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 Warner, Kinnickinnic Consulting

Chapter Contents

6.1 Summary

Key Findings

Wild and Scenic Rivers (WSRs) provide a special suite of goods and services, valued highly by the public, that are inextricably linked to their flow dynamics and the interaction of flow with the landscape. The WSR System was created to protect and preserve the biological, ecological, historic, scenic, and other “outstandingly remarkable values” for which they have been selected. The management goals for WSRs center on the preservation and protection of these conditions and values. Currently there are 165 WSRs across the country, representing more than 11,000 stream miles. Most states have at least one designated river or river segment, but 100 of the WSRs fall within just four states (Oregon, Alaska, Michigan, and California with 46, 25, 16, and 13 WSRs respectively). 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.

Climate change adds to and magnifies risks that are already present in many watersheds with WSRs 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 both reactive and proactive management responses if the nation’s valuable river assets are to be protected.

The context of WSRs within their watershed and the ability to manage the many stressors that interact with climate change exert a large influence on their future.
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, but also of how it is managed and how human behavior will affect the river (the human context). Even if impacts are small at present, consideration of the human context is critical because so many WSRs are not within a fully protected basin. This means that in addition to climate change, impacts associated with activities such as development and water withdrawals are likely to become issues in the future. Thus, stress associated with the *future human context* will interact with climate change, often exacerbating problems and intensifying management challenges. To the extent that managers are able to control aspects of this “context,” they are better placed to manage for adaptation to climate change.

Impacts of climate change on WSRs will vary by region and human context, and will be manifest through changes in hydrology, geomorphology, and ecology. Climate change is expected to have a significant impact on running waters throughout the world, including WSRs. Impacts are 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. For a given change in temperature, rainfall, and CO_2 relative to the natural range of variability, WSRs in highly developed watersheds are expected to experience the most significant changes. Changes outside the natural range of flow or temperature variability may have drastic consequences for ecosystem structure and function, and thus the values for which the river was designated as wild and scenic. Species may be locally extirpated or shift their distributions. Changes in flow regimes also may affect recreational opportunities, and could affect valued cultural resources.

Management approaches for many WSRs will require collaborations with federal and non-federal partners in the respective river basins.
WSR managers could strengthen collaborative relationships among federal, state, and local resource agencies and stakeholders to ease the implementation of adaptive river management strategies. Options to protect WSRs and river segments are diverse and most of them require cooperation and collaboration with other groups, including local landowners, reservoir and dam managers, as well as city, county or state agencies. Options presented assume WSR managers/administering agencies will actively seek cooperative arrangements with the needed parties to ensure WSR ecosystems are protected. Land acquisition is an option that may provide the most security for WSRs that are in watersheds with some non-federal land.

Managers may forge partnerships and develop mechanisms to ensure environmental flows for WSRs in basins that experience water stress, work with land use planners to minimize additional development in WSR watersheds, or ensure that land adjacent to a WSR is in protected status.
Methods to manage and store surface and groundwater will be important for WSRs in developed or dammed watersheds that are in regions expected to experience more floods or droughts. 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. Similarly, working to develop agreements to limit water extractions, purchase additional water rights or dry-year agreements with willing parties, and working with land use planners to minimize additional development may be very important in regions of the country that are expected to experience water stress.

In the face of climate change, management of WSRs will require both proactive approaches as well as reactive actions to be taken if impacts occur.
The ability of a WSR to provide the ecosystem goods and services in the future that originally prompted its designation will depend largely on how it is managed. Without deliberate management actions that react to stress already occurring or that anticipate future stress, the provision of ecosystem services will not be guaranteed. Some actions are far more desirable to undertake proactively (*e.g.*, acquire land to protect floodplains), and others may be done proactively *or* reactively (*e.g.*, restore riparian habitat). Those actions that are more desirable to undertake reactively occur where the costs of acting before an event are high and the uncertainty of an event occurring is high (*e.g.*, severe damage occurs from an extreme event that requires channel reconfiguration). Among the most important proactive measures is expanding the technical capacity of WSR managers so they have the needed tools and expertise to prepare for and implement new management.

Priority management strategies that include a focus on increased monitoring and the development of tools to project future impacts will better enable river managers to prioritize actions and evaluate effectiveness.
A task critical to prioritizing actions and evaluating effectiveness is to monitor and develop regional-scale (preferably WSR basin-specific) tools for projecting the likely impacts of climate change in concert with other stressors. Monitoring efforts may begin by providing adequate

baseline information on water flows and water quality. Then management plans for WSRs may be designed with flexibility built in so that they may be updated regularly to reflect new information and scientific understanding, based on monitoring and modeling efforts.

6.2 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.[1]

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.

Figure 6.1. Photo of Snake River below Hell’s Canyon Dam. Photograph courtesy 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 “any river or section of a river existing or flowing in natural condition without impoundment, diversion, straightening, rip-rapping, or other modification of the waterway.”[2] One should note, however, that low dams or other minor structures do not preclude a river from being considered for designation. 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), including attempting to keep them in a free-flowing condition with high water quality and protected cultural and recreational values.

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

[2] Section 16(b) of the Wild and Scenic Rivers Act, 16 U.S.C. 1271-1287 P.L. 90-542.

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.

Figure 6.2. Wild and Scenic Rivers in the United States. Data from USGS, National Atlas of the United States.[3]

Figure 6.3. Selected milestones in the evolution of the Wild and Scenic Rivers system. Adapted from National Wild and Scenic Rivers System website.[4]

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.

6.3 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. They are distinctive because river-specific outstanding values have been identified and river-administrating agencies have been directed to monitor and protect them as much as possible. More specifically, 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. This makes WSRs ideal for implementing and monitoring the

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[3] **U.S. Geological Survey**, 2005: Federal land features of the United States - parkways and scenic rivers. *Federal Land Features of the United States*. http://www-atlas.usgs.gov/mld/fedlanl.html. Available from nationalatlas.gov. **U.S. Geological Survey**, 2006: Major dams of the United States. *Federal Land Features of the United States*. http://www-atlas.usgs.gov/mld/dams00x.html. Available from nationalatlas.gov.

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

results of management strategies to minimize the impacts of climate change—the responsible manager (*e.g.*, the river-administering agency) is specified and the ecosystem values in need of protection have been identified.

6.3.1 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 managed 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.

6.3.2 Hydrogeomorphic Context

6.3.2.1 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 than 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.

6.3.2.2 What it Means to be Wild

WSRs include headwaters with undisturbed watersheds as well as river segments that have only modest watershed impacts. The term "wild river" in its strictest sense would include a river with no human impacts in its entire watershed. One of the key features of these truly wild rivers is their 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 (see Case Study Summary 6.1). 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).

6.3.3 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 some 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 federally owned WSR corridors. The vulnerability of rivers generally increases in relation to the area of contributing watershed in nonfederal control; the protection of these areas depends on coordinated management with local landowners and governments. In general, 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 (see Case Study Summary 6.2). Protection of headwaters is especially important, since they support critical (keystone) ecosystem processes and often support sensitive species.

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.

6.3.3.1 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 (Fig 6.6).[5] 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.

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[5] **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*. http://water.usgs.gov/pubs/circ/2004/circ1268/.

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.[5] 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 the largest use, followed by water for industrial uses, then public supply.[5]

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 (Fig 6.6).[5] 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.[6]

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 by as much as 40% (Fig. 6.7 and Case Study Summary 6.3) (Fitzhugh and Richter, 2004). 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

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[6] **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, DC.

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.[7]

6.3.3.2 Dam Operations

Nearly 80,000 dams are listed in the National Inventory of Dams for the United States.[8] Approximately 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.[3]

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; 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);

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[7] **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.
[8] **U.S. Army Corps of Engineers**, 2000: National inventory of dams. http://crunch.tec.army.mil/nid/webpages/nid.cfm, Federal Emergency Management Agency. CD-ROM.

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.[9] 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).

6.3.3.3 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).[10] 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).[11] 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,

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[9] **Olsen**, S.B., T.V. Padma, and B.D. Richter, Undated: Managing freshwater inflows to estuaries: a methods guide. U.S. Agency for International Development, Washington, DC.

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

[11] See also **U.S. Geological Survey**, 2001: Hydrological simulation program—Fortran. http://water.usgs.gov/software/hspf.html. U.S. Geological Survey, Reston, VA.

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. Geological Survey National Water Quality Assessment (NAWQA) found that most of the rivers sampled in agricultural areas contained at least five different pesticides,[11] 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 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.[11] 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 to 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.

6.3.4 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 rest of this 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.[12]

Regardless of how a WSR is classified—wild, scenic, or recreational—administering agencies must seek to protect existing river-related values and, to the greatest extent possible, enhance those values. 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. So, for example while many WSRs had dams in place prior to the river segment being designated as wild and scenic (Fig. 6.8), the Wild and Scenic Rivers Act charges the administering agency with reviewing any new federally assisted water resource projects (such as dams) to ensure they will not degrade river values.

6.3.4.1 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. 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.

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

Figure 6.10. Organization of the WSR system. Adapted from National Wild and Scenic Rivers System website.[4]

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.[12]

6.3.4.2 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 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 identify the water quantity and quality that are needed to ensure river values are protected: (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.[13]

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 are 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.

6.3.4.3 Legal and Management Tools

The federal and state agencies administering WSRs 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

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[13] **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.

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 also apply to designated WSRs.[12] 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 in-stream purposes, and implementing water conservation and demand-management strategies to keep more water in-stream (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.[14]

Figure 6.11. Farmington WSR. Photo courtesy 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 a WSR includes up to 320 acres per river mile (twice this for Alaskan rivers), measured from the ordinary high water mark.[14] 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.[14] For instance, the administering agency can work cooperatively with landowners and establish binding agreements that offer them technical assistance with measures

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

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.[14]

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.[12]

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.[13]

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.

6.4 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, 2007a). 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 adaptation options for WSRs.

6.4.1 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 (2007b) 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, much of the world can expect warmer conditions and many watersheds will experience more severe weather events.

6.4.1.1 Temperature

During the 21st century, the average global surface temperature is projected to increase with the best estimate across six IPCC (2007a) scenarios being 1.8–4.0°C during the 21st century. Increases will vary geographically and seasonally. For instance, in summer, rivers in Nevada, Utah, and Idaho will be most strongly affected (Fig. 6.12). In the past, for snowmelt-dominated rivers in the western United States, temperature increases have affected the onset of the spring pulse and the timing of the center of mass for flow (Stewart, Cayan, and Dettinger, 2005) (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.[15]

6.4.1.2 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 WSRs 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, Presque 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.[15]

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.

6.4.1.3 Discharge

Because of the projected changes in temperature, precipitation, and CO_2 concentrations, 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

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[15] **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.

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.

Fig. 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).

6.4.1.4 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.*, 2008), 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.

6.4.2 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 6.4 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.[16]

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

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[16] **Nelson**, K., M.A. Palmer, J.E. Pizzuto, G.E. Moglen, P.L. Angermeier, R. Hilderbrand, M. Dettinger, and K. Hayhoe, submitted: Forecasting the combined effects of urbanization and climate change on stream ecosystems: from impacts to management options. *Journal of Applied Ecology*.

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 than 40% between the year 2000 and 2030.[17] 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.[18]

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 change 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.

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[17] **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.

[18] **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.

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.*, 2008). Ideally this will be done proactively to minimize the need to repair and restore damaged infrastructure and ecosystems.

6.4.3 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 classified as "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 (Palmer *et al.*, 2008). However, as noted earlier, because many WSRs are in reality river *segments* within watersheds 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, it may be that other 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 natural 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 runoff 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.*, 2008). 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.

6.4.3.1 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.*, 2008).

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 that 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 come 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.*, 2008). 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).

6.4.3.2 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 PO_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.

6.4.4 Options for Protection Assuming New Management

Options to protect WSRs and river segments are diverse, and most of them require cooperation and collaboration with other groups. Depending on the specific watershed and the level of human use (development, agriculture, forestry, etc.), these groups could include local landowners, reservoir and dam managers, as well as city, county or state agencies. As pointed out several times in this chapter, WSRs are distinctive—as are some other ecosystems on federally owned land—because rivers are affected by *all* activities in their watershed whether the land is federal or not. Thus the options we discuss below extend well beyond federal boundaries and assume

WSR managers/administering agencies will be proactive in seeking cooperative arrangements with the needed parties to ensure WSR ecosystems are protected.

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 did (IPCC, 2007a). 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.*, (2008) 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. Some actions are far more desirable to undertake proactively (*e.g.*, acquire land to protect floodplains), others may be done proactively *or* reactively (*e.g.*, riparian restoration), and some are more desirable to undertake reactively, such as where the costs of acting before an event are high and the uncertainty of an event occurring is high (*e.g.*, severe damage occurs from an extreme event that requires channel reconfiguration). (Boxes 6.5 and 6.6).

6.4.4.1 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 responding to events such as floods, droughts, erosion, and species loss as they occur. Extreme flow events in areas expected to have later snowmelt with the potential for rain-on-snow events may lead to substantial erosion of river banks, not only placing sensitive riparian ecosystems at risk but potentially causing water quality problems downstream due to higher suspended sediment loads. At the other extreme, arid regions that experience more droughts may find populations of valued species isolated due to dropping water levels. For these examples, reactive management efforts may be needed to stem future degradation of ecosystems or extirpation of a species.

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. To reduce future occurrences of severe erosion, more stormwater infrastructure may be needed. Other measures, such as creating wetlands or off-channel storage basins, may be a way to absorb high flow energy and provide refugia for fauna during droughts or floods. 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.*, (2008) 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.

6.4.4.2 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 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. For WSR segments fed by non-designated headwaters that are not protected in some way from human impacts, efforts should be made to extend the designation to these small tributaries through land acquisition or partnerships with landowners. Indeed, since headwaters often support rare and sensitive species, protecting multiple small headwaters will provide a sort of "insurance" against regional species loss if losses occur in one or a few tributaries.

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 are needed. These responses 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.

Improve Water Monitoring Capabilities and Apply Climate Forecasting

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, adequate monitoring to detect trends in flow is needed to show that flooding is increasing as a consequence of more rapid melting in spring. River managers may use the monitoring data to determine where to pursue additional land conservation easements or where to encourage local zoning that limits development on floodplains.

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 indicates 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.[19]

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.

Designate More River Corridors as Wild and Scenic and Acquire Land Adjacent to WSRs

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.

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[19] **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.

A second reason for increasing the number of designated rivers in some regions is that if there is a high risk of species extinctions, due for example to a high drought probability, spreading that risk among rivers within the same ecoregions may provide protection (across space) for species. At any given time, there may be rivers within the ecoregion that are not as affected by drought. Land acquisition around existing WSRs may also reduce extinction if the land helps buffer the river segment from nearby development pressures or the land allows for floodplain expansion.

Consider Conjunctive Groundwater/Surface Water Management

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. 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. For WSR segments in watersheds with dams, there may be a need to develop reservoir release options with dam managers and/or design structures for temporary storage of flood waters before they reach reservoirs. In regions with extremely high rates of evaporation, managers may wish to work with requisite authorities to consider removing dams below shallow, high-surface-area reservoirs. In such cases, alternative strategies for water storage will be needed. Finally, with large changes in reservoir water levels, the outlet height on dams may need adjusting to ensure high quality water to downstream WSRs.

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. Additionally, 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.

Implement Restoration Projects

Restoration can be done either proactively to protect existing resources or, as in the examples provided in Section 6.4.4.1 above, projects may be required to repair damage associated with a changing climate. Since floodplains and riparian corridors are critical regions both for mitigating floods and for storing water, measures should be taken to ensure they are as healthy as possible. This could include removal of invasive plants that threaten native species, re-grading river banks to reconnect floodplains to the active channel, and a whole host of other measures that are more fully described elsewhere (Bernhardt *et al.*, 2007; Palmer *et al.*, 2008; Wohl, Palmer, and Kondolf, 2008).

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 need to be evaluated and amended as appropriate 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.[20] 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.

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—an open and fair process in which climate change impacts are considered needs to be used to evaluate the priorities. To protect ecosystem services, strong consideration should be given to prioritizing those natural assets *most at risk* from climate change.

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.

It is critical to recognize that only a subset of WSRs are headwater rivers in watersheds that are free of development, extractive uses, or dams. Since human activities on the land and those affecting ground waters have a very significant impact on rivers and will exert stress that could exacerbate any problems associated with climate change, WSR managers alone can not ensure the protection of many WSRs. Thus, forging partnerships with nonfederal water managers, land owners, towns, and states will be necessary to protect and to preserve the “outstandingly remarkable values” that are the basis for the designation of many rivers as wild and scenic.

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:

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[20] **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.

- 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.

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

- Forge partnerships and develop mechanisms to ensure environmental flows for WSRs in basins that experience water stress.

- Work with land use planners to minimize additional development on parcels of land adjacent to WSRs, and optimally to acquire floodplains and nearby lands that are not currently federally owned or ensure they are placed in protected status.

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

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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, floods become more frequent and higher in 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 in 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 warming continues.

Major shifts in ecological assemblages may occur. 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 farther south years before they face similar changes.

Box 6.5. WSR Adaptation Options

- Maintain the natural flow regime through managing dam flow releases upstream of the WSR (through option agreements with willing partners) to protect flora and fauna in drier downstream river reaches, or to prevent losses from extreme flooding.
- Use drought-tolerant plant varieties to help protect riparian buffers.
- Create wetlands or off-channel storage basins to reduce erosion during high flow periods.
- Actively remove invasive species that threaten key native species.
- Purchase or lease water rights to enhance flow management options.
- Manage water storage and withdrawals to smooth the supply of available water throughout the year.
- Develop more effective stormwater infrastructure to reduce future occurrences of severe erosion.
- Consider shifting access points or moving existing trails for wildlife or river enthusiasts.
- Increase genetic diversity through plantings or by stocking fish.
- Increase physical habitat heterogeneity in channels to support diverse biotic assemblages.
- Establish special protection for multiple headwater reaches that support keystone processes or sensitive species.
- Conduct river restoration projects to stabilize eroding banks, repair in-stream habitat, or promote fish passages from areas with high temperatures and less precipitation.
- Restore the natural capacity of rivers to buffer climate-change impacts (*e.g.*, through land acquisition around rivers, levee setbacks to free the floodplain of infrastructure, riparian buffer repairs).
- Plant riparian vegetation to provide fish and other organisms with refugia.
- Acquire additional river reaches for the WSR where they contain naturally occurring refugia from climate change stressors.
- Create side-channels and adjacent wetlands to provide refugia for species during droughts and floods.
- Establish programs to move isolated populations of species of interest that become stranded when water levels drop.

Box 6.6. Examples of potential river management and restoration actions. Actions may be taken *proactively* to prepare for and minimize the impacts of climate change on ecosystems and people, or could be required *reactively* at the time of or after impact. The type and extent of these actions will vary among rivers and river segments that experience an increase in available water (increased discharge and/or groundwater storage) vs. those that experience water stress. WSRs that are free-flowing throughout their watersheds are expected to require fewer management interventions than river segments in watersheds with dams (as outlined in Palmer *et al.*, 2008); however, the need for intervention will also vary depending on if and how much a watershed containing a WSR segment is in developed use (*e.g.*, agriculture, urban) and the magnitude of climate change for the region.

Type of Management Action	Context and Purpose
Improve environmental monitoring and develop WSR-scale climate forecasts	To facilitate planning and better understand local effects of climate change.
Build capacity to offer technical assistance	National or regional enhancement of technical capacity can provide assistance to WSR managers who may not have the resources to do this on their own.
Designate more WSRs and/or acquire land around existing WSRs	May raise awareness of value of WSRs, potentially leading to additional protection; land acquisition may enhance floodplain extent and buffer river segments from impacts in surrounding watershed, and could provide “replication” in space of at-risk habitats and refugia for species.
Conjunctive Groundwater/Surface Water Management	Purchasing more water rights may be needed for WSRs under water stress due to droughts or extractions. If dams are present, develop reservoir release options with dam managers and/or design structures for temporary storage of flood waters before they reach reservoir; remove dams in areas with high evaporation, and consider methods to divert water to groundwater storage to provide for later use; adjust outlet height on dam to release high quality water to downstream rivers.
Restoration Projects	Needed particularly for rivers in watersheds with some level of development: *riparian management* to revegetate damaged areas to slow runoff in the event of more floods, OR to remove drought-tolerant exotic species in drier regions; *stormwater management projects* and *wetland creation* to reduce runoff and sediment flux to river or to store flood water; *channel reconfiguration* and/or *stream bank stabilization*—some configurations may help channel withstand peak flow releases, OR in drier regions stream bank may need to be re-graded to reconnect floodplain to channel to enhance water storage and habitat.

6.9 Case Study Summaries

The summaries below provide overviews of the case studies prepared for this chapter. The case studies are available in Appendix A6.

Case Study Summary 6.1

Wekiva River Basin, Florida

Southeast United States

Why this case study was chosen

The Wekiva River Basin:

- Is a spring-fed system that requires management of surface and sub-surface water resources;
- Is a sub-tropical, coastal ecosystem and thus faces potential impacts from tropical storms and sea level rise;
- Is dealing directly with large and expanding urban and suburban populations, and associated water and land use changes.

Management context

The Wekiva River basin is a complex system of streams, springs, lakes, and swamps that are generally in superb ecological condition and harbor an impressive list of endangered species, including the West Indian Manatee and endemic invertebrates. The springs that feed the river are affected by pumping of groundwater and by proximity to the expanding population of Orlando. Agricultural and urban expansion is affecting groundwater and surface water systems critical to the ecological balance of the WSR. Other management issues include urban and agricultural pollution, and invasive exotic species. The National Park Service has overall coordinating responsibility for the Wekiva WSR, while land, water, and natural resources management in the basin is provided through cooperation among state agencies, local governments, and private landowners. Even without climate change considerations, the basin is expected to reach maximum sustained yields of water use by 2013. Agencies in the basin are monitoring water quantity and quality, ecosystem health, and native and invasive species populations, and are taking an increasingly proactive approach to water management.

Key climate change impacts

- Projected increase in average temperatures (2.2–2.8°C in Central Florida by 2100);
- Projected increase in the frequency of tropical storms and hurricanes;
- Projected sea level rise of 0.18–0.59 m by 2099;
- Projected decline of water availability due to increased evaporation and transpiration.

Opportunities for adaptation

- Monitoring programs could support more robust modeling to project management needs in a climate change scenario, including how rising sea level might affect saltwater intrusion into the groundwater.
- The possible shift to longer droughts, punctuated by more intense rain events, could be addressed through aggressive practices to maintain water quality and availability, *e.g.*, by maximizing recharge of the aquifer during rain events and minimizing withdrawals during droughts through water conservation programs;
- Additional measures could be pursued to reduce pollution of surface and groundwater reaching the Wekiva River; management changes should be informed by more research into how pollutants in reclaimed water are transported through the porous karst geology to the aquifer and springs.
- There is considerable public interest in the importance of water; therefore, management programs have the opportunity to provide education to the public and other stakeholder groups on conserving water

and reducing pollution, including limiting runoff of nitrate-based fertilizers and encouraging the use of central sewage treatment facilities instead of septic tanks.

Conclusions

The preservation of ecological conditions in the Wekiva WSR will require integrated management of the complex interactions between surface and ground water in the watershed. Expanded water monitoring and advanced modeling programs will be keys to maintaining water quantity and quality in the Floridian aquifer, and for regulating runoff to maximize reuse for urban and rural uses while ensuring optimal water reaching the river.

Case Study Summary 6.2

Rio Grande River

Southwest United States

Why this case study was chosen

The Rio Grande River:

- Is the second largest river in the Southwest, and provides an important water resource for hydropower and agricultural and municipal needs in the United States and Mexico;
- Exemplifies the complex domestic and international water rights issues typical of the American West;
- Is an example of a WSR managed by federal agencies, as is typical for many WSR in the West;
- Provides so much water to diversions and extraction in Colorado and New Mexico that the riverbed is dry for about 80 miles south of El Paso, Texas, resulting in two distinct hydrologic systems: the northern segment of the WSR is strongly influenced by spring snowmelt, while the segment forming the border between Texas and Mexico receives most of its water from summer rains in Mexico.

Management context

Management responsibilities for the Rio Grande WSR corridor rest with the Bureau of Land Management, the Forest Service, the National Park Service, and state and local agencies, while water in the river basin is largely controlled through complex water rights agreements and international treaties. Ecological management goals in the upper and lower WSR address similar priorities: preserving the natural flow regime, maintaining and improving water quality, conserving plant and animal species, and addressing invasive species. Impoundments and water extractions have reduced stream flow by over 50%, and invasive species have significantly altered ecosystems, particularly in the lower segment of the WSR. Water rights were established before the river was designated as a WSR, so they have priority over management goals of the WSR. Extraction of groundwater exceeds recharge in parts of the basin, and existing international agreements to provide the river with water have not been met in recent drought years, leaving the river as a series of pools in segments of the WSR along the border with Mexico.

Key climate change impacts

- Projected increase in average temperatures;
- Projected reductions in snowpack and earlier spring melts;
- Projected 5% decrease in annual precipitation by 2010, leading to recurring droughts;
- Projected increases in population and development, leading to greater water demands;
- Projected decline in water availability due to increased evaporation and runoff;
- Projected increase in invasive species due to warming of water and irregularity of the flow regime.

Opportunities for adaptation

- Scenario-based forecasting could be used by water managers to better anticipate trends and address their ramifications.
- Management of water releases, diversions, and extractions could be adapted to store water from early snowmelt and summer rains, and release water to the river to mimic the natural flow regime.
- Economic incentives can bring flexibility to water rights, including purchasing or leasing of water rights for the river and incentives that promote water efficiency and reduce pollution.
- Improving efficiency of agricultural and urban water use through conservation and reuse of water could reduce demand and improve water quality.

Conclusions

Meeting the management goals for the Rio Grande WSR is challenging even today, and will be more so as historic problems of water availability and international water rights are complicated by climate change. Even so, the WSR may be maintained through improved water use forecasting, water conservation, and reduced water demand, combined with economic incentives to ensure that enough water is provided to the WSR on a schedule that mimics the natural flow regime.

Case Study Summary 6.3

Upper Delaware River, New York, and Pennsylvania

Northeast United States

Why this case study was chosen

The Upper Delaware River:

- Has recently been affected by unusually frequent and severe flooding, including three separate hundred-year flood events in less than two years;
- Serves as the major water source to New York City and surrounding areas;
- Exemplifies a largely natural river on the Atlantic coast;
- Represents a WSR “Partnership River,” with little public ownership of the WSR corridor.

Management context

Predominately private ownership of the WSR corridor requires that the National Park Service, along with local and state government agencies, work with private interests to develop and implement the river management plan. The goals of the plan include maintaining and improving water quality and ecosystems, providing opportunities for recreation, and maintaining scenic and historic values of the river. The rights of private landowners are especially emphasized in the management plan. In addition to providing water to New York City (the city takes about 50% of the available water) and flood control, the reservoirs in the upper tributaries strategically release water downstream to the keep the salt front in the tidal zone from reaching upstream infrastructure that would be damaged by the salt water. The timing and quantity of these water releases do not match natural flow regimes of the river, and occasional low water levels tend to concentrate pollutants and increase water temperature in some river segments. Water conservation in the Delaware Basin and New York City has significantly helped address drought-related water shortages.

Key climate change impacts

- Observed and projected increase in mean temperature and annual precipitation;
- Observed and projected increase in severe flood events;
- Projected decrease in snowpack and earlier spring melts;
- Projected periodic droughts;
- Projected rise in sea level that will push the salt front further upstream.

Opportunities for adaptation

- Modeling tools can be used to project climate change impacts on the water system, and to determine the reservoir levels and water releases that can best establish an optimal water flow regime and offset river water warming in the WSR.
- Incentives and ordinances could be used to improve water quality by reducing agricultural pollutants reaching the river, reducing storm water runoff, and improving flood and erosion control through restoration of wetlands and riparian buffers.
- Support for water-efficient measures could further improve efficiency of water use in New York City and throughout the basin, thereby reducing per-capita demand for household water.
- Reservoir management could be adapted to store water from early snowmelt and release water to the river, in order to mimic the natural flow regime.

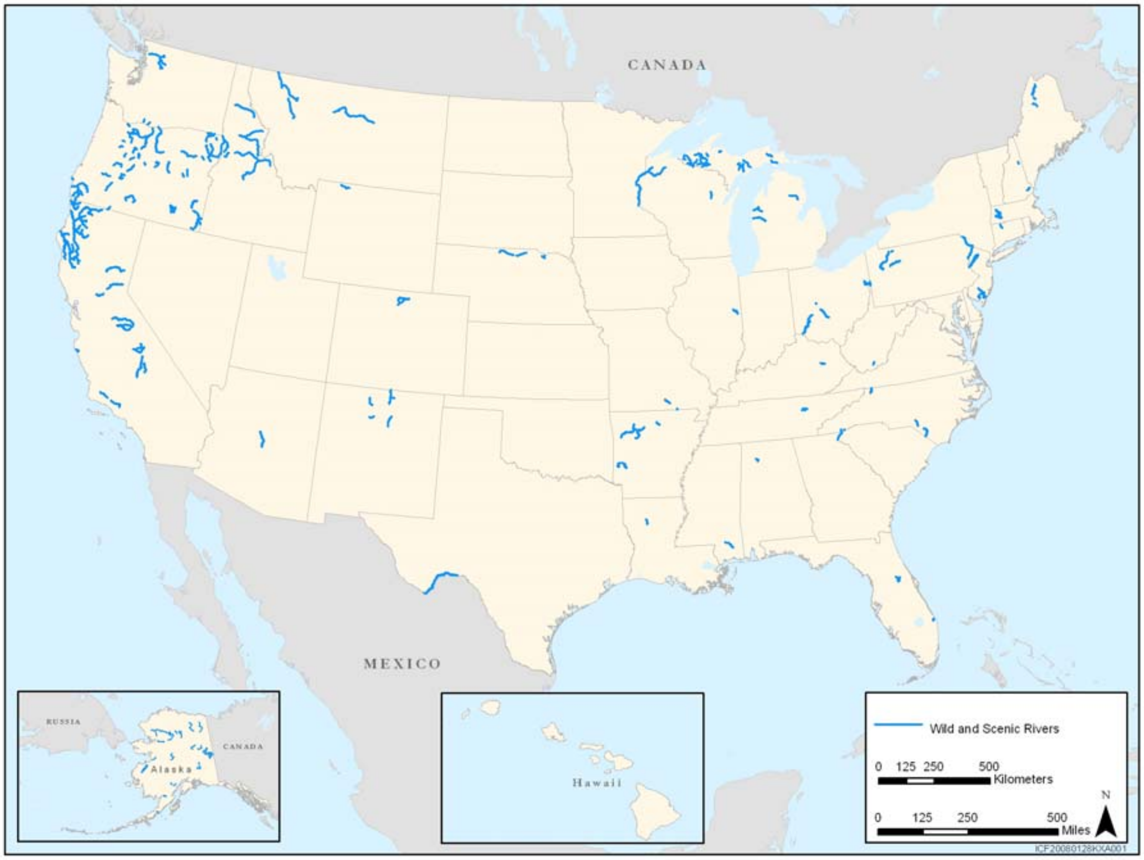
Conclusions

The Upper Delaware River currently has good water quality and provides natural and scenic resources for residents of nearby urban areas. However, recent acute climatic events and projected climate change strongly suggest that new management programs must be considered by the Delaware River Basin Commission, local communities, and private interests that manage land and water resources in the basin and Upper Delaware WSR corridor. Reservoir and landscape management to reduce impacts of floods, to manage flow regime and water temperature, and to expand water conservation programs will become increasingly important as the population continues to grow and impacts of climate change increase.

6.10 Figures

Figure 6.1. Photo of Snake River below Hell’s Canyon Dam. Photograph courtesy 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.[3]



Note: this map is missing three Wild and Scenic Rivers updated through 2006. The Missouri River in Nebraska, White Clay Creek in Delaware and Pennsylvania, and Wilson Creek in North Carolina will be included in the final version.

Figure 6.3. Selected milestones in the evolution of the Wild and Scenic Rivers system. Adapted from National Wild and Scenic Rivers System website.[4]

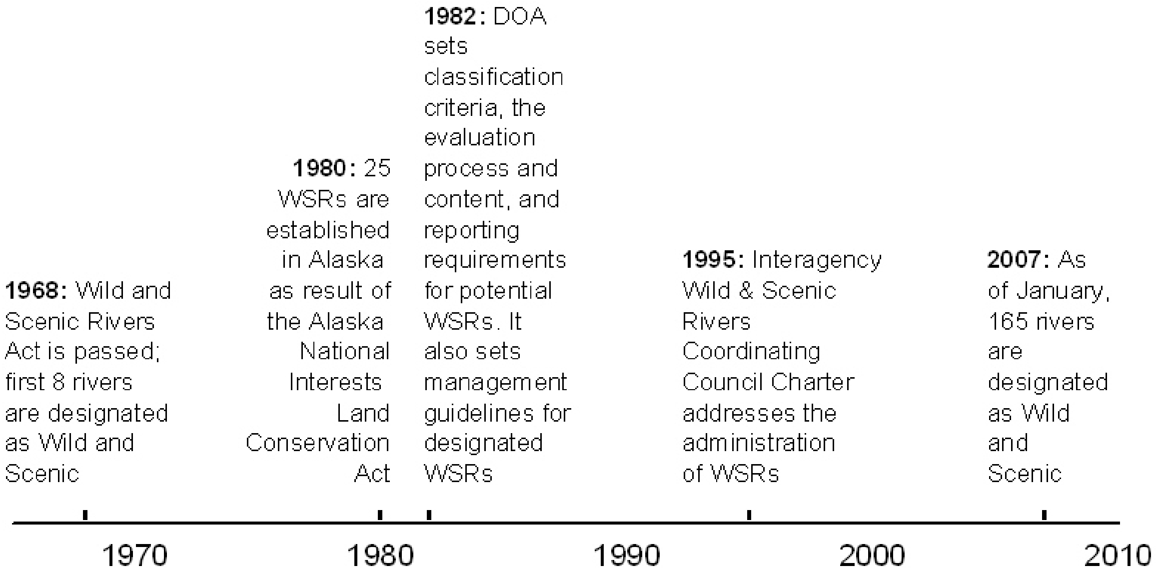


Figure 6.4. Conditions and factors affecting the future conditions of Wild and Scenic Rivers.

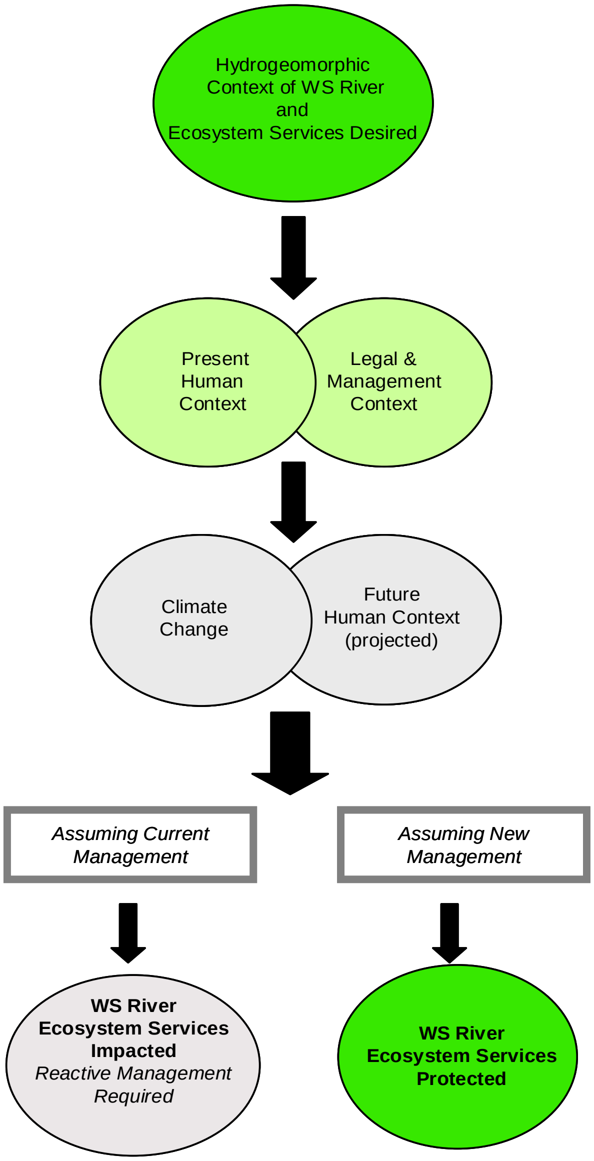


Figure 6.5. Illustration of natural flow regimes from four unregulated streams in the United States: (a) the upper Colorado River (CO), (b) Satilla Creek (GA), (c) Augusta Creek (MI), and (d) Sycamore Creek (AZ). For each the year of record is given on the x-axis, the day of the water year (October 1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

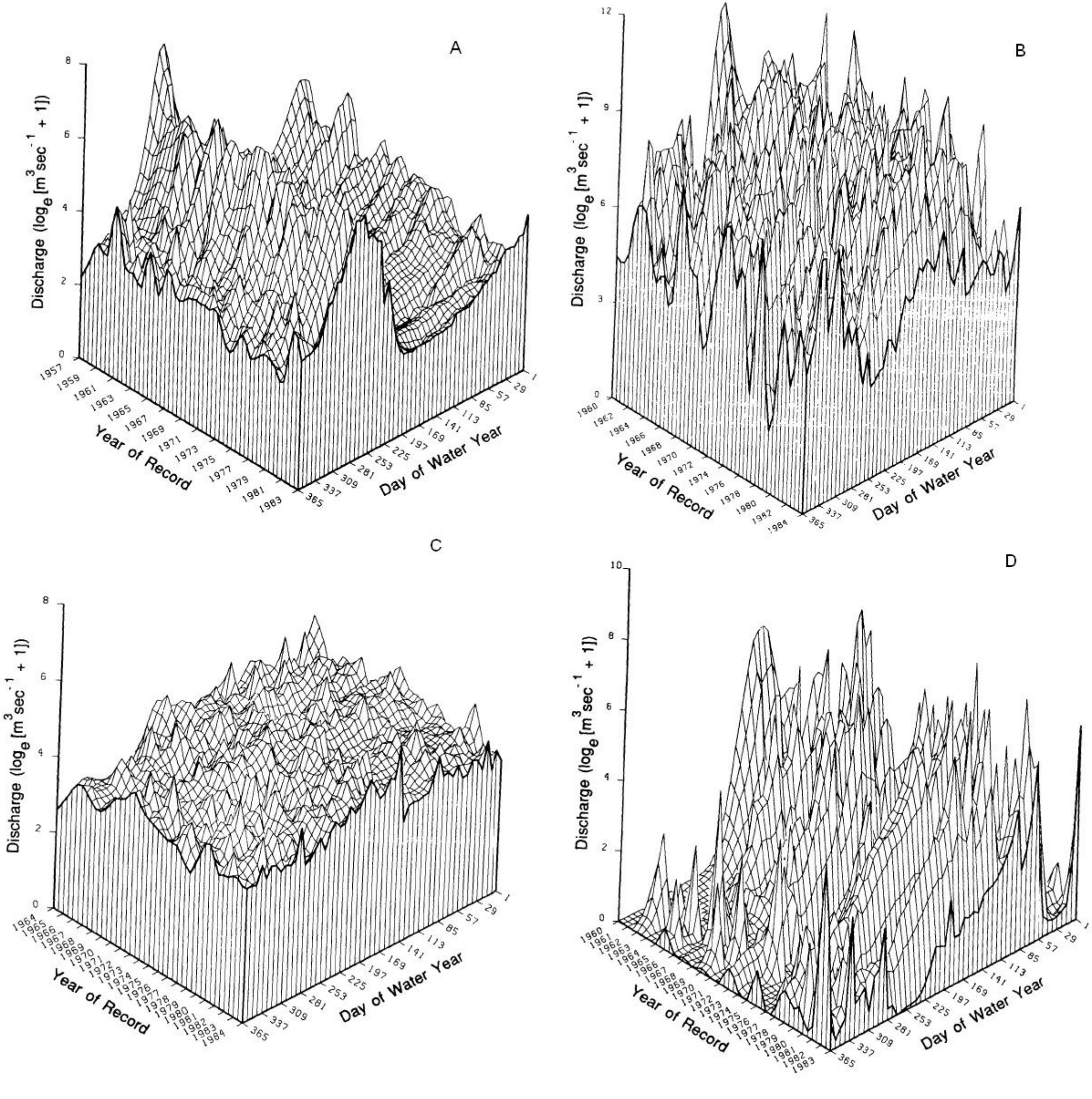


Figure 6.6. Trends in water withdrawals by water-use category. As the population has grown, water has been increasingly withdrawn for public use since 1950 as indicated by total withdrawals (blue line). Water withdrawn for power production and water for irrigation represent largest use, followed by water for industrial uses, then public supply.[5]

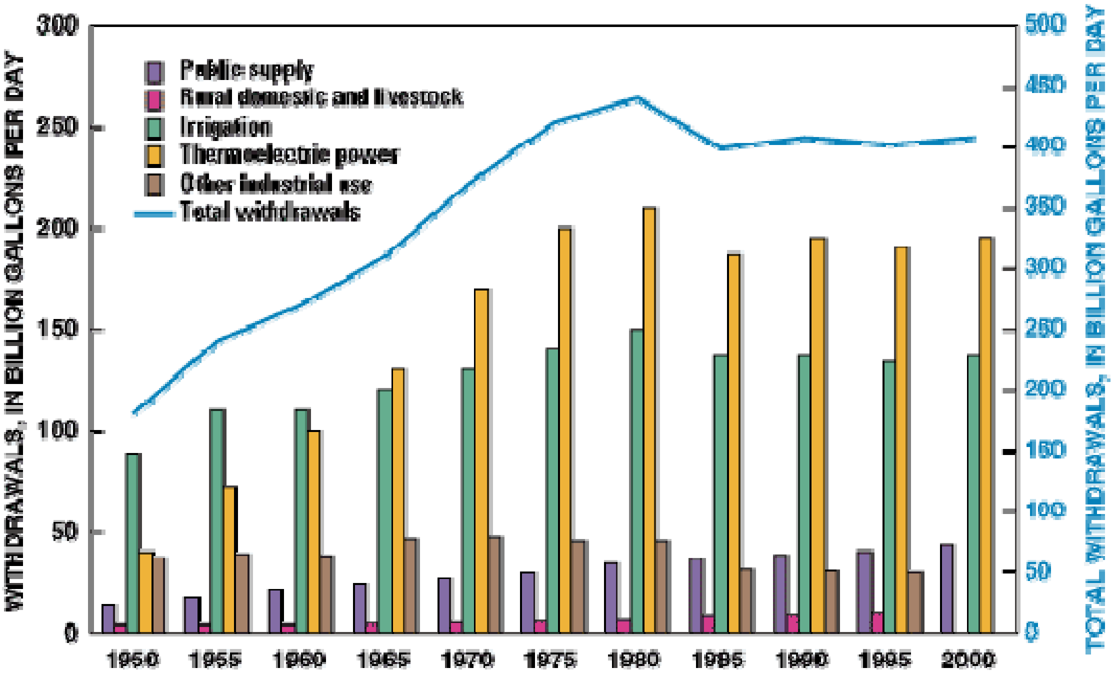


Figure 6.7. Changes in monthly average river flows on the Delaware River, in the Upper Delaware Scenic and Recreational River segment. Lowered flows in December–July result from upstream depletions for New York City water supply. Increased flows result from upstream reservoir releases during summer months for the purpose of controlling salinity levels in the lower Delaware. Figure based on data provided by USGS.[7]

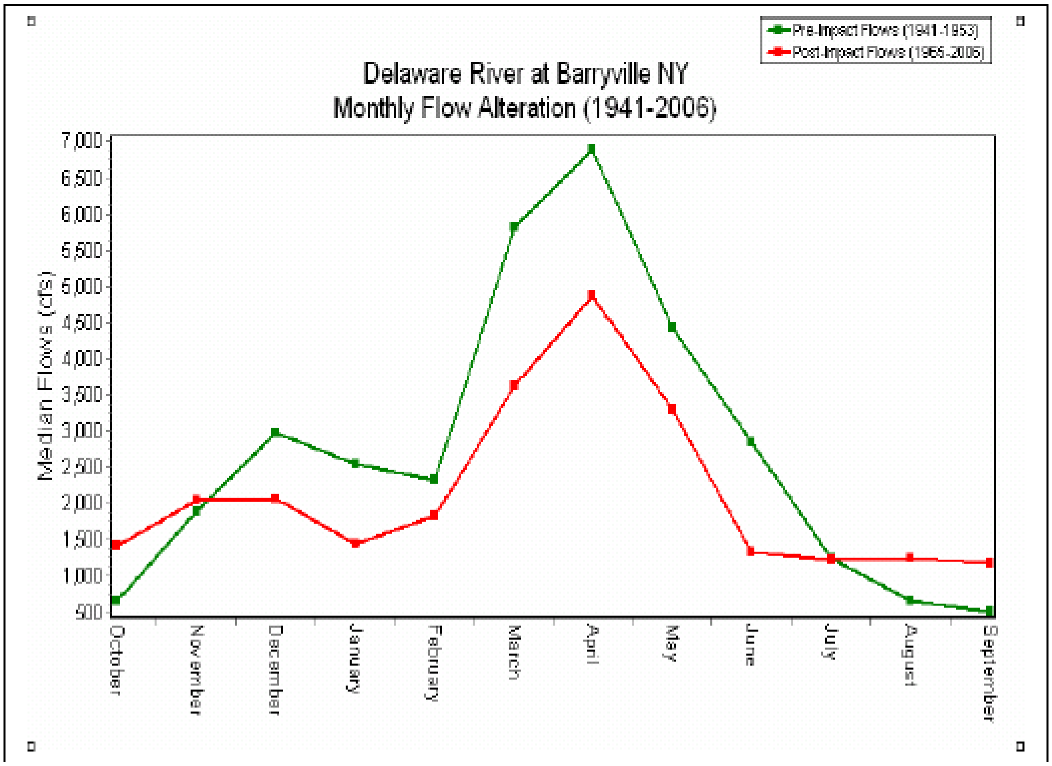
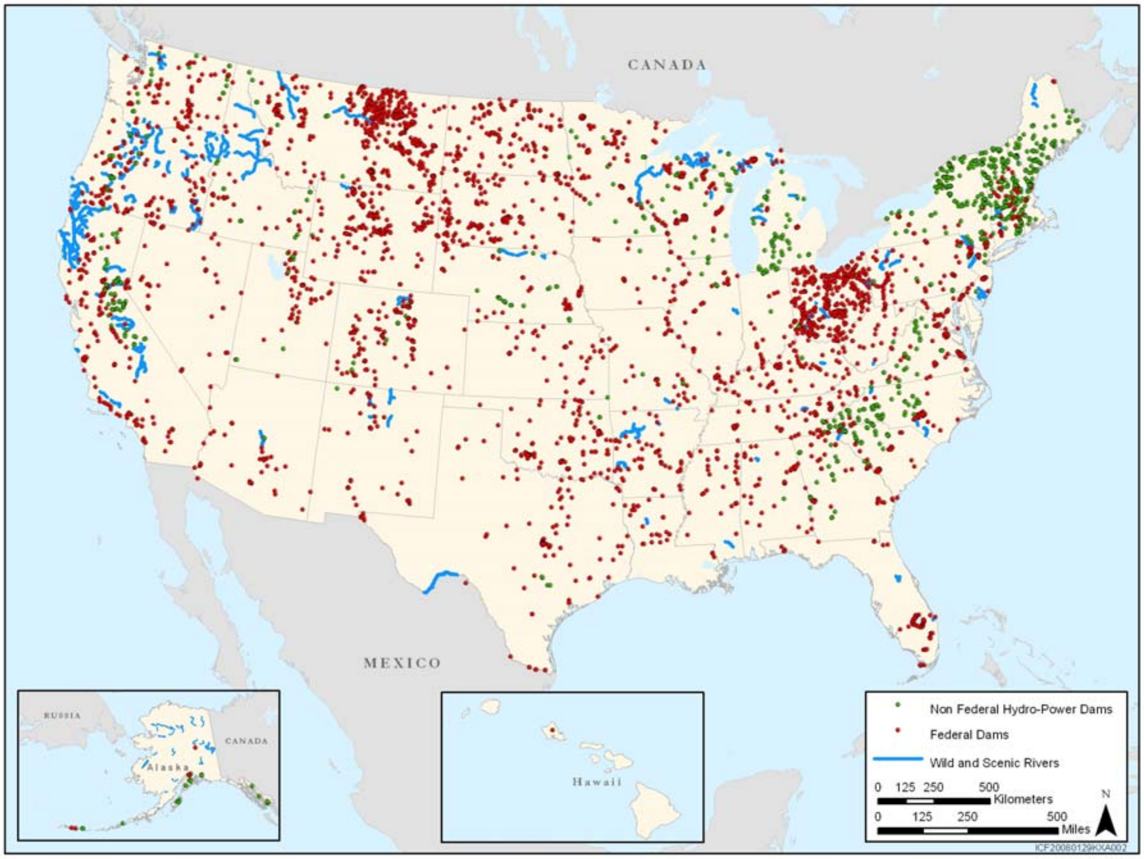


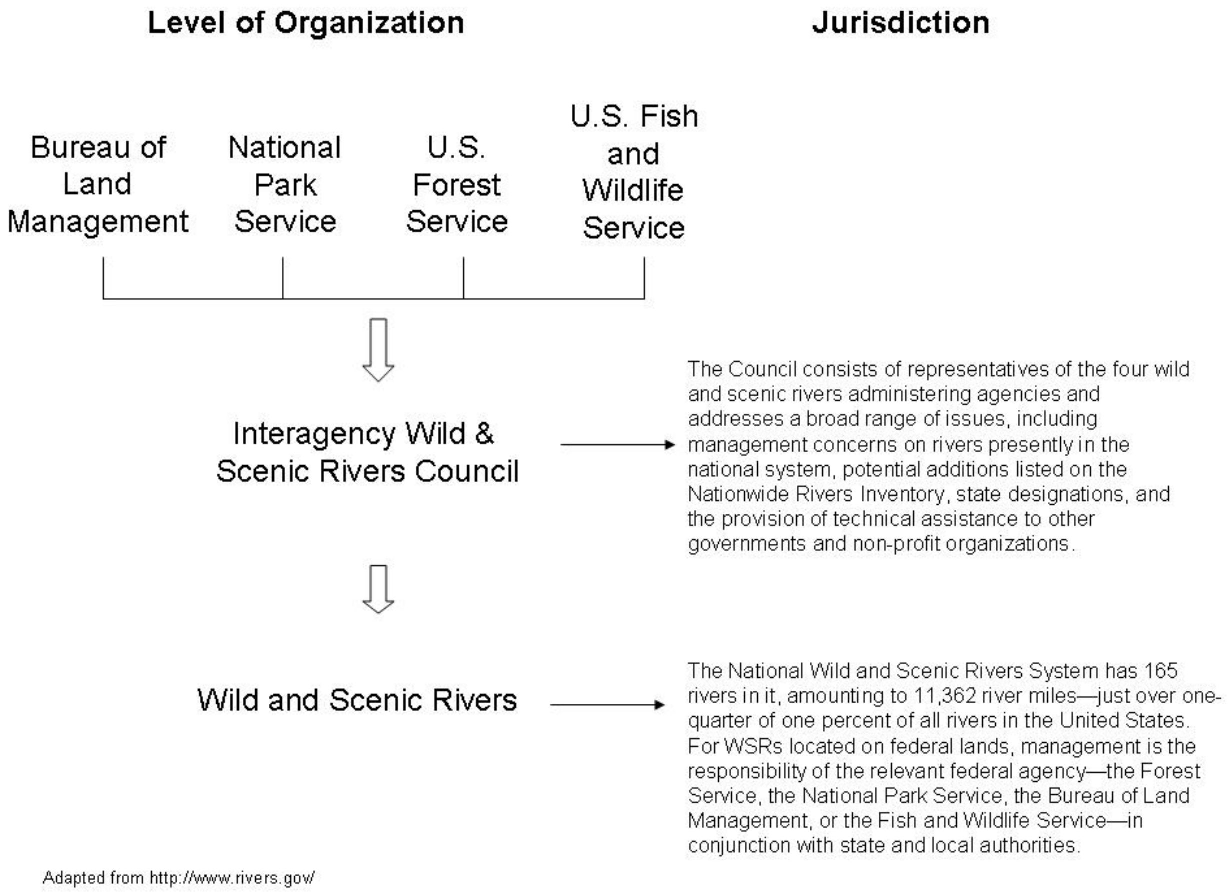
Figure 6.8. Location of dams and WSRs in the United States. Data from USGS, National Atlas of the United States.[3]



Note: map is missing three Wild and Scenic Rivers updated through 2006. The Missouri River in Nebraska, White Clay Creek in Delaware and Pennsylvania, and Wilson Creek in North Carolina will be included in the final version.

Figure 6.9. Photo of scientists standing on the bed of an urban stream whose channel has been incised more than 5 m due to 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.[4]



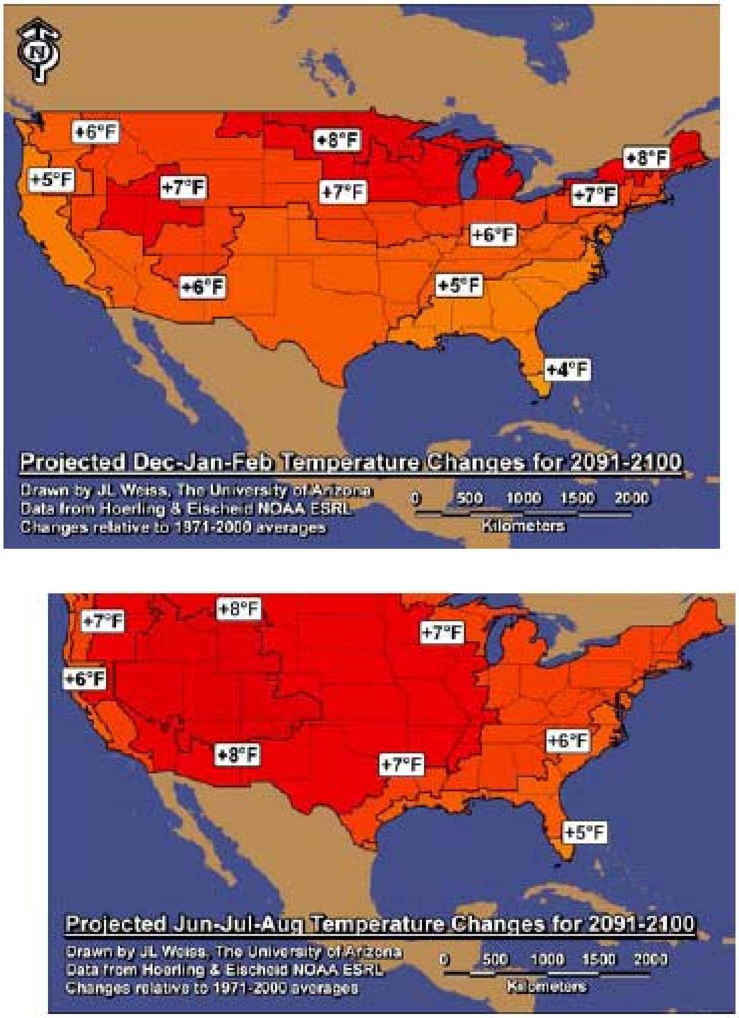
The Council consists of representatives of the four wild and scenic rivers administering agencies and addresses a broad range of issues, including management concerns on rivers presently in the national system, potential additions listed on the Nationwide Rivers Inventory, state designations, and the provision of technical assistance to other governments and non-profit organizations.

The National Wild and Scenic Rivers System has 165 rivers in it, amounting to 11,362 river miles—just over one-quarter of one percent of all rivers in the United States. For WSRs located on federal lands, management 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 state and local authorities.

Adapted from http://www.rivers.gov/

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

Figure 6.12. Projected temperature changes for 2091-2100.[15]



Projected Dec-Jan-Feb Temperature Changes for 2091-2100

Drawn by JL Weiss, The University of Arizona
Data from Hoerling & Eischeid NOAA ESRL
Changes relative to 1971-2000 averages

Projected Jun-Jul-Aug Temperature Changes for 2091-2100

Drawn by JL Weiss, The University of Arizona
Data from Hoerling & Eischeid NOAA ESRL
Changes relative to 1971-2000 averages

(www.geo.arizona.edu/dgesl/research/regional/projected_US_climate_change.htm

Figure 6.13. Projected annual precipitation changes for 2091-2100.[15]

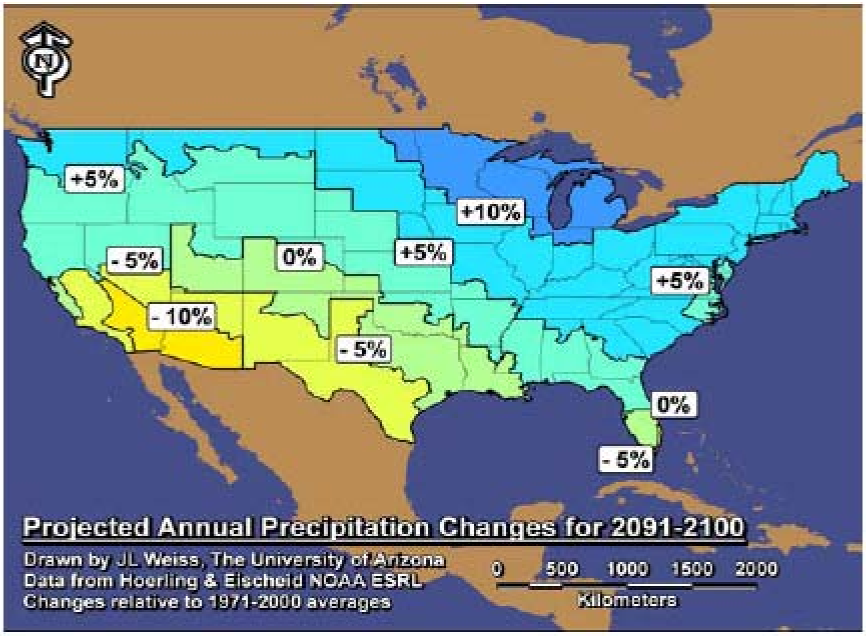


Figure 6.14. Median, over 12 climate models, of the percent changes in runoff from United States water resources regions for 2041–2060 relative to 1901–1970. More than 66% of models agree on the sign of change for areas shown in color; diagonal hatching indicates greater than 90% agreement. Recomputed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

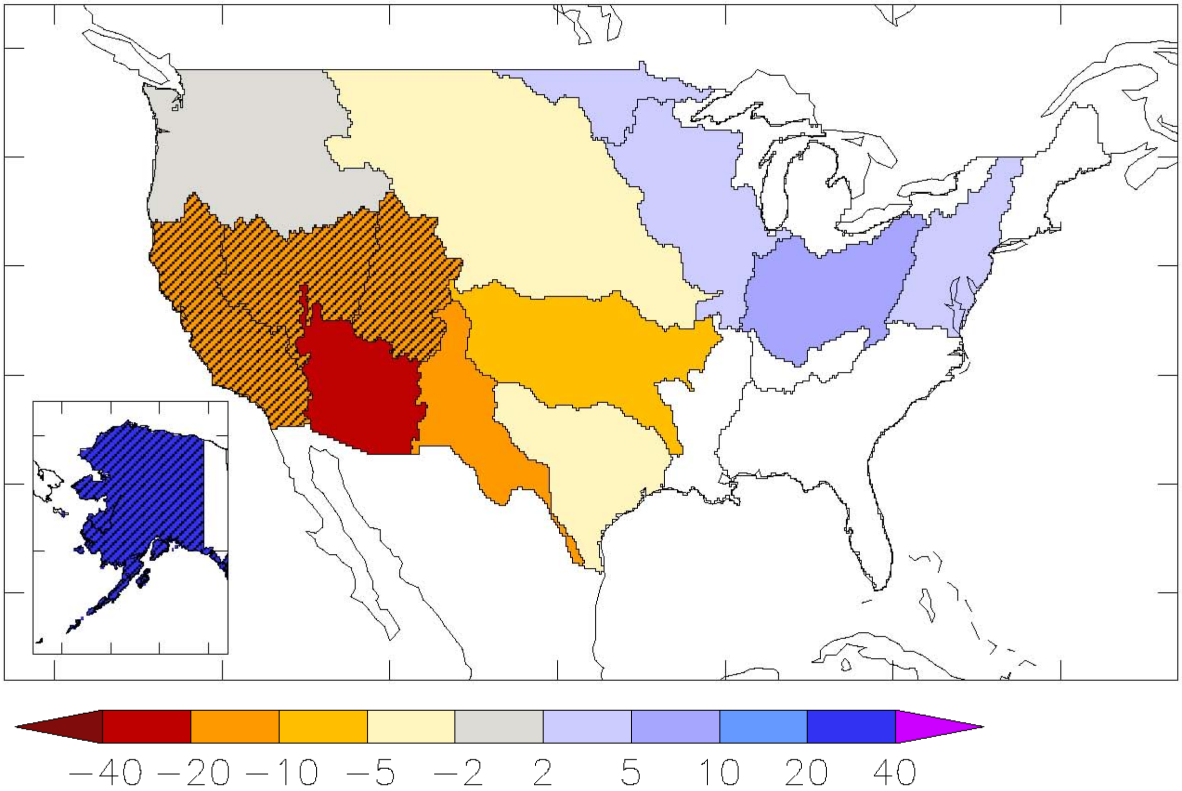


Figure 6.15. Photo of snowmelt in WSR during winter-spring flows. Photo courtesy of National Park Service, Lake Clark National Park & Preserve.

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).

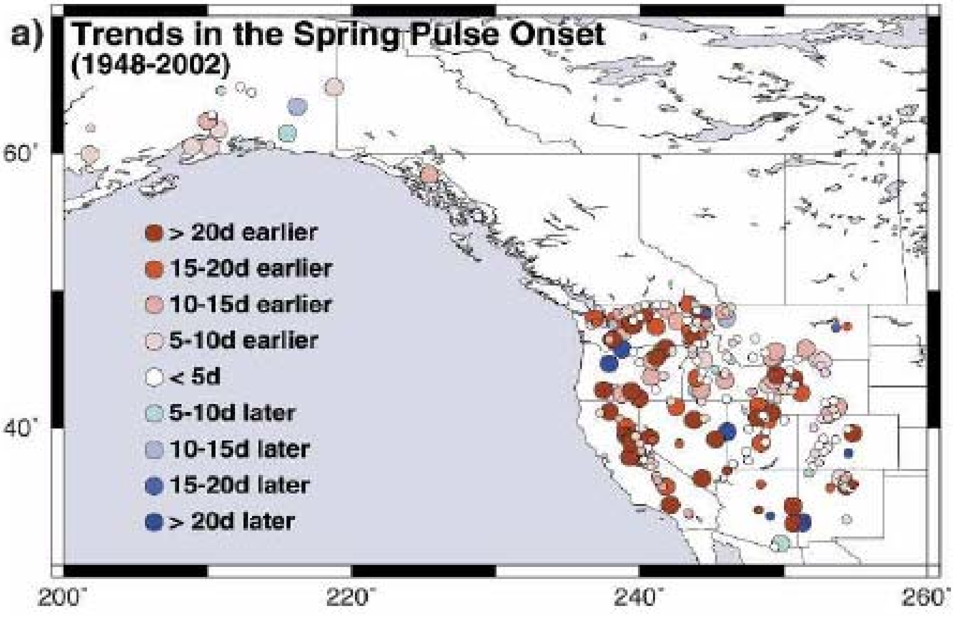


Figure 6.17. Very rapid increases (1–4 hours) in water temperature (temperature “spikes”) in urban streams north of Washington D.C. have been found to follow local rain storms. *Top graph:* dark line shows stream discharge that spikes just after a rainfall in watersheds with large amounts of impervious 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).

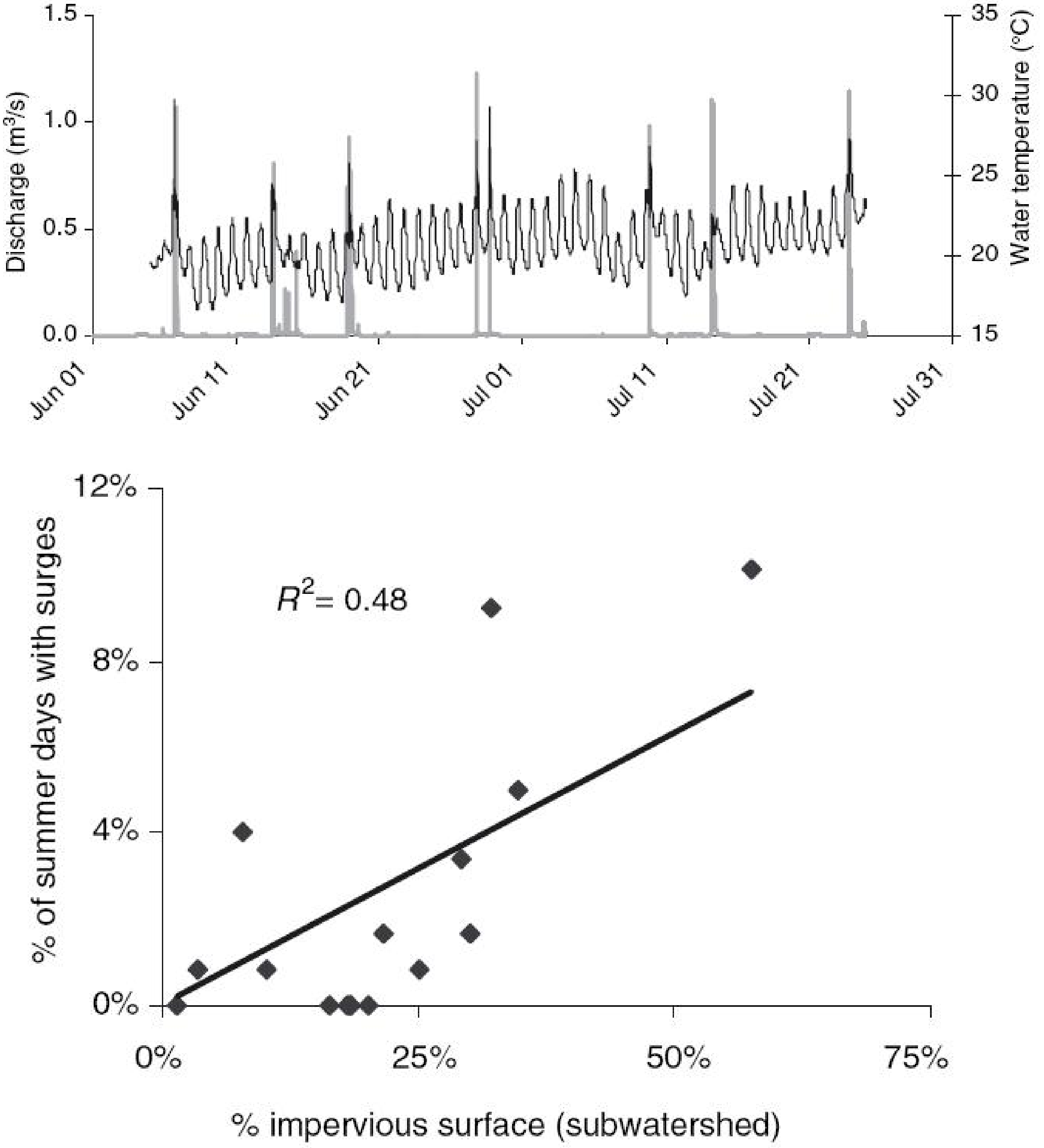


Figure 6.18. Water stress projected for the 2050s based on withdrawals-to-availability ratio, where availability corresponds to annual river discharge (combined surface runoff and groundwater recharge). From Alcamo, Flörke, and Märker (2007).