructed three reservoirs on major tributaries (the East and West Branches of the Delaware River and the Neversink River) to provide drinking water for more than 17 million people. New York City gets the majority of its water—in fact, its best quality water—from these Catskill reservoirs.

The negligible public ownership, complex private ownership, and significant extraction of water for New York City require that the Upper Delaware be managed as a "Partnership River." The National Park Service, the Upper Delaware Council (*e.g.*, local jurisdictions), the Delaware River Basin Commission (DRBC, which manages the water releases), the Commonwealth of Pennsylvania, and the State of New York collaborated in preparing the River Management Plan (Conference of the Upper Delaware Townships, 1986) and collaborate in managing the river.

The goals described in the River Management Plan include maintaining or improving water quality and aquatic ecosystems, providing opportunities for recreation, and maintaining scenic values of river corridor and selected historic sites. The rights of private land owners are described in great detail and heavily emphasized throughout the plan, while management actions essential to maintain ecosystem services are more generalized.

The Upper Delaware was chosen as a case study because it exemplifies river ecology for the northeast and management challenges typical of the region, including a significant human population, intense water extraction for enormous urban centers, and its status as a "Partnership River."

6.4.3.1 Current Stressors of Ecosystems and Management Methods Used to Address Them

The primary ecosystem stressors in the Upper Delaware include water extraction and unnatural flow regimes associated with reservoir management. Water quality, water temperature, fish and other river biota are negatively affected by these stressors (Mid-Atlantic Regional Assessment Team, 2000). In 2004 to 2006 unusually frequent and severe flooding—three separate hundred-year flood events in a 22-month period—further stressed the river system and added to the management challenges (Delaware River Basin Commission, 2006).

Water managers in the Delaware Basin are addressing at least four priority issues: (1) provision of drinking water for major metropolitan areas, (2) flood control, (3) biotic integrity and natural processes of the WSR, and (4) recreation activities, including coldwater fisheries. New York City takes about half of the water available in the Upper Delaware River Basin above the designated WSR. Hence, the primary mechanism remaining to manage the flow regime, water quality, and river ecology and processes in the WSR is dam management, and the secondary mechanism is improved surface water management throughout the Upper Basin. Considering the volume of water extracted, water released from the reservoirs is, overall, significantly below historic flows. Furthermore, while goals for *annual* average releases are met, they do not always conform to the periodicity that stream biologists and anglers say are required for native species and ecological processes. When too little water is released, particularly in the spring and summer, water temperature increases beyond optimal conditions for many species, and pollutants are more concentrated. Aquatic invertebrates decline, trout and other species up the food chain are negatively affected and tourism based on river boating and anglers suffers (Parasiewicz, Undated).

Water is also released from the Upper Delaware reservoirs to help maintain river levels adequate to prevent saltwater intrusion from Delaware Bay up river. During droughts in the past 50 years, the “salt front” has moved up river considerably. This intrusion may play a role in the conversion of upland forest areas to marshes, which could affect adjacent river ecosystems (Partnership for the Delaware Estuary, 2007). The saltwater is problematic for industries using water along the river front and increases sodium in the aquifer that supplies water to Southern New Jersey. Water conservation in the Delaware Basin and New York City has significantly helped address drought-related water shortages.

Flood control and water quality in the Upper Basin are managed through restoration of stream banks, riparian buffers and floodplain ecosystems and through improved land and water management. The Delaware River Basin Commission sets specific objectives for ecosystem management in the basin (Delaware River Basin Commission, 2004). Land use along the river is regulated by Township (PA) and Town (NY) zoning regulations, which are influenced by state regulations and requirements to qualify for FEMA flood insurance. The NPS and other partners work with the towns and townships to promote, through planning and zoning, maintenance of native vegetation in the floodplain and river corridor and to improve storm water management throughout the watershed.

The NPS and state agencies also manage river recreation, providing access to boaters and hikers and regulating their impacts. Following recent floods, agencies assisted with evacuation of residents in low-lying flood-prone areas; evacuated their own boats, vehicles, and equipment to higher ground; and mobilized post-flood boat patrols to identify hazardous materials (*e.g.*, propane tanks, etc.) left in the floodway and hazards to navigation in the river channel.

NPS and others are beginning to work more closely with the National Weather Service to provide them with data on local precipitation amounts, snowpack, and river ice cover, and to coordinate with their Advanced Hydrologic Prediction Service to enable better forecasting and advanced warning to valley residents of flood crests and times.

6.4.3.2 Potential Effects of Climate Change on Ecosystems

Climate in the Delaware Basin can be highly variable, sometimes bringing severe winter ice storms and summer heat-waves. However, there has been a steady increase in mean temperature over the last 50 years as well as an increase in precipitation (Lins and Slack, 1999; Rogers and McCarty, 2000; Najjar *et al.*, 2000). The expectations are for this pattern to continue and, in particular, for there to be the potential for less snowpack that melts earlier in the spring, and rain in the form of more intense rain events that may create greater fluctuations in river levels and greater floods. Severe flood events will likely continue to disrupt the river channel and impact floodplain ecosystems. Furthermore, during periodic droughts there will be increased potential for combinations of shallower water and warmer temperatures, leading to significantly warmer water that cold be especially damaging to coldwater invertebrates and fish. It is possible that dam management could offset this warming if water can be drawn from sufficient depths in the reservoir (*e.g.*, with a temperature control device on the dam).

As with any river system, such climate-induced changes in environmental conditions may have serious ecological consequences, including erosion of streambanks and bottom sediments that may decrease the availability of suitable habitat, shifts in the growth rate of species due to thermal and flood-related stresses, and unpredictable changes in ecological processes such as carbon and nitrogen processing (see section 6.3.3).

6.4.3.3 Potential for Altering or Supplementing Current Management to Enable Adaptation for Climate Change

Management of the reservoir levels and dam releases are the most direct methods to maintain riverine ecosystems under increased burdens of climate change. The DRBC Water Resource Program report for 2006–2012 (Delaware River Basin Commission, 2006) identifies the current water management issues for the Basin and their program to address the challenges, including a river flow management program to ensure human and ecosystem needs (Delaware River Basin Commission, 2006). A major thrust of the Commission's program is research and modeling to help find a balanced approach to managing the limited water resources. This approach of establishing flow regime based on sound scientific data, with models and projects extended over decades will serve well in a future impacted by climate change.

Improved watershed management to reduce aberrant flood events and minimize water pollution is one of the most useful long-term tools for managing river resources in a changing climate (Mid-Atlantic Regional Assessment Team, 2000). Federal, state and local authorities can create incentives and pass ordinances to encourage better water and land use that protect the river and its resources. For example, improved efficiency of water use and storm water management (*e.g.*, household rain barrels and rain gardens, holding ponds), improved use of agrochemicals and soil management, and restoration of wetlands and riparian buffers would combine to reduce severity of floods, erosion damage and water pollution.

Finally, continual improvements in municipal and household water conservation are among the most promising approaches to manage water in the Delaware River Basin. Populations in and around the Delaware Basin will grow, increasing demand on water supplies and river access for recreational uses. Per capita water use in New York City has declined from more than 200 gallons per capita per day around 1990 to 138 gallons per capita per day in 2006 (New York City Department of Environmental Protection, 2006). Water pricing can be use to promote further conservation (Mid-Atlantic Regional Assessment Team, 2000). An important component of this approach is educating the public so that consumers better understand the important role that water conservation plays in protecting river ecosystems and future water supplies.

6.5 Conclusions

The WSR System was created to protect and preserve the biological, ecological, historic, scenic and other "remarkable" values of the nation's rivers. These assets are increasingly at risk due to land-use changes, population growth, pollution discharges, flow-altering dams and diversions, excessive groundwater pumping, and other pressures within watersheds and river systems. Climate change adds to and magnifies these risks through its potential to alter rainfall, temperature, and runoff patterns, as well as to disrupt biological communities and sever ecological linkages in any given locale. Thus, the anticipation of climate change effects requires a proactive management response if the nation's valuable river assets are to be protected.

In a world of limited budgets, it may not be possible to implement all of the measures identified in the previous section and summarized in Box 6.5. But given limited financial and human resources, the highest priorities for the protection of WSR assets under conditions of climatic change are the following:

- Increase monitoring capabilities in order to acquire adequate baseline information on water flows and water quality, thus enabling river managers to prioritize actions and evaluate effectiveness.

- Increase forecasting capabilities and develop comprehensive scenarios so that the spectrum of possible impacts, and their magnitude, can reasonably be anticipated.

- Build flexibility and adaptive capacity into the CRMPs for WSRs, and update these plans regularly to reflect new information and scientific understanding.

- Strengthen collaborative relationships among federal, state, and local resource agencies and stakeholders to ease the implementation of adaptive river management strategies.

- Keep stakeholders informed, concerned, and engaged in what the WSR administering agencies are doing to protect the outstandingly remarkable values of the nation's rivers as climate change impacts unfold.

6.6 References

Ahearn, D.S., R.W. Sheibley, and R.A. Dahlgren, 2005: Effects of river regulation on water quality in the lower Mokelumne River, California. *River Research and Applications*, **21(6)**, 651-670.

Alcamo, J., P. Doell, T. Henrichs, F. Kaspar, B. Lehner, T. Roesch, and S. Siebert, 2003: Global estimates of water withdrawals and availability under current and future "business-as-usual" conditions. *Hydrological Sciences Journal*, **48(3)**, 339-348.

Alcamo, J., M. Flörke, and M. Märker, 2007: Future long-term changes in global water resources driven by socio-economic and climatic changes. *Hydrological Sciences Journal*, **52(2)**, 247-275.

Allan, J.D., 1995: *Stream Ecology: Structure and Function of Running Waters*. Kluwer Academic Pub.

Allan, J.D., 2004: Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution and Systematics*, **35**, 257-284.

Allan, J.D. and A.S. Flecker, 1993: Biodiversity conservation in running waters. *BioScience*, **43(1)**, 32-43.

Allan, J.D., M. A. Palmer, and N. L. Poff, 2005: Freshwater ecology, In: *Climate Change and Biodiversity*, [Lovejoy, T.E. and L. Hannah (eds.)]. Yale University Press, New Haven.

Arnold, C.L., Jr. and C.J. Gibbons, 1986: Impervious surface coverage: the emergence of a key environmental indicator. *Journal of the American Planning Association*, **62(2)**, 243-258.

Auch, R., J. Taylor, and W. Acevedo, 2004: *Urban Growth in American Cities*. U.S. Geological Survey Circular 1252, US Geological Survey, EROS Data Center, Reston, VA.

Bachelet, D., R.P. Neilson, J.M. Lenihan, and R.J. Drapek, 2001: Climate change effects on vegetation distribution and carbon budget in the United States. *Ecosystems*, **4**, 164-185.

Barker, R., 1999: Saving fall Chinook could be costly. The Idaho Statesman, http://www.bluefish.org/saving.htm, accessed on 2-9-2006.

Baron, J.S., H.M. Rueth, A.M. Wolfe, K.R. Nydick, E.J. Allstott, J.T. Minear, and B. Moraska, 2000: Ecosystem responses to nitrogen deposition in the Colorado Front Range. *Ecosystems*, **3(4)**, 352-368.

Baron, J.S., N.L. Poff, P.L. Angermeier, C.N. Dahm, P.H. Gleick, N.G. Hairston, Jr., R.B. Jackson, C.A. Johnston, B.D. Richter, and A.D. Steinman, 2002: Meeting ecological and societal needs for freshwater. *Ecological Applications*.

Battin, J., M.W. Wiley, M.H. Ruckelshaus, R.N. Palmer, E. Korb, K.K. Bartz, and H. Imaki, 2007: Projected impacts of climate change on salmon habitat restoration. *Proceedings of the National Academy of Sciences of the United States of America*, **104(16)**, 6720.

Beitinger, T.L., W.A. Bennett, and R.W. McCauley, 2000: Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. *Environmental Biology of Fishes*, **58**, 237-275.

Bergkamp, G., B. Orlando, and I. Burton, 2003: *Change: Adaptation of Water Management to Climate Change*. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland and Cambridge, UK.

Bledsoe, B.P. and C.C. Watson, 2001: Effects of urbanization on channel instability. *Journal of American Water Resources Association*, **37**, 255-270.

Brown, B.L., 2003: Spatial heterogeneity reduces temporal variability in stream insect communities. *Ecology Letters*, **6(4)**, 316-325.

Bunn, S.E. and A.H. Arthington, 2002: Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, **30(4)**, 492-507.

Bureau of Land Management, 2000: *The Rio Grande Corridor Final Plan*. U.S. Department of Interior, pp.1-54.

Clarkson, R.W. and M.R. Childs, 2000: Temperature effects of hypolimnial-release dams on early life stages of Colorado River basin big-river fishes. *Copeia*, **2000(2)**, 402-412.

Climate Impacts Group, University of Washington, 2004: *Overview of Climate Change Impacts in the U.S. Pacific Northwest*. Climate Impacts Group, University of Washington, Seattle.

Collier, M., R.H. Webb, and J.C. Schmidt, 1996: *Dams and Rivers: a Primer on the Downstream Effects of Dams*. U.S. Geological Survey, Denver, CO.

Conference of the Upper Delaware Townships, 1986: *Final Management Plan: Upper Delaware Scenic and Recreational River*. pp.1-197.

Delaware River Basin Commission, 2004: *Water Resource Plan for the Delaware River Basin*. Delaware River Basin Commission, pp.1-100.

Delaware River Basin Commission, 2006: *Water Resource Program FY2006 – FY 2012*. Delaware River Basin Commission, pp.1-9.

Delaware River Basin Commission, 2007: Wild and Scenic Rivers map. Delaware River Basin Commission Website, http://www.state.nj.us/drbc/wild_scenic_map.htm, accessed on 7-20-2007.

Dunne, T. and L.B. Leopold, 1978: *Water in Environmental Planning*. W.H. Freeman and Co., San Francisco, pp. 1-818.

Dynesius, M., R. Jansson, M.E. Johansson, and C. Nilsson, 2004: Intercontinental similarities in riparian-plant diversity and sensitivity to river regulation. *Ecological Applications*, **14(1)**, 173-191.

Eaton, J.G. and R.M. Scheller, 1996: Effects of climate warming on fish thermal habitat in streams of the United States. *Limnology and Oceanography*, **41**, 1109-1115.

Ewert, S.E.D., 2001: Evolution of an environmentalist: Senator Frank Church and the Hells Canyon controversy. *Montana*, **51(Spring)**, 36-51.

Fitzhugh, T.W. and B.D. Richter, 2004: Quenching urban thirst: growing cities and their impacts on freshwater ecosystems. *BioScience*, **54(8)**, 741-754.

Florida Department of Community Affairs, 2005: *Guidelines for Preparing Comprehensive Plan Amendments for the Wekiva Study Area Pursuant to the Wekiva Parkway and Protection Act*. pp.1-50.

Florida Department of Environmental Protection, 2005: *Wekiva River Basin State Parks, Multi-Unit Management Plan*. pp.1-98.

Galbraith, H., D. Yates, D.D. Purkey, A. Huber-Lee, J. Sieber, J. West, S. Herrod-Julius, and B. Joyce, In Press: Climate warming, water storage, and chinook salmon in California's Sacramento Valley. *Climatic Change*.

Garrett, G.P. and R.J. Edwards, In Press: Changes in fish populations in the Lower Canyons of the Rio Grande. *Proceedings of the Sixth Symposium on Natural Resources of the Chihuahuan Desert Region, Chihuahuan Desert Research Institute*.

Gibson, C., 1998: *Population of the 100 Largest Cities and Other Urban Places in the United States: 1790-1990*. Population Division, U.S. Bureau of the Census, Washington, D.C.

Hassol, S.J., 2004: *Impacts of a Warming Arctic*. Cambridge University Press, Cambridge, UK.

Hilborn, R., T.P. Quinn, D.E. Schindler, and D.E. Rogers, 2003: Biocomplexity and fisheries sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, **100(11)**, 6564-6568.

Hill, W.R., 1996: Effects of light, In: *Algal Ecology: Freshwater Benthic Ecosystems*, [Stevenson, R.J., M.L. Bothwell, and R.L. Lowe (eds.)]. Academic Press, San Diego, California, pp. 121-149.

Hodgkins, G.A. and R.W. Dudley, 2006: Changes in the timing of winter-spring streamflows in eastern North America, 1913-2002. *Geophysical Research Letters*, **33(6)**.

Hutson, S.S., N.L. Barber, J.F. Kenny, K.S. Linsey, D.S. Lumia, and M.A. Maupin, 2004: Estimated use of water in the United States in 2000. *U. S. Geological Survey Circular 1268*.

Interagency Wild and Scenic Rivers Coordinating Council, 1996: *Protecting Resource Values on Non-Federal Lands*. National Wild and Scenic Rivers System.

Interagency Wild and Scenic Rivers Coordinating Council, 2002: *Wild & Scenic River Management Responsibilities*. National Wild and Scenic Rivers System.

Interagency Wild and Scenic Rivers Coordinating Council, 2003: *Water Quantity and Quality As Related to the Management of Wild & Scenic Rivers*. National Wild and Scenic Rivers System.

IPCC, 2007a: *Climate Change 2007: Impacts, Adaptation and Vulnerability*. *Summary for Policymakers*. Cambridge University Press, pp.1-22.

IPCC, 2007b: *Climate Change 2007: the Physical Science Basis. Summary for Policymakers*.

Knighton, D., 1998: *Fluvial Forms and Processes: a New Perspective*. Oxford University Press, New York.

Lehmkuhl, D.M., 1974: Thermal regime alterations and vital environmental physiological signals in aquatic systems, In: *Thermal Ecology*, [Gibbons, J.W. and R.R. Sharitz (eds.)]. AEC Symposium Series, CONF-730505, pp. 216-222.

Leopold, A., 1978: *A Sand County Almanac: With Essays on Conservation of Round River*. Ballantine Books, New York.

Lettenmaier, D.P., E.F. Wood, and J.R. Wallis, 1994: Hydro-climatological trends in the continental United States, 1948-88. *Journal of Climate*, **7(4)**, 586-607.

Ligon, F.K., W.E. Dietrich, and W.J. Trush, 1995: Downstream ecological effects of dams: a geomorphic perspective. *BioScience*, **45(3)**, 183-192.

Lins, H.F. and J.R. Slack, 1999: Streamflow trends in the United States. *Geophysical Research Letters*, **26(2)**, 227-230.

Loomis, J., J. Koteen, and B. Hurd, 2003: Economic and institutional strategies for adapting to water resource effects of climate change, In: *Water and Climate in the Western United States*, [Lewis, W.M., Jr. (ed.)]. University Press of Colorado, Boulder.

Lowe, R.L. and Y. Pan, 1996: Benthic algal communities as biological monitors, In: *Algal Ecology: Freshwater Benthic Ecosystems*, [Stevenson, R.J., M.L. Bothwell, and R.L. Lowe (eds.)]. Academic Press, San Diego, California, pp. 705-739.

Lytle, D.A. and N.L. Poff, 2004: Adaptation to natural flow regimes. *Trends in Ecology & Evolution*, **19(2)**, 94-100.

Magilligan, F.J., K.H. Nislow, and B.E. Graber, 2003: Scale-independent assessment of discharge reduction and riparian disconnectivity following flow regulation by dams. *Geology*, **31(7)**, 569-572.

McCabe, G.J. and M.P. Clark, 2005: Trends and variability in snowmelt runoff in the western United States. *Journal of Hydrometeorology*, **6(4)**, 476-482.

McCully, P., 1996: *Silenced Rivers: the Ecology and Politics of Large Dams*. Zed Books, London, U.K.

McGurk, B.E. and P.F. Presley, 2002: *Simulation of the Effects of Groundwater Withdrawals on the Floridan Aquifer System in East-Central Florida: Model Expansion and Revision*. St. Johns River Water Management District, pp.1-196.

McMahon, G. and T.F. Cuffney, 2000: Quantifying urban intensity in drainage basins for assessing stream ecological conditions. *Journal of the American Water Resources Association*, **36(6)**, 1247-1262.

Mid-Atlantic Regional Assessment Team, 2000: *Preparing for a Changing Climate: Mid-Atlantic Overview*. U.S. Global Change Research Program, U.S. Environmental Protection Agency and Pennsylvania State University.

Middle Rio Grande Bosque Initiative, 2007: Dams and diversions of the Middle Rio Grande. Middle Rio Grande Bosque Initiative Website, http://www.fws.gov/southwest/mrgbi/Resources/Dams/index.html, accessed on 5-17-2007.

Milly, P.C.D., K.A. Dunne, and A.V. Vecchia, 2005: Global pattern of trends in streamflow and water availability in a changing climate. *Nature*, **438(7066)**, 347-350.

Moyle, P.B. and J.F. Mount, 2007: Homogenous rivers, homogenous faunas. *Proceedings of the National Academy of Sciences of the United States of America*, **104(14)**, 5711-5712.

Murdoch, P.S., J.S. Baron, and T.L. Miller, 2000: Potential effects of climate change on surface-water quality in North America. *Journal of the American Water Resources Association*, **36(2)**, 347-366.

Naiman, R.J., H. Décamps, and M.E. McClain, 2005: *Riparia: Ecology, Conservation, and Management of Streamside Communities*. Elsevier Academic Press, San Diego, pp. 1-430.

Najjar, R.G., H.A. Walker, P.J. Anderson, E.J. Barron, R.J. Bord, J.R. Gibson, V.S. Kennedy, C.G. Knight, J.P. Megonigal, and R.E. O'Connor, 2000: The potential impacts of climate change on the mid-Atlantic coastal region. *Climate Research*, **14**, 219-233.

National Park Service, 1996: *Water Resources Management Plan - Big Bend National Park*. Department of Hydrology and Water Resources, Univ. of Arizona, Tucson, Big Bend National Park, Texas, and National Park Service - Water Resources Division, Fort Collins, CO, pp.1-163.

National Park Service, 1999: *Wekiva River, Rock Spring Run & Seminole Creek Wild and Scenic River Study*. US Department of Interior, pp.1-49.

National Park Service, 2004: *Rio Grande Wild and Scenic River: Final General Management Plan / Environmental Impact Statement.*

National Park Service, 2007: Floating the lower canyons. National Park Service, http://www.nps.gov/rigr/planyourvisit/lower_cyns.htm, accessed on 4-14-2007.

National Research Council, 1993: *Soil and Water Quality: an Agenda for Agriculture*. National Academy Press, Washington, D.C.

National Research Council, 2004: *Developing a Research and Restoration Plan for Arctic-Yukon-Kuskokwim (Western Alaska) Salmon*. Washington, D.C.

National Wild and Scenic Rivers System, 2007a: Homepage: National Wild and Scenic Rivers System. National Wild and Scenic Rivers System Website, http://www.rivers.gov, accessed on 5-30-2007a.

National Wild and Scenic Rivers System, 2007b: Rio Grande Wild and Scenic River, New Mexico. National Wild and Scenic Rivers System Website, http://www.rivers.gov/wsr-rio-grande-new-mexico.html, accessed on 5-17-2007b.

Nelson, K. and M. Palmer, 2004: Surviving in a warmer, more urban world: a spatially/temporally explicit habitat model for fish. In: *Ecological Society of America Annual Meeting.*

Nelson, K.C. and M.A. Palmer, 2007: Stream temperature surges under urbanization and climate change: data, models, and responses. *Journal of the American Water Resources Association*, **43(2)**, 440-452.

New Mexico Department of Game and Fish, 2006: *Comprehensive Wildlife Conservation Strategy for New Mexico*. New Mexico Department of Game and Fish, Santa Fe, New Mexico, pp.1-526.

New Mexico Office of State Engineer and Interstate Stream Commission, 2006: *The Impact of Climate Change on New Mexico's Water Supply and Ability to Manage Water Resources*. New Mexico Office of State Engineer/Interstate Stream Commission.

New York City Department of Environmental Protection, 2006: *Water Conservation Program*. pp.1-54.

Nowak, D.J. and J.T. Walton, 2005: Projected urban growth (2000-2050) and its estimated impact on the US forest resource. *Journal of Forestry*, **103(8)**, 383-389.

Olsen, S.B., T.V. Padma, and B.D. Richter, Undated: Managing freshwater inflows to estuaries: a methods guide.

Palmer, M., A.P. Covich, B.J. Finlay, J. Gibert, K.D. Hyde, R.K. Johnson, T. Kairesalo, S. Lake, C.R. Lovell, R.J. Naiman, C. Ricci, F. Sabater, and D. Strayer, 1997: Biodiversity and ecosystem processes in freshwater sediments. *Ambio*, **26(8)**, 571-577.

Palmer, M.A., E.S. Bernhardt, J.D. Allan, P.S. Lake, G. Alexander, S. Brooks, J. Carr, S. Clayton, C.N. Dahm, and J.F. Shah, 2005: Standards for ecologically successful river restoration. *Journal of Applied Ecology*, **42(2)**, 208-217.

Palmer, M.A., C.A. Reidy, C. Nilsson, M. Flörke, J. Alcamo, P.S. Lake, and N. Bond, In Press: Climate change and the world's river basins: anticipating management options. *Frontiers in Ecology and the Environment*.

Parasiewicz, P., Undated: Strategy for sustainable management of the Upper Delaware River basin.

Partnership for the Delaware Estuary, 2007: Partnership for the Delaware Estuary, a National Estuary Program homepage. Partnership for the Delaware Estuary Website, http://www.delawareestuary.org/, accessed on 7-12-2007.

Paul, M.J. and J.L. Meyer, 2001: Streams in the urban landscape. *Annual Review of Ecology and Systematics*, **32**, 333-365.

Pizzuto, J.E., G.E. Moglen, M.A. Palmer, and K.C. Nelson, In Press: Two model scenarios illustrating the effects of land use and climate change on gravel riverbeds of suburban Maryland, U.S.A. *Gravel Bed Rivers 6 - From Process Understanding to River Restoration*.

Poff, J.L., P. L. Angermeier, S. D. Cooper, P. S. Lake, K. D. Fausch, K. O. Winemiller, L. A. K. Mertes, and M. W. Oswood, 2006: Global change and stream fish diversity, In: *Future Scenarios of Global Biodiversity*, [Chapin III, F.S., O.E. Sala, and E. Huber-Sanwald (eds.)]. Oxford University Press, Oxford.

Poff, N.L., 2002: Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions: Mathematical, Physical & Engineering Sciences*, **360(1796)**, 1497-1510.

Poff, N.L. and J.V. Ward, 1990: Physical habitat template of lotic systems: recovery in the context of historical pattern of spatiotemporal heterogeneity. *Environmental Management*, **14(5)**, 629-646.

Poff, N.L.R., J.D. Olden, D.M. Merritt, and D.M. Pepin, 2007: Homogenization of regional river dynamics by dams and global biodiversity implications. *Proceedings of the National Academy of Sciences of the United States of America*, **104(14)**, 5732-5737.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R. Sparks, and J. Stromberg, 1997: The natural flow regime: a new paradigm for riverine conservation and restoration. *BioScience*, **47**, 769-784.

Poff, N.L., M.M. Brinson, and J.W. Day, Jr., 2002: *Aquatic Ecosystems & Global Climate Change:Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States*. Pew Center on Global Climate Change, pp.1-56.

Postel, S. and B. Richter, 2003: *Rivers for Life: Managing Water for People and Nature*. Island Press, Washington, DC.

Postel, S.L., 2007: Aquatic ecosystem protection and drinking water utilities. *Journal AWWA*, **99(2)**, 52-63.

Richter, B.D., J.V. Baumgartner, R. Wigington, and D.P. Braun, 1997: How much water does a river need? *Freshwater Biology*, **37(1)**, 231-249.

Richter, B.D., R. Mathews, D.L. Harrison, and R. Wigington, 2003: Ecologically sustainable water management: managing river flows for ecological integrity. *Ecological Applications*, **13(1)**, 206-224.

Rier, S.T., N.C. Tuchman, R.G. Wetzel, and J.A. Teeri, 2002: Elevated CO_2-induced changes in the chemistry of quaking aspen (*Populus tremuloides* Michaux) leaf litter: subsequent mass loss and microbial response in a stream ecosystem. *Journal of The North American Benthological Society*, **21**, 16-27.

Rogers, C.E. and J.P. McCarty, 2000: Climate change and ecosystems of the mid-Atlantic region. *Climate Research*, **14**, 235-244.

Sala, O.E., F.S. Chapin III, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L.F. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.M. Lodge, H.A. Mooney, M. Oesterheld, N.L. Poff, M.T. Sykes, B.H. Walker, M. Walker, and D.H. Wall, 2000: Global biodiversity scenarios for the year 2100. *Science*, **287**, 1770-1774.

Schmidt, J.C., B. L. Everitt, and G. A. Richard, 2003: Hydrology and geomorphology of the Rio Grande and implications for river rehabilitation, In: *Aquatic Fauna of the Northern Chihuahuan Desert.Museum of Texas Tech University*, [Garrett, G.P. and N.L. Allan (eds.)]. Museum of Texas Tech University, Special Publications, Lubbock, TX, pp. 25-45.

Shafroth, P.B., J.C. Stromberg, and D.T. Patten, 2002: Riparian vegetation response to altered disturbance and stress regimes. *Ecological Applications*, **12(1)**, 107-123.

Silk, N. and K. Ciruna, 2005: *A Practitioner's Guide to Freshwater Biodiversity Conservation*. Island Press, Washington, DC.

Smith, L.C., Y. Sheng, G.M. MacDonald, and L.D. Hinzman, 2005: Disappearing Arctic lakes. *Science*, **308(5727)**, 1429.

St. Johns River Water Management District, 2002: *Middle St. Johns River Basin Surface Water Improvement and Management Plan*. Palatka, Florida, pp.1-78.

St. Johns River Water Management District, 2006a: *Middle St. Johns River Basin Initiative: Fiscal Year 2007-2008*. Palatka, Florida, pp.1-22.

St. Johns River Water Management District, 2006b: *Water Supply Assessment and Water Supply Plan*. Palatka, Florida, pp.1-4.

Stewart, I.T., D.R. Cayan, and M.D. Dettinger, 2004: Changes in snowmelt runoff timing in Western North America under a 'business as usual' climate change scenario. *Climatic Change*, **62**, 217-232.

Stewart, I.T., D.R. Cayan, and M.D. Dettinger, 2005: Changes toward earlier streamflow timing across western North America. *Journal of Climate*, **18(8)**, 1136-1155.

Thuiller, W., 2004: Patterns and uncertainties of species' range shifts under climate change. *Global Change Biology*, **10(12)**, 2020-2027.

Tockner, K. and J.A. Stanford, 2002: Riverine flood plains: present state and future trends. *Environmental Conservation*, **29(3)**, 308-330.

Todd, C.R., T. Ryan, S.J. Nicol, and A.R. Bearlin, 2005: The impact of cold water releases on the critical period of post-spawning survival and its implications for Murray cod (*Maccullochella peelii peelii*): a case study of the Mitta Mitta river, south-eastern Australia. *River Research and Applications*, **21**, 1035-1052.

Tuchman, N.C., K.A. Wahtera, R.G. Wetzel, and J.A. Teeri, 2003: Elevated atmospheric CO_2 alters leaf litter quality for stream ecosystems: an in situ leaf decomposition study. *Hydrobiologia*, **495(1)**, 203-211.

Tuchman, N.C., R.G. Wetzel, S.T. Rier, K.A. Wahtera, and J.A. Teeri, 2002: Elevated atmospheric CO_2 lowers leaf litter nutritional quality for stream ecosystem food webs. *Global Change Biology*, **8(2)**, 145-153.

U.S. Army Corps of Engineers, 2000: National inventory of dams.

U.S. Census Bureau, 2004: State interim population projections by age and sex: 2004 - 2030. U.S.Census Bureau Projection Website, www.census.gov/population/www/projections/projectionsagesex.html, accessed on 4-1-2007.

U.S. Environmental Protection Agency, 2000: *National Water Quality Inventory*. EPA-841-R-02-001, U.S. Environmental Protection Agency, Washington, DC.

U.S. Geological Survey, 2001: Hydrological simulation program--fortran.

U.S. Geological Survey, 2005: Federal land features of the United States - parkways and scenic rivers.

U.S. Geological Survey, 2006a: Major dams of the United States.

U.S. Geological Survey, 2006b: *Rates, Trends, Causes and Consequences of Urban Land-Use Change in the United States*. USGS Professional Paper 1726.

U.S. Geological Survey, 2007: USGS surface water data for the nation. USGS Website, http://waterdata.usgs.gov/nwis/sw, accessed on 7-26-2007.

University of Arizona, Environmental Studies Laboratory, 2007: Climate change projections for the United States. University of Arizona, http://www.geo.arizona.edu/dgesl/, accessed on 5-17-2007.

University of New South Wales, 2007: Fire in the snow: thirsty gum trees put alpine water yields at risk. University of New South Wales Website, http://www.science.unsw.edu.au/news/2007/bushfire.html, accessed on 1-20-2007.

Van der Kraak, G. and N. W. Pankhurst, 1997: Temperature effects on the reproductive performance of fish, In: *Global Warming: Implications for Freshwater and Marine Fish*, [Wood, C.M. and D.G. McDonald (eds.)]. Cambridge University Press, Cambridge.

Vannote, R.L. and B.W. Sweeney, 1980: Geographic analysis of thermal equilibria: a conceptual model for evaluating the effect of natural and modified thermal regimes on aquatic insect communities. *The American Naturalist*, **115(5)**, 667-695.

Vörösmarty, C.J., M. Meybeck, B. Fekete, K. Sharma, P. Green, and J.P.M. Syvitski, 2003: Anthropogenic sediment retention: major global impact from registered river impoundments. *Global and Planetary Change*, **39(1-2)**, 169-190.

Vörösmarty, C.J., P. Green, J. Salisbury, and R.B. Lammers, 2000: Global water resources: vulnerability from climate change and population growth. *Science*, **289**, 284-288.

Walsh, C.J., T.D. Fletcher, and A.R. Ladson, 2005: Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. *Journal of The North American Benthological Society*, **24(3)**, 690-705.

Walsh, C.J., A.H. Roy, J.W. Feminella, P.D. Cottingham, P.M. Groffman, and R.P. Morgan, 2005: The urban stream syndrome: current knowledge and the search for a cure. *Journal of The North American Benthological Society*, **24**, 706-723.

Ward, J.V., 1992: *Aquatic Insect Ecology: Biology and Habitat*. John Wiley & Sons, New York, pp. 1-438.

Webster, J.R. and E.F. Benfield, 1986: Vascular plant breakdown in freshwater ecosystems. *Annual Review of Ecology and Systematics*, **17**, 567-594.

Williams, G.P. and M.G. Wolman, 1984: *Downstream Effects of Dams on Alluvial Rivers*. Professional Paper 1286, U.S. Geological Survey, Washington, D.C.

Willis, C.M. and G.B. Griggs, 2003: Reductions in fluvial sediment discharge by coastal dams in California and implications for beach sustainability. *Journal of Geology*, **111(2)**, 167-182.

Wolman, M.G., 1967: A cycle of sedimentation and erosion in urban river channels. *Geografiska Annaler Series A: Physical Geography*, **49(2-4)**, 385-395.

Woodhouse, B., 2005: An end to Mexico's Rio Grande deficit? *Southwest Hydrology*, **4(5)**, 19.

World Commission on Dams, 2000: *Dams and Development: a New Framework for Decisions-Making*. Earthscan Publications, London.

World Wildlife Fund, 2004: *Rivers at Risk: Dams and the Future of Freshwater Ecosystems*.

Xenopoulos, M.A., D.M. Lodge, J. Alcamo, M. Marker, K. Schulze, and D.P. Van Vuuren, 2005: Scenarios of freshwater fish extinctions from climate change and water withdrawal. *Global Change Biology*, **11(10)**, 1557-1564.

6.7 Acknowledgements

Authors' Acknowledgements
Cassie Thomas of the National Park Service provided assistance with the Alaska text box. Mary Brabham, Rob Mattson and Brian McGurk of the St. Johns River Water Management District; and Jaime Doubek-Racine of the National Park Service provided assistance with the Wekiva River Case Study.

Workshop Participants

- Daniel M. Ashe, U.S. Fish and Wildlife Service
- Donita Cotter, U.S. Fish and Wildlife Service
- Jackie Diedrich, U.S. Forest Service
- Andrew Fahlund, American Rivers
- Dave Forney, National Park Service
- Dan Haas, U.S. Fish and Wildlife Service
- Kristy Hajny, Niobrara National Scenic River
- Mike Huggins, U.S. Fish and Wildlife Service
- Quinn McKew, American Rivers
- David Purkey, Stockholm Environment Institute-U.S. Center
- Jason Robertson, Bureau of Land Management
- Cassie Thomas, National Park Service

6.8 Boxes

Box 6.1. Management Goals for Wild and Scenic Rivers

(1) Preserve “free flowing condition”:
- with natural flow
- with high water quality
- without impoundment

(2) Protect “outstandingly remarkable values”:
- scenic
- recreational
- geologic
- fish and wildlife
- historic
- cultural

Box 6.2. Rivers provide a number of goods and services, referred to here as ecosystem functions, that are critical to their health and provide benefits to society. The major functions are outlined below along with the ecological processes that support the function, how it is measured, and why it is important. Information synthesized from (Palmer *et al.*, 1997; Baron *et al.*, 2002; Naiman, Décamps, and McClain, 2005).

Ecosystem Function	**Supporting Ecological Process**	**Measurements Required**	**Potential Impacts if Impaired**
Water Purification (a) Nutrient Processing	Biological uptake and transformation of nitrogen, phosphorus and other elements	Direct measures of rates of transformation of nutrients; for example: microbial denitrification, conversion of nitrate to the more useable forms of nitrogen	Excess nutrients can build up in the water making it unsuitable for drinking or supporting life
Water Purification (b) Processing of Contaminants	Biological removal by plants and microbes of materials such as excess sediments, heavy metals, contaminants, etc.	Direct measures of contaminant uptake or changes in contaminant flux.	Toxic contaminants kill biota; excess sediments smother invertebrates, foul the gills of fish, etc; water not potable
Decomposition of Organic Matter	The biological (mostly by microbes and fungi) degradation of organic matter such as leaf material or organic wastes	Decomposition is measured as the rate of loss in weight of organic matter over time.	Without this, excess organic material builds up in streams, which can lead to low oxygen and thus death of invertebrates and fish; water may not be drinkable
Primary Production Secondary Production	Measured as a rate of new plant or animal tissue produced over time	For primary production, measure the rate of photosynthesis in the stream; for secondary, measure growth rate of organisms or annual biomass	Primary production supports the food web; secondary production support fish and wildlife and humans.
Temperature Regulation	Water temperature is "buffered" if there is sufficient infiltration in the watershed & riparian zone AND shading of the stream by riparian vegetation keeps the water cool.	Measure the rate of change in water temperature as air temperature changes or as increases in discharge occur.	If infiltration or shading are reduced (due to clearing of vegetation along stream), stream water heats up beyond what biota are capable of tolerating
Flood Control	Slowing of water flow from the land to streams or rivers so that flood frequency and magnitude are reduced; intact floodplains and riparian vegetation help buffer increases in discharge	Measure the rate of infiltration of water into soils OR discharge in stream in response to rain events	Without the benefits of floodplains, healthy stream corridor, and watershed vegetation increased flood frequency and flood magnitude
Biodiversity Maintenance	Maintenance of intact food web and genetic resources that together provide other ecosystem goods. Local genetic adaptation contributes to landscape-scale resilience of river ecosystems.	Enumeration of genotypes, species, or species guilds.	Impoverishment of genetic diversity at broader spatial scales. Reduced capacity for resilience and sustainability of many ecosystem goods and services.

Box 6.3. Wild and Scenic Rivers Act of 1968

It is hereby declared to be the policy of the United States that certain selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values, 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. The Congress declares that the established national policy of dam and other construction at appropriate sections of the rivers of the United States needs to be complemented by a policy that would preserve other selected rivers or sections thereof in their free-flowing condition to protect the water quality of such rivers and to fulfill other vital conservation purposes.

Box 6.4. Climate Change and WSRs in Alaska

Approximately 28% of the designated WSR river miles in the nation are in Alaska, including 55% of those designated as wild. In Alaska there are 3,210 WSR miles, of which 2,955 are wild, 227 scenic, and 28 recreational. About half of Alaska's 25 WSRs are located north of the Arctic Circle. The federal government owns much of the designated river corridors and in many cases controls most or all of the upstream watersheds. None of the WSRs in Alaska are dammed above or below the designated segments.

Potential Effects of Climate Change on Ecosystems and Current Management

Climate change is happening faster in the Arctic than at lower latitudes and is the predominant stressor of WSR ecosystems in Alaska today. The annual average Arctic temperature has risen almost twice as fast as temperate and equatorial zones, precipitation has increased, glaciers are melting, winter snows and river ice are melting earlier and permafrost is vanishing (Hassol, 2004). Research in Siberia has shown large lakes permanently lost and attributes the loss to thawing of permafrost, which allows the lakes and wetlands to drain (Smith *et al.*, 2005). Major impacts of climate change on the rivers include earlier ice breakup in spring, earlier floods with higher flows, more erosion, and greater sediment loads. These trends are projected to accelerate as the climate continues warming.

Major shifts in ecological assemblages may occur, including, for example, where permafrost thaws new wetlands will form, although these may be temporary and in turn may be displaced by forest. In currently forested areas, insect outbreaks and fires are very likely to increase and may facilitate invasions of non-native species (Hassol, 2004). Invasive plants have also begun to colonize gravel bars near roads, railway and put-ins; although this is not attributed to climate change, climatic changes may favor these species to displace some native species.

Shifts in flow regime (from earlier snowmelt), increased sedimentation, and warmer water, combined with climate change impacts on marine and estuarine systems, may negatively affect anadromous fish populations with far-reaching ecological and human impacts. Higher water temperatures in rivers are thought to be associated with outbreaks of fish diseases such as *Ichthyophonus*, a fungal parasite suspected of killing some salmon before they spawn and degrading the quality of dried salmon. Salmonid runs are an important component of many WSRs, providing a critical food source for other wildlife and for Alaska Natives. Increased erosion along riverbanks results in loss of archeological sites and cultural resources since there is a long history of seasonal human settlement on many Alaskan rivers.

Potential for Altering or Supplementing Current Management Practices to Enable Adaptation to Climate Change

Managing these large rivers in extremely remote regions of Alaska can not be compared to managing WSRs in the lower 48 states, where river managers are dealing with urban centers, intensive rural land use, dams, diversions, and water extraction infrastructure—all of which can potentially be manipulated. Most of the WSRs in Alaska are truly *wild* rivers.

Even in these remote regions, there are opportunities to manage WSRs affected by climate change. For example, invasive species might be minimized by educating people to avoid introducing problematic species. Archeological and cultural resources of Alaska Natives and their ancestors are abundant along the rivers that have been the transportation corridors for millennia. In consultation with Alaska Natives, these sites should be inventoried, studied, and, where possible, saved from negative impacts of permafrost thaw and erosion resulting from climate change.

Finally, the wild rivers of Alaska are a laboratory for researching climate change impacts on riverine ecosystems and species, and for informing managers further south years before they face similar changes.

Box 6.5. Adaptation Options for Resource Managers

Wild and Scenic Rivers: Adaptation Options for Resource Managers

- ✓ Manage dam flow releases upstream of the WSR to save flora and fauna in drier downstream river reaches.
- ✓ Use drought-tolerant plant varieties to help protect riparian buffers.
- ✓ Establish dry-year option agreements with willing private partners to ensure that flows during droughts remain sufficient to protect critical habitats and maintain water quality.
- ✓ Remove undesirable non-native species.
- ✓ Claim or purchase more water rights.
- ✓ Manage water storage and withdrawals to smooth the supply of available water throughout the year. Re-evaluate institutional mechanisms governing water use and management with an eye toward increasing flexibility (*e.g.*, apply forecasting to water management, improve water monitoring capabilities).
- ✓ Consider shifting access points or moving existing trails for wildlife or river enthusiasts.
- ✓ Establish programs to move isolated populations of species of interest that become stranded when water levels drop.
- ✓ Increase genetic diversity through plantings or via stocking fish.
- ✓ Increase physical habitat heterogeneity in channels to benefit aquatic fauna.
- ✓ Replant native riparian vegetation with drought-resistant vegetation in areas with higher temperatures and less precipitation.
- ✓ Restore the natural capacity of rivers to buffer climate-change impacts (*e.g.*, stormwater management in developed basins, land acquisition around rivers, levee setbacks to free the floodplain of infrastructure, riparian buffer repairs).
- ✓ Conduct river restoration projects to stabilize eroding banks, repair in-stream habitat, or promote fish passages from areas with high temperatures and less precipitation.

Box 6.6. Climate Change, Multiple Stressors and WSRs

Examples are provided to illustrate categories of change and common complicating factors; however, a very large number of combinations are expected around the United States and some of the complicating factors may be present in all regions (*e.g.*, invasive species). See Case Studies for literature citations.

Dominant Climate Change	*Examples of Climate Change Impacts*	*Common Complicating Stressors*	*Example of Region*	*Case study*
Early snowmelt run-off	Species life histories temporally out of synch with flow regime	Dams, flow diversions or changes in reservoir releases	Pacific Northwest	North Fork of the American River
More flooding	Flood mortality, channel erosion, poor water quality	Development in watershed	Northeast, Upper Midwest	Upper Delaware
Droughts, intense heat	Drought mortality, shrinking habitat, fragmentation	Over-extraction of water Invasive Species	Southwest	Rio Grande
Little change in rainfall, moderately warmer	Impacts modest unless complicating stressors	Development in watershed	Northern Florida, Mississippi, parts of middle and western states	Wekiva River

Box 6.7. Migratory Fish

Many fish species are anadromous and adapted to cooler waters—living much of their lives in oceans, but migrating inland to spawn in colder reaches of freshwaters. Several species of salmon and sturgeon reproduce in the rivers of Alaska and the Pacific Northwest, while others, including Atlantic salmon, sturgeon, and striped bass, spawn in eastern seaboard rivers from the Rio Grande to the Canadian coast. Many of these species were also introduced to the Great Lakes, where they migrate up many of Michigan's WSRs. Such species played a significant role in the establishment of the Wild and Scenic Rivers Act and continue to be a primary focus in the management of WSRs. The life cycles of most of these species are determined largely by water temperatures and flows, driven by snowmelt or low water in the summer and fall.

Anadromous fish in the United States are exposed to several anthropogenic stressors that may be exacerbated by climate change. Dams impede or prevent fish migrations, including dams upstream of river stretches designated "wild and scenic." Water withdrawals and reservoir management have affected flow regimes, and water temperatures and pollutants—combined with increased sediment loads—have made many rivers uninhabitable for some migratory fish.

Climate change effects, including reduced streamflows, higher water temperatures, and altered frequencies and intensities of storms and droughts, will further degrade fish habitat (Climate Impacts Group, University of Washington, 2004). Battin et al. (2007) estimate a 20–40% decline in populations of Chinook salmon by 2050 due to higher water temperatures degrading thermal spawning habitat, and winter and early spring floods scouring riverbeds and destroying eggs. This may be a conservative estimate since the analysis did not address the effects that increased sea levels and ocean temperatures would have on Chinook during the oceanic phase of their life cycle, and the study focused on the run of Chinook salmon that spawns in late winter or spring and migrates to the sea by June. Yearlings that remain in freshwater throughout the summer months may be even more vulnerable.

Fish habitat restoration efforts are widespread throughout the United States. However, the models used to guide restoration efforts rarely include projected impacts of climate change. Nevertheless, Chinook salmon studies suggest that habitat restoration in lower elevation rivers (including reforesting narrow reaches to increase shade and decrease water temperatures) may reduce the adverse impacts of climate change (Battin *et al.*, 2007). Galbraith *et al.*(In Press) also identify the potential importance of releases of cool water from existing dams for the preservation of thermal spawning and rearing habitat. Also, mitigating watershed-level anthropogenic stressors that could exacerbate climate change impacts (*e.g.*, water withdrawals, pollutants) could be an effective adaptation option.

Ultimately, management of anadromous fish in WSR will need to reflect species and local circumstances. However, including climate change projections in habitat restoration plans, working to mitigate human-induced stressors, and implementing effective monitoring programs will likely be three of the most important actions managers can take to facilitate the adaptation of anadromous fish to climate change.

6.9 Figures

Figure 6.1. Photo of Snake River below Hell’s Canyon Dam. Photograph compliments of Marshall McComb, Fox Creek Land Trust.

Figure 6.2. Wild and Scenic Rivers in the United States. Data from USGS, National Atlas of the United States (2005).

Figure 6.3. Selected milestones in the evolution of the Wild and Scenic Rivers system. Adapted from National Wild and Scenic Rivers System website (2007a).

Figure 6.4. Conditions and factors affecting the future conditions of Wild and Scenic Rivers.

Figure 6.5. Illustration of natural flow regimes from four unregulated streams in the United States, (a) the upper Colorado River (CO), (b) Satilla Creek (GA), (c) Augusta Creek (MI), and (d) Sycamore Creek (AZ). For each the year of record is given on the x-axis, the day of the water year (October 1 – September 30) on the y-axis, and the 24-hour average daily streamflow on the z-axis (Poff and Ward, 1990).

Figure 6.6. Trends in water withdrawals by water-use category. As the population has grown, water has been increasingly withdrawn for public use since 1950 as indicated by total withdrawals (blue line). Water withdrawn for power production and water for irrigation represent largest use followed by water for industrial uses then public supply. From Hutson *et al.* (2004).

Figure 6.7. Changes in monthly average river flows on the Delaware River, in the Upper Delaware Scenic and Recreational River segment. Lowered flows in December–July result from upstream depletions for New York City water supply. Increased flows result from upstream reservoir releases during summer months for the purpose of controlling salinity levels in the lower Delaware. Figure based on data provided by USGS (2007).

Figure 6.8. Location of dams and WSRs in the United States. Data from USGS, National Atlas of the United States (U.S. Geological Survey, 2005; 2006a).

Figure 6.9. Photo of scientists standing on the bed of an urban stream whose channel has been incised more than 5 m due inadequate storm water control. Incision occurred on the time scale of a decade but the bank sediments exposed near the bed are marine deposits laid down during the Miocene epoch. Photograph courtesy of Margaret Palmer.

Figure 6.10. Organization of the WSR system. Adapted from National Wild and Scenic Rivers System website (2007a).

Figure 6.11. Farmington WSR. Photo compliments of the Farmington River Watershed Association.

Figure 6.12. Projected temperature changes for 2091-2100 (University of Arizona, Environmental Studies Laboratory, 2007).*

* Note: This figure is provisional, based on securing permission to reprint.

Figure 6.13. Projected annual precipitation changes for 2091-2100 (University of Arizona, Environmental Studies Laboratory, 2007).

* Note: This figure is provisional, based on securing permission to reprint.

Figure 6.14. Median, over 12 climate models, of the percent changes in runoff from United States water resources regions for 2041–2060 relative to 1901–1970. More than 66% of models agree on the sign of change for areas shown in color; diagonal hatching indicates greater than 90% agreement. Recomputed from data of Milly, Dunne, and Vecchia (2005) by Dr. P.C.D. Milly, USGS.

Figure 6.15. Photo of snowmelt in WSR during winter-spring flows. Photo courtesy of National Park Service, Lake Clark National Park & Preserve.

Figure 6.16. Earlier onset of spring snowmelt pulse in river runoff from 1948–2000. Shading indicates magnitude of the trend expressed as the change (days) in timing over the period. Larger symbols indicate statistically significant trends at the 90% confidence level. From Stewart, Cayan, and Dettinger (2005).

Figure 6.17. Very rapid increases (1–4 hours) in water temperature (temperature “spikes”) in urban streams north of Washington D.C. have been found to follow local rain storms. *Top graph:* dark line shows stream discharge that spikes just after a rainfall in watersheds with large amounts of impervious cover; gray line shows temperature surges that increase 2–7ºC above pre-rain levels and above streams in undeveloped watersheds in the region. There is no temperature buffering effect that is typical in wildlands where rain soaks into soil, moves into groundwater, and laterally into streams. *Bottom graph:* shows that the number of temperature surges into a stream increases with the amount of impervious cover. From Nelson and Palmer (2007).

Figure 6.18. Water stress projected for the 2050s based on withdrawals-to-availability ratio, where availability corresponds to annual river discharge (combined surface runoff and groundwater recharge). From Alcamo, Flörke, and Märker (2007).

Figure 6.19. The Wild and Scenic portions of the Wekiva River. Data from USGS, National Atlas of the United States (2005).

Figure 6.20. The Wild and Scenic portions of the Rio Grande WSR in New Mexico. Data from USGS, National Atlas of the United States (2005).

Figure 6.21. The Wild and Scenic portions of the Rio Grande WSR in Texas. Data from USGS, National Atlas of the United States (2005).

Figure 6.22. Dams and diversions along the Rio Grande (Middle Rio Grande Bosque Initiative, 2007).

Figure 6.23. Map of Wild and Scenic stretches in the Delaware River basin. Courtesy of Delaware River Basin Commission (Delaware River Basin Commission, 2007).