

6 Wild and Scenic Rivers

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1	Chapter Contents	
2		
3	6.1 Background and History	6-4
4	6.2 Current Status of Management System.....	6-5
5	6.2.1 Framework for Assessing Present and Future Status.....	6-5
6	6.2.2 Hydrogeomorphic Context.....	6-6
7	6.2.3 Present Human Context	6-9
8	6.2.4 The Policy Context: Present Management Framework Legal and Management	
9	Context.....	6-14
10	6.3 Adapting to Climate Change.....	6-19
11	6.3.1 Climate Change Impacts	6-19
12	6.3.2 Future Human Context: Interactive Effects of Multiple Stressors.....	6-22
13	6.3.3 Ecosystem Goods and Services Assuming Present Management.....	6-24
14	6.3.4 Options for Protection Assuming New Management	6-27
15	6.4 Case Studies	6-31
16	6.4.1 Wekiva River Case Study	6-32
17	6.4.2 Rio Grande Case Study.....	6-37
18	6.4.3 Upper Delaware River Case Study	6-42
19	6.5 Conclusions.....	6-46
20	6.6 References.....	6-47
21	6.7 Acknowledgements.....	6-59
22	6.8 Boxes.....	6-60
23	6.9 Figures.....	6-67
24		

Chapter Structure

6.1 Background and History

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

6.2 Current Status of Management System

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

6.3 Adapting to Climate Change

Discusses approaches to adaptation for planning and management in the context of climate change

6.4 Case Studies

Explores methods for and challenges to incorporating climate change into specific management activities and plans for three WSRs

Wekiva River

Rio Grande

Upper Delaware River

6.5 Conclusions

1
2

1 **6.1 Background and History**

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

9
 10 Oxbow is situated just below Hell’s Canyon—North America’s deepest river gorge—which was
 11 carved by the Snake River and remains one of the largest wilderness areas in the West. In the
 12 1950s, this gorge contained one of the last free-flowing stretches of the Snake River (Fig. 6.1)
 13 and became the focus of a major fight that spanned two decades. Idaho Senator Frank Church
 14 played a pivotal role in deciding who would build dams and where they would be built (Ewert,
 15 2001). As a New Deal Democrat, Church had supported development and dam construction that
 16 he felt were keys to the growth and prosperity of Idaho. However, the Oxbow Incident had a
 17 profound effect on Church. He witnessed the severe effect of dams on fisheries, and even began
 18 to ponder the value of riverine corridors to wildlife and their growing value to tourism and
 19 recreation.

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 21
 22
 23
 24 **Fig. 6.1.** Photo of Snake River below Hell’s Canyon Dam. Photograph compliments of
 25 Marshall McComb, Fox Creek Land Trust.

26
 27 Frank Church’s efforts in the U.S. Senate resulted in passage of the national Wild and Scenic
 28 Rivers Act in 1968. While it was not until 1975 that the Hell’s Canyon of the Snake River was
 29 designated as wild and scenic, two of the eight rivers originally designated as wild and scenic
 30 were in Idaho.

31
 32 Fundamental to the Act was the desire to preserve select rivers with “outstandingly remarkable
 33 values” in a “free-flowing condition.” The Act defines free-flowing as “existing or flowing in
 34 natural condition without impoundment,” and the term generally has been interpreted to mean
 35 that water quality is high and there are no major dams or obstructions within the stretch of river
 36 to be designated, although there can be impoundments upstream. The “outstandingly remarkable
 37 values” encompass a range of scenic, biological, and cultural characteristics that are valued by
 38 society. The management goals for Wild and Scenic Rivers (WSRs) center on the preservation
 39 and protection of these conditions and values (Box 6.1).

40
 41 There are currently 165 WSRs across the country, representing more than 11,000 stream miles
 42 (Fig. 6.2). Oregon ranks highest with 46 designations, most of which were designated in 1988
 43 when a large number of forest management plans were developed to deal with concerns over
 44 salmonids. Alaska follows with 25 WSRs that became designated as a result of the Alaska
 45 National Interests Land Conservation Act in 1980. This act created nearly 80 million acres of

1 wildlife refuge land in Alaska, much of which is wilderness. Michigan and California are the
 2 only other states with a significant number of rivers that have the wild and scenic designation (16
 3 and 13, respectively); however, most states have at least one designated river or river segment.
 4 Selected milestones in the evolution of the Wild and Scenic Rivers system are shown in Fig. 6.3.

5
 6
 7 **Fig. 6.2.** Wild and Scenic Rivers in the United States. Data from USGS, National Atlas of
 8 the United States (2005).

9
 10
 11 **Figure 6.3.** Selected milestones in the evolution of the Wild and Scenic Rivers system.
 12 Adapted from National Wild and Scenic Rivers System website (2007a).

13
 14 As severe as the dam effects were on fisheries in Oxbow, Idaho, there is equal or greater concern
 15 today about the potential future impacts of climate change on WSRs. Climate change is expected
 16 to alter regional patterns in precipitation and temperature, and this has the potential to change
 17 natural flow regimes at regional scales. The ecological consequences of climate change and the
 18 required management responses for any given river will depend on how extensively the
 19 magnitude, frequency, timing, and duration of key runoff events change relative to the historical
 20 pattern of the natural flow regime for that river, and how adaptable the aquatic and riparian
 21 species are to different degrees of alteration.

22 **6.2 Current Status of Management System**

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

32
 33 Because the original intent of the Wild and Scenic Rivers Act was to protect rivers from the
 34 harmful effects of water resource projects, the Federal Energy Regulatory Commission is
 35 prohibited from licensing new dams or diversions that would alter the free-flowing character of
 36 designated rivers or diminish their outstanding character. However, because the Act allows
 37 existing uses of a river to continue, today there are actually a number of segments designated
 38 wild and scenic that are within dammed watersheds.

39 **6.2.1 Framework for Assessing Present and Future Status**

40 Climate change is expected to have a significant impact on running waters throughout the world,
 41 not only in terms of changes in flow magnitude and timing, but in terms of thermal regimes and
 42 the flora and fauna that currently inhabit these waters (Sala *et al.*, 2000). The focus in this
 43 chapter is not only on identifying the likely impacts of climate change, but also identifying

1 management options for protecting riverine ecosystems and their values against these impacts.
2 However, rivers across the United States have been designated as wild and scenic for diverse
3 reasons, and they exist in diverse settings. Thus climate change is not the only risk they face.
4

5 Anticipating the future condition of a river in the face of climate change requires explicit
6 consideration not only of the current climatic, hydrogeologic, and ecological conditions (the
7 *hydrogeomorphic context*), but also of how it is currently management and how human behavior
8 will affect the river (the *human context*) (Fig. 6.4). Even if impacts are small at present,
9 consideration of the human context is critical to a river’s future unless it is within a fully
10 protected basin. If it is not, then impacts associated with activities such as development and
11 water withdrawals are likely to become issues in the future. Stress associated with the *future*
12 *human context* will interact with climate change, often exacerbating problems and intensifying
13 management challenges (Fig. 6.4)
14
15
16

17 **Figure 6.4.** Conditions and factors affecting the future conditions of Wild and Scenic
18 Rivers.
19

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

25 **6.2.2 Hydrogeomorphic Context**

26 **6.2.2.1 Ecosystem Goods and Services**

27 WSRs provide a special suite of goods and services valued highly by the public (Box 6.2) that
28 are inextricably linked to their flow dynamics and the interaction of flow with the landscape. The
29 ecological processes that support these goods and services are fueled by the movement of water
30 as it crosses riparian corridors, floodplains, and the streambed transporting nutrients, sediment,
31 organic matter, and organisms. Thus, water purification, biological productivity and diversity, as
32 well as temperature and flood control are all mediated by interactions between the local
33 hydrology and geologic setting. For this reason, the particular goods and services offered by
34 WSRs vary greatly across the nation, reflecting the great variety of landscape settings and
35 climates in which WSRs occur.
36

37 The Rogue River in Oregon supports whitewater rafting through dramatic gorges, while the
38 Loxahatchee River in Florida supports highly productive cypress swamp. The goods and services
39 provided by any river depend in no small measure on how “healthy” it is, *i.e.*, the degree to
40 which the fundamental riverine processes that define and maintain the river’s normal ecological
41 functioning are working properly. One of the main threats of climate change to WSRs is that it
42 may modify these critical underlying riverine processes and thus diminish the health of the
43 system, with potentially great ecological consequences. Of particular concern is the possibility
44 that climate-induced changes can exacerbate human-caused stresses, such as depletion of water

1 flows, already affecting these rivers. The likelihood of this happening will depend on the current
2 conditions in the river and the extent to which future changes in precipitation and temperature
3 differ from present conditions.

4
5 Although every river is arguably unique in terms of the specific values it provides and the
6 wildlife it supports, an important scientific perspective is to identify the general underlying
7 processes that dictate how a river functions, so that researchers may consider the vulnerabilities
8 of these systems to climate change. This report uses the phrase “hydrogeomorphic context” to
9 mean the combination of fundamental riverine processes that interact with the particular
10 landscape setting of a river to define its fundamental character and potential for ecological
11 resilience in the face of natural variation and future climate change.

12
13 From a physical perspective, rivers function to move water and sediment off the landscape and
14 downhill toward the sea. The regime of rainfall and the geology of a river’s watershed control
15 landscape soil erosion rates and influence how fast precipitation falling on a watershed is moved
16 to the river channel, as well as the likelihood that the channel will develop an active floodplain
17 (Knighton, 1998). Thus, a river’s hydrogeomorphic context is largely defined by the nature of
18 the flow regime and the river’s channel features. For example, rivers flowing through steep
19 mountains with bedrock canyons and boulder-strewn beds, such as Colorado’s Cache la Poudre
20 River, represent very different environments than rivers flowing slowly across flat land where
21 channels can be wide and meandering due to sandy banks, such as Mississippi’s Black Creek.
22 Likewise, rivers draining watersheds with porous soils and high groundwater levels respond very
23 sluggishly to rainfall storm events, compared with those that drain impervious soils and show a
24 rapid flood response to heavy rains (Paul and Meyer, 2001). Such differences exert strong
25 control over the temporal dynamics of critical low and high flow events and thus directly
26 influence many ecological processes and populations of aquatic and riparian species (Poff *et al.*,
27 1997; Bunn and Arthington, 2002).

28
29 But the hydrogeomorphic context can also be extended beyond precipitation and geology.
30 Specifically, the thermal regime of a river is also a critical component of its fundamental nature,
31 because water temperature directly controls animal and plant metabolism and thus influences the
32 kinds of species that can flourish in a particular environment and the rates of biogeochemical
33 processes within the river ecosystem (Ward, 1992; Allan, 1995). This thermal response explains
34 the categorization of fishes as being either cold-water species (*e.g.*, trout, salmon) or warm-water
35 species (*e.g.*, largemouth bass) (Eaton and Scheller, 1996; Beitinger, Bennett, and McCauley,
36 2000). Regional climate largely determines air temperature, and hence water temperature
37 (Nelson and Palmer, 2007), and this factor also influences whether precipitation falls as rain or
38 snow. When it falls as snow, regional climate also influences the time and rate of melt to provide
39 the receiving river with a prolonged pulse of runoff.

40
41 At a broad, national scale, it is important to appreciate the differences in hydrogeomorphic
42 context of WSRs. Not only do these differences influence the kind and quality of human
43 interactions with WSRs, they also serve to generate and maintain ecological variation. For
44 example, the cold and steep mountain rivers of the West, such as Montana’s Flathead River,
45 support different species of fish and wildlife compared with the warmer rivers in the South, such
46 as the Lumber River in the south-central coastal plains of North Carolina. Aquatic and riparian

1 species are adapted to these local and regional differences (Lytle and Poff, 2004; Naiman,
2 Décamps, and McClain, 2005), thereby generating great biodiversity across the full range of
3 river types across the United States. The wide geographic distribution of WSRs is important not
4 only in ensuring large-scale biodiversity but also the concomitant ecosystem processes
5 associated with different river systems. This is particularly true for “wild” rivers, *i.e.*, those that
6 are not dammed or heavily modified by human activities and that are protected over the long
7 term due to their WSR status. Thus, wild rivers across the United States can serve as a valuable
8 natural repository of the nation’s biological heritage (*e.g.*, Poff *et al.*, 2007; Moyle and Mount,
9 2007), and the threats of climate change to this ecological potential is of great national concern.

10 **6.2.2.2 What it Means to be Wild**

11 One of the key defining features of a “wild” river is its natural flow regime; *i.e.*, the day-to-day
12 and year-to-year variation in the amount of water flowing through the channel. Research over the
13 last 10 years has clearly demonstrated that human modification of the natural flow regime of
14 streams and rivers degrades the ecological integrity and health of streams and rivers in the
15 United States and around the world (Poff *et al.*, 1997; Richter *et al.*, 1997; Bunn and Arthington,
16 2002; Postel and Richter, 2003; Poff *et al.*, 2007).

17
18 From an ecological perspective, some of the key features of a natural flow regime are the
19 occurrence of high flood flows and natural drought flows. These flows act as natural
20 disturbances that exert strong forces of natural selection on species, which have adapted to these
21 critical events over time (Lytle and Poff, 2004). But it’s not just the magnitude of these critical
22 flows that is ecologically important; it’s also their frequency, duration, timing, seasonal
23 predictability, and year-to-year variation (Poff *et al.*, 1997; Richter *et al.*, 1997; Lytle and Poff,
24 2004), because various combinations of these features can dictate the success or failure of
25 aquatic and riparian species in riverine ecosystems. Thus, for example, a river that has frequent
26 high flows that occur unpredictably at any time of the year provides a very different natural
27 environment than one that typically has only one high flow event predictably year-in and year-
28 out.

29
30 Across the United States there are large differences in climate and geology, and thus there is a
31 geographic pattern to the kinds of natural flow regimes across the nation. This is illustrated in
32 Fig. 6.5. from Poff and Ward (1990). For example, in the Rocky Mountain states and in the
33 northern tier of states, most annual precipitation falls in the winter in the form of snow, which is
34 stored on the land until the spring, when it melts and enters the rivers as an annual pulse (Fig.
35 6.5a). In more southerly regions where there is frequent rainfall, floods can occur unpredictably
36 and flow regimes are much more variable over days to weeks (Fig 6.5b). In watersheds with
37 highly permeable soils, such as those in Michigan, falling rain infiltrates into the ground and is
38 delivered slowly to the stream as groundwater (Fig. 6.5c). The frequency of floods and river low
39 flows depends on precipitation patterns and specific hydrologic conditions within a given
40 watershed. Yet other streams may be seasonally predictable but present harsh environments
41 because they cease to flow in some seasons (Fig. 6.5d).

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43
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1 **Figure 6.5.** Illustration of natural flow regimes from four unregulated streams in the
 2 United States, (a) the upper Colorado River (CO), (b) Satilla Creek (GA), (c) Augusta
 3 Creek (MI), and (d) Sycamore Creek (AZ). For each the year of record is given on the x-
 4 axis, the day of the water year (October 1–September 30) on the y-axis, and the 24-hour
 5 average daily streamflow on the z-axis (Poff and Ward, 1990).
 6

7 These different flow regime types result in very different hydrogeomorphic contexts, which in
 8 turn support very different ecological communities. For example, Montana’s Upper Missouri
 9 River supports extensive stands of native cottonwood trees along the riverbanks. These trees
 10 become established during annual peak flows that jump the banks and create favorable
 11 establishment conditions during the annual snowmelt runoff event. Arkansas’ Buffalo River is
 12 nestled in the Ozark Mountains and supports a tremendous diversity of fish and other aquatic life
 13 such as native mussels, as well as diverse riparian tree species. This near-pristine river is
 14 seasonally very dynamic, due to the steep mountain topography and rapid runoff from frequent
 15 rainfall events. Florida’s Wekiva River is a flatwater system that is heavily influenced by
 16 groundwater and streamside wetlands that store and release water to the river over the year. This
 17 creates a highly stable flow regime and stable wetland complexes that support a great diversity of
 18 plant species and community types.
 19

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

25 **6.2.3 Present Human Context**

26 To the American public, the designation of a river as “Wild and Scenic” conjures an image of a
 27 river protected in pristine condition, largely unchanged by human development. However, as
 28 mentioned above, in reality many of the rivers in the WSR system have experienced considerable
 29 ecological degradation from a variety of human activities.
 30

31 Due to their vulnerable position as the lowermost features of landscapes, rivers are the recipients
 32 of myriad pollutants that flush from the land, the bearers of sediment loads washed from
 33 disturbed areas of their watersheds, and the accumulators of changes in the hydrologic cycle that
 34 modify the volume and timing of surface runoff and groundwater discharge. As Aldo Leopold
 35 once said, “It is now generally understood that when soil loses fertility, or washes away faster
 36 than it forms, and when water systems exhibit abnormal floods and shortages, the land is sick”
 37 (Leopold, 1978). Because rivers are integrators of changes in a watershed, they are also often
 38 indicators of ecological degradation beyond their banks.
 39

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

1 headwater river embedded in a federal wilderness area, far less susceptible to human influences
2 than the Rio Grande in Texas.

3
4 To prepare a foundation for understanding the potential consequences of climate change, this
5 report summarizes current influences and historic trends in water use and dam operations that
6 affect the ecological condition of WSRs.

7 **6.2.3.1 Water Use**

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

15
16 The depletion of river flows fundamentally alters aquatic habitats because it reduces the quantity
17 of habitat available (Poff *et al.*, 1997; Richter *et al.*, 1997; Bunn and Arthington, 2002).
18 Adequate water flows can also be important in maintaining proper water temperature and
19 chemistry, particularly during low-flow periods. The depth of water can strongly influence the
20 mobility of aquatic animals such as fish, and river levels can also influence water table levels in
21 adjacent riparian areas, particularly in rivers with high degrees of hydraulic connectivity between
22 the rivers and alluvial floodplain aquifers.

23
24 During the latter half of the 20th century, water withdrawals in the United States more than
25 doubled (Hutson *et al.*, 2004) (Fig 6.6). Virtually all of this increase occurred during 1950–1980,
26 and withdrawals leveled off in 1980–2000 even while the U.S. population grew by 24%. This
27 flattening of water withdrawals resulted primarily from lessened demand for thermoelectric
28 power and irrigation. Thermoelectric-power water withdrawals primarily were affected by
29 federal legislation that required stricter water quality standards for return flow, and by limited
30 water supplies in some areas of the United States (Hutson *et al.*, 2004). Consequently, since the
31 1970s, power plants increasingly were built with or converted to closed-loop cooling systems or
32 air-cooled systems, instead of using once-through cooling systems. Declines in irrigation
33 withdrawals are due to changes in climate, shifts in crop types, advances in irrigation efficiency,
34 and higher energy costs that have made it more expensive to pump water from ground- and
35 surface-water sources.

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

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

8
 9 Water withdrawals for urban and agricultural water supplies are having substantial impacts on
 10 the natural flow regimes of rivers across the United States, including WSRs. For example,
 11 upstream withdrawals for New York City’s water supply have depleted average annual flows in
 12 the Upper Delaware Scenic and Recreational River by 20%, with flows in some months lowered
 13 as much as 40% (Fitzhugh and Richter, 2004; Fig. 6.7). Heavy agricultural and municipal
 14 withdrawals along the Rio Grande in Colorado, New Mexico, Texas, and Mexico have
 15 increasingly depleted river flows during the past century (Collier, Webb, and Schmidt, 1996).

16
 17 While national trends in water use provide insight into large-scale factors influencing river flows
 18 in WSRs, the impact of water withdrawals on hydrologic systems varies greatly across the
 19 United States, as illustrated by Fig. 6.5. Ultimately, the consequences of water withdrawals on a
 20 specific WSR can best be understood by developing hydrologic simulation models for the local
 21 region of interest, or by examining changes or trends in river flows such as those presented in
 22 Fig. 6.7.

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 24
 25
 26 **Figure 6.7.** Changes in monthly average river flows on the Delaware River, in the Upper
 27 Delaware Scenic and Recreational River segment. Lowered flows in December–July result
 28 from upstream depletions for New York City water supply. Increased flows result from
 29 upstream reservoir releases during summer months for the purpose of controlling salinity
 30 levels in the lower Delaware. Figure based on data provided by USGS (2007).

32 **6.2.3.2 Dam Operations**

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

37
 38
 39
 40 **Figure 6.8.** Location of dams and WSRs in the United States. Data from USGS, National
 41 Atlas of the United States.

42
 43 Most dams provide substantial benefits to local or regional economies (World Commission on
 44 Dams, 2000). Hydroelectric power dams currently provide 7% of the U.S. electricity supply. By
 45 capturing and storing river flows for later use, dams and reservoirs have contributed to the

1 national supply of water for urban, industrial, and agricultural uses. Storage of water in
2 reservoirs helped to meet the steep growth in water use in the United States during the 20th
3 century, particularly for agricultural water supply. Nearly 9,000 (12%) of the U.S. dams were
4 built solely or primarily for irrigation.

5
6 However, damming of the country's rivers has come at great cost to their ecological health and
7 ecosystem services valued by society (Ligon, Dietrich, and Trush, 1995; World Commission on
8 Dams, 2000; Postel and Richter, 2003; World Wildlife Fund, 2004; Poff *et al.*, 2007). The most
9 obvious change in river character results from the conversion of a flowing river into an
10 impounded reservoir. Also obvious is the fact that dams create barriers for upstream-downstream
11 movements of mobile aquatic species such as fish. A dam can artificially divide or isolate species
12 populations, and prevent some species from completing anadromous or diadromous life cycles,
13 such as by blocking access to upriver spawning areas (Silk and Ciruna, 2005). For example,
14 Pacific salmon migrations through WSR segments on the Salmon and Snake rivers in Idaho, and
15 pallid sturgeon migrations on the Missouri River are impeded by dams. The consequences of
16 such population fragmentation have been documented for many fish species, including many
17 local extirpations following damming. Hence, dams located downstream of WSRs likely have
18 consequences for movements of aquatic animals, particularly widely ranging fish.

19
20 Dams have considerable influence on downstream river ecosystems as well, in some cases
21 extending for hundreds of miles below a dam (Collier, Webb, and Schmidt, 1996; McCully,
22 1996; Willis and Griggs, 2003). Dam-induced changes affect water temperature (Clarkson and
23 Childs, 2000; Todd *et al.*, 2005) and chemistry (Ahearn, Sheibley, and Dahlgren, 2005);
24 sediment transport (Williams and Wolman, 1984; Vörösmarty *et al.*, 2003); floodplain vegetation
25 communities (Shafroth, Stromberg, and Patten, 2002; Tockner and Stanford, 2002; Magilligan,
26 Nislow, and Graber, 2003). Dams may even affect downstream estuaries, deltas, and coastal
27 zones by modifying salinity patterns, nutrient delivery, disturbance regimes, and the transport of
28 sediment that builds deltas, beaches, and sandbars (Olsen, Padma, and Richter, Undated). Of all
29 the environmental changes wrought by dam construction and operation, the alteration of natural
30 water flow regimes (Fig. 6.5) has had the most pervasive and damaging effects on river
31 ecosystems (Poff *et al.*, 1997; Postel and Richter, 2003). Dams can heavily modify the
32 magnitude (amount) of water flowing downstream, change the timing, frequency, and duration of
33 high and low flows, and alter the natural rates at which rivers rise and fall during runoff events.

34
35 The location of a WSR relative to upstream dams can have great influence on the ecological
36 health of the WSR. As a general rule, ecological conditions improve with distance downstream
37 of dams due to the influence of tributaries, which moderate dam-induced changes in water flow,
38 sediment transport, water temperature, and chemistry. For example, flow alterations associated
39 with hydropower dams in the Skagit River are most pronounced immediately downstream of the
40 dams, but lessen considerably by the time the river reaches its estuary. It is quite difficult to
41 assess the dam-induced biophysical changes that have transpired in WSRs, because long-term
42 measurements of sediment, temperature, water quality, and biological conditions are rarely
43 available. However, for many rivers, dam-related changes to hydrologic regimes can be
44 evaluated by examining streamflow changes before and after dams were built (see Fig. 6.7 for
45 example).

1 **6.2.3.3 Land-Use Changes**

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

10
11 Nearly half of the billion hectares of land in the United States has been cultivated for crops or
12 grazed by livestock. As described above, agriculture accounts for approximately 70% of water
13 withdrawals in the United States. While most of this water is consumed through
14 evapotranspiration, the portion of irrigation water that returns to streams and rivers is commonly
15 tainted with chemicals or laden with sediment (National Research Council, 1993; U.S.
16 Geological Survey, 2001). Because much of the land converted to agricultural use in recent
17 decades has been wetlands and riparian areas, this conversion has severely affected the natural
18 abilities of landscapes to absorb and filter water flows. Major pollutants in freshwater
19 ecosystems include excessive sediment, fertilizers, herbicides, and pesticides (Silk and Ciruna,
20 2005). Agriculture is the source of 60% of all pollution in U.S. lakes and rivers; nitrogen is the
21 leading pollution problem for lakes and the third most important pollution source for rivers in the
22 United States (U.S. Environmental Protection Agency, 2000). The U.S. Geologic Survey
23 National Water Quality Assessment (NAWQA) found that most of the rivers sampled in
24 agricultural areas contained at least five different pesticides (U.S. Geological Survey, 2001),
25 including DDT, dieldrin, and chlordane. Intensive agriculture often leads to the eutrophication of
26 freshwater ecosystems, resulting in deoxygenation of water, production of toxins, and a general
27 decline in freshwater biodiversity. Agriculture is a major source of sedimentation problems as
28 well, resulting from large-scale mechanical cultivation, channelization of streams, riparian
29 clearing, and accentuated flood runoff.

30
31 After agriculture, the next three top sources of river ecosystem degradation include
32 hydromodification, urban runoff/storm sewers, and municipal point sources—all associated with
33 urban environments (Silk and Ciruna, 2005). Although urban areas occupy only a small fraction
34 of the U.S. land base, the intensity of their impacts on local rivers can exceed that of agriculture
35 (see Fig. 6.9 for an example). More than 85% of the U.S. population lives in cities, potentially
36 concentrating the impacts from urban activities and exacerbating conditions affected by rainfall
37 runoff events, such as water use, wastewater discharge, polluted surface runoff, and impervious
38 surfaces. Industrial activities located in cities pose several threats to river ecosystems, including
39 effluent discharge and risk of chemical spills, in addition to water withdrawals. The USGS
40 NAWQA program reports the highest levels of phosphorus in urban rivers. Other highly
41 problematic forms of pollution in urban areas include heavy metals, hormones and
42 pharmaceutical chemicals, and synthetic organic chemicals from household uses (U.S.
43 Geological Survey, 2001). Excellent reviews on the effects of urbanization on streams have been
44 published (Paul and Meyer, 2001; Walsh *et al.*, 2005), but in brief the most obvious impacts are
45 increases in impervious surface area resulting in increased runoff, higher peak discharges, higher
46 sediment loads, and reduced invertebrate and fish biodiversity (Dunne and Leopold, 1978;

1 Arnold, Jr. and Gibbons, 1986; McMahon and Cuffney, 2000; Walsh, Fletcher, and Ladson,
2 2005).

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

10 **6.2.4 The Policy Context: Present Management Framework Legal and Management** 11 **Context**

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

22

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

41

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

1 **6.2.4.1 Administering Agencies and Authorities**

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

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

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

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

41 **6.2.4.2 Management Plans**

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

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

14
15 The long-term protection of WSR values, including the maintenance of a designated river’s
16 “free-flowing condition,” requires that the river managers identify objectives for both water
17 flows and water quality. The Interagency Wild and Scenic Rivers Coordinating Council, a
18 government body established to coordinate management of WSRs among the responsible
19 agencies, has identified six steps to ensure that management strategies protect the river’s
20 outstandingly remarkable values and free-flowing condition: (1) clearly define the water-related
21 values to be protected, (2) document baseline conditions against which to assess future changes
22 or threats, (3) identify potential threats and protection opportunities, (4) identify an array of
23 protection options in the management plan, (5) vet the plan through legal counsel, and (6) decide
24 upon and implement the best protection strategies for achieving the management objectives for
25 the river (Interagency Wild and Scenic Rivers Coordinating Council, 2003).

26
27 In order to fulfill the Act’s intent to “protect and enhance” WSR values, the collection and
28 documentation of adequate baseline information for each WSR, along with a detailed narrative
29 description of the characteristics and values that qualified the river for the WSR designation, is
30 critical to both river managers and stakeholders. For example, a long-term record of river flows
31 is invaluable for developing a water rights claim (see water rights discussion below), and
32 background data on water quality is often essential for pursuing action to stop some proposed
33 activity that threatens a river’s ecological services and outstandingly remarkable values. In a case
34 decided in 1997, for instance, the Oregon Natural Desert Association claimed that the BLM’s
35 river management plan was failing to protect the riparian vegetation and aquatic habitat of the
36 Donner and Blitzen WSR, which studies had shown were adversely affected by livestock
37 grazing. The court ultimately determined that grazing could continue, but only in a manner that
38 fulfilled BLM’s obligation to “protect and enhance” the values that qualified the river as a WSR.
39 Without adequate baseline information, it is difficult, if not impossible to implement a “protect
40 and enhance” policy.

41
42 Since passage of the Act, scientific understanding of the ecological importance of the natural
43 variability of a river’s historic flow regime has expanded markedly (Poff *et al.*, 1997; Postel and
44 Richter, 2003; Richter *et al.*, 2003). In particular, a prior emphasis on the maintenance of
45 “minimum flows”—ensuring that some water flows in the channel—has been succeeded by the
46 more sophisticated and scientifically based “natural flow paradigm,” which calls on river

1 managers to mimic, to some degree, the variable natural flows that created the habitats and
2 ecological conditions that sustain the river’s biodiversity and valuable goods and services.
3 Especially in the face of climate change and the resulting likelihood of altered river flow
4 patterns, an understanding of the importance of a river’s historical natural flow pattern to the
5 maintenance of its ecological services will be critical to the development of effective climate
6 adaptation strategies.

7 **6.2.4.3 Legal and Management Tools**

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

14 **Water Rights Claims and Purchases**

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

24
25 Because most WSR designations are less than 30 years old, WSRs typically have very junior
26 rights in the western system of “first-in-time, first-in-right” water allocations. In over-allocated
27 western rivers, another way of ensuring flows for a WSR segment is often to purchase water
28 rights from private entities willing to sell them. In any effort to secure more flow for a WSR, the
29 CRMP developed for the river must demonstrate how the river’s outstandingly remarkable
30 values depend on a particular volume or pattern of flow, and include a strategy for protecting
31 flow-dependent river values.

32 **Environmental Flow Protections**

33
34 An environmental flow study can assist river managers in establishing scientifically based limits
35 on flow alterations that are needed to protect a WSR’s habitat, biodiversity, fishery, and other
36 values (Richter *et al.*, 1997; Postel and Richter, 2003). Where allowed by state laws, state
37 agencies (often working in partnership with federal and local authorities) may secure more flows
38 for designated rivers by legislating environmental flows, using permit systems to enforce limits
39 on flow modifications, transferring water rights for instream purposes, and implementing water
40 conservation and demand-management strategies to keep more water instream (Postel and
41 Richter, 2003; Postel, 2007). The WSR study for Connecticut’s Farmington River (pictured in
42 Fig. 6.11), for example, resulted in state water allocation authorities and a water utility
43 committing themselves to the protection of flows needed to safeguard fisheries and other flow-
44

1 dependent outstandingly remarkable values (Interagency Wild and Scenic Rivers Coordinating
2 Council, 1996).

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

8 9 **Land Protection Agreements with Landowners Adjacent to WSR Corridors**

10 Protection of the land included in the designated river corridor is critical to the protection of the
11 habitat, scenic, scientific, and other values of a WSR. The boundary of an WSR includes up to
12 320 acres per river mile (twice this for Alaskan rivers), measured from the ordinary high water
13 mark (Interagency Wild and Scenic Rivers Coordinating Council, 1996). Under the WSR Act,
14 the federal government may acquire non-federal lands, if necessary, to achieve adequate river
15 protection, but only if less than 50% of the entire acreage within the WSR boundary is in public
16 ownership. However, other options for land protection, besides acquisition, exist (Interagency
17 Wild and Scenic Rivers Coordinating Council, 1996). For instance, the administering agency can
18 work cooperatively with landowners and establish binding agreements that offer them technical
19 assistance with measures to alleviate potentially adverse impacts on the river resulting from their
20 land-use activities. The National Park Service proposes such cooperative agreements, for
21 instance, in its management plan for the Rio Grande WSR in Texas (National Park Service,
22 2004). In addition, landowners may voluntarily donate or sell lands, or interests in lands (*i.e.*,
23 easements) as part of a cooperative agreement. Local floodplain zoning and wetlands protection
24 regulations can also be part of a land-protection strategy (Interagency Wild and Scenic Rivers
25 Coordinating Council, 1996).

26 27 **Limitations on Impacts of Federally Assisted Water Projects on WSRs**

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

44 45 **Cooperative Arrangements with Other Agencies to Mitigate Impacts on WSRs**

46 The WSR administering agencies can work proactively with other federal or state agencies to
47 secure their cooperation in protecting the natural flows and outstandingly remarkable values of

1 designated rivers. For example, the NPS could establish an agreement with an upstream dam
2 operator, such as the Army Corps of Engineers, to help ensure flows adequate to protect the
3 WSR’s habitat and other values. In addition, working with local governments and communities
4 to secure zoning restrictions that protect a WSR’s water quality or other values can be effective.
5 For example, cooperative work on WSR studies for the Sudbury, Assabet, and Concord Rivers in
6 Massachusetts (which received WSR designation in 1999) led to a “nutrient trading” program
7 designed to reduce pollution loads and eutrophication problems within the river systems
8 (Interagency Wild and Scenic Rivers Coordinating Council, 2003).

10 **Establishment of Effective Baseline Information**

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

20 **Technical Assistance**

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

27 **6.3 Adapting to Climate Change**

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

39 **6.3.1 Climate Change Impacts**

40 Output from climate change models indicate that global temperature will increase, with the
41 direction and magnitude varying regionally. Projections of changes in precipitation are less
42 certain but include change in the amount or timing of rainfall as well as the frequency and
43 magnitude of extreme rainfall events. The latest IPCC (2007a) assessment report states: [We are]

1 “*virtually certain* to experience warmer and fewer cold days over most land areas as well as
 2 warmer and more frequent hot days; we are *very likely* to experience heat waves and heavy
 3 rainfall events more frequently; and we are *likely* to experience more drought in some regions.”
 4 Thus, in general, much of the world can expect warmer conditions with more severe weather
 5 events.

6 **6.3.1.1 Temperature**

7 The average global surface temperature is projected to increase by 1.2–6.4°C during the 21st
 8 century (IPCC, 2007a), but increases may be greater in the western United States, thus more
 9 strongly affecting rivers such as those in Nevada, Utah, and Idaho in the summer, and rivers in
 10 parts of Colorado, Arizona, New Mexico, and Wyoming throughout the year (Fig. 6.12).
 11 Because streams and rivers are generally well mixed and turbulent, they respond to changes in
 12 atmospheric conditions fairly easily and thus they would become warmer under projected climate
 13 change (Eaton and Scheller, 1996). Rivers that are fed by groundwater, such as Michigan’s Au
 14 Sable and Florida’s Wekiva, should be somewhat buffered from atmospheric heating (Allan,
 15 2004). Those that do warm could experience reductions in water quality due to increased growth
 16 of nuisance algae and to lower oxygen levels (Murdoch, Baron, and Miller, 2000).
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 18
 19

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

22 **6.3.1.2 Precipitation**

23 Little to no change in precipitation is projected in southern Utah, southern Colorado,
 24 northeastern New Mexico, eastern Texas, and Louisiana, where only a few wild and scenic rivers
 25 are designated (the Saline Bayou, Louisiana; Upper Rio Grande and Pecos, New Mexico) (Fig.
 26 6.13). Up to a 10% increase in rainfall may occur around the Great Lakes region where there are
 27 a number of designated rivers including the Indian, Sturgeon, Presques Isle, and St. Croix. As
 28 much as a 10% decrease in precipitation may occur in southern Arizona and southeastern
 29 California where the Verde, Kern, Tuolumne, and Merced rivers are designated as Wild and
 30 Scenic.
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34 **Figure 6.13.** Projected annual precipitation changes for 2091-2100 (University of Arizona,
 35 Environmental Studies Laboratory, 2007).
 36

37 In regions that receive most of their precipitation as snow, the increased temperatures may result
 38 in a shift from winter snow to rain or rain plus snow. A recent analysis of long-term USGS
 39 discharge gauge records showed that most rivers north of 44° North latitude—roughly from
 40 southern Minnesota and Michigan through northern New York and southern Maine—have had
 41 progressively earlier winter-spring streamflows over the last 50–90 years (Hodgkins and Dudley,
 42 2006). Rivers in mountainous regions also may experience earlier snowmelt, and in some
 43 regions, less snowpack (Stewart, Cayan, and Dettinger, 2005; McCabe and Clark, 2005). Many

1 parts of Oregon and southern Washington, which are states notable for their large number of
 2 WSRs, may experience earlier snowmelt and thus higher winter-spring discharges.

3 **6.3.1.3 Discharge**

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

13
 14 Milly, Dunne, and Vecchia (2005) evaluated global fields of relative (*i.e.*, percent) change in
 15 runoff from a 1900–1970 baseline (2006 IPCC 20C3M model runs) to a 2041–2060 period (2006
 16 IPCC A1B model runs). They averaged the relative change across 24 pairs of model runs,
 17 obtained from 12 different models, some of which performed replicate runs. Fig. 4 in Milly,
 18 Dunne, and Vecchia (2005) shows projected changes in runoff globally in two ways: (1) as the
 19 mean, across 24 pairs of runs, of the relative changes in runoff, and (2) as the difference between
 20 the number of pairs of runs showing increases in runoff minus the number showing decreases in
 21 runoff. Fig. 6.14 shows similar results from the same analysis, but with (1) central estimates of
 22 change based on the more stable median instead of the mean, (2) equal weighting of the 12
 23 models instead of the 24 pairs of model runs, and (3) relative changes of areal-averages of runoff
 24 over United States water regions instead of relative changes of point values of runoff.

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28 **Figure 6.14.** Median, over 12 climate models, of the percent changes in runoff from
 29 United States water resources regions for 2041–2060 relative to 1901–1970. More than
 30 66% of models agree on the sign of change for areas shown in color; diagonal hatching
 31 indicates greater than 90% agreement. Recomputed from data of Milly, Dunne, and
 32 Vecchia (2005) by Dr. P.C.D. Milly, USGS.

33

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

40

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

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

3
 4 It is important to note that and some of the regions in Fig. 6.14 are small and are not well
 5 resolved by the climate models, so important spatial characteristics—such as mountain ranges in
 6 the western United States—are only very approximately represented in these results. However,
 7 these regions are generally larger than many of the river basins for which Milly, Dunne, and
 8 Vecchia (2005) demonstrated substantial model skill in reproducing historical observations.

9
 10 In regions in which snowmelt occurs earlier due to warmer temperatures, stream flows will
 11 increase early in the season and flooding may be pronounced (see Fig. 6.15 for a picture of river
 12 flooding) if high flows coincide with heavy rainfall events (“rain on snow events”). As
 13 evidenced by increases in discharge, a shift in the timing of springtime snowmelt toward earlier
 14 in the year is already being observed (1948–2000) in many western rivers (Fig. 6.16),
 15 particularly in the Pacific Northwest, Sierra Nevada, Rockies, and parts of Alaska (Stewart,
 16 Cayan, and Dettinger, 2004).

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

22
 23
 24
 25 **Figure 6.16.** Earlier onset of spring snowmelt pulse in river runoff from 1948–2000.
 26 Shading indicates magnitude of the trend expressed as the change (days) in timing over the
 27 period. Larger symbols indicate statistically significant trends at the 90% confidence level.
 28 From Stewart, Cayan, and Dettinger (2005).

29 **6.3.1.4 Channel and Network Morphology**

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

38 **6.3.2 Future Human Context: Interactive Effects of Multiple Stressors**

39 The effects of multiple environmental stressors on ecosystems are still poorly understood, yet
 40 their impacts can be enormous. Any consideration of climate change is by definition a
 41 consideration of future conditions; *i.e.*, a look at what is expected over the next century. Many
 42 factors other than climate influence the health of ecosystems, and these factors certainly will not
 43 remain static while climate changes (see Box 6.5 for examples). The stressors most likely to

1 intensify the negative effects of climate change include land use change - particularly the
 2 clearing of native vegetation for urban and suburban developments – and excessive extractions
 3 of river water or groundwater that feed WSRs (Allan, 2004; Nelson and Palmer, 2007).

4
 5 WSRs in watersheds with a significant amount of urban development are expected to not only
 6 experience the greatest changes in temperature under future climates but also to experience
 7 temperature spikes during and immediately following rain storms (Nelson and Palmer, 2007)
 8 (Fig 6.17). Such changes may result in the extirpation of cool water species (Nelson and Palmer,
 9 2004).

10
 11
 12
 13 **Figure 6.17.** Very rapid increases (1–4 hours) in water temperature (temperature “spikes”)
 14 in urban streams north of Washington D.C. have been found to follow local rain storms.
 15 *Top graph:* dark line shows stream discharge that spikes just after a rainfall in watersheds
 16 with large amounts of impervious cover; gray line shows temperature surges that increase
 17 2–7°C above pre-rain levels and above streams in undeveloped watersheds in the region.
 18 There is no temperature buffering effect that is typical in wildlands where rain soaks into
 19 soil, moves into groundwater, and laterally into streams. *Bottom graph:* shows that the
 20 number of temperature surges into a stream increases with the amount of impervious cover.
 21 From Nelson and Palmer (2007).

22
 23 The number of extreme flow events would also increase more in WSRs in urbanized basins
 24 compared with those that are mostly wild. Large amounts of impervious cover are well known to
 25 cause an increase in flashiness in streams—both higher peak flows during the rainy season and
 26 lower base flows in the summer (Walsh *et al.*, 2005). Thus, flooding may be a very serious
 27 problem in regions of the United States that are expected to have more rainfall and more
 28 urbanization in the future (*e.g.*, the Northeast and portions of the mid-Atlantic) (Nowak and
 29 Walton, 2005) (see Fig. 6.13). Areas of the United States that will experience the greatest
 30 increase in population size are the South and West, with increases of more than 40% between the
 31 year 2000 and 2030 (U.S. Census Bureau, 2004). More specifically, significant growth is
 32 occurring in the following regions that have rivers designated as wild and scenic: most of
 33 Florida; central and southern California; western Arizona; around Portland, Oregon; much of the
 34 mid-Atlantic; and parts of Wisconsin, northern Illinois, and Michigan (Auch, Taylor, and
 35 Acevedo, 2004).

36
 37 Excessive water extractions are already affecting some WSRs (*e.g.*, the Rio Grande) and this
 38 impact will be exacerbated in regions of the country expected to experience even more water
 39 stress under future climates. Alcamo, Flörke, and Märker (2007) used a global water model to
 40 analyze the combined impacts of climate change and future water stress due to socioeconomic
 41 driving forces (income, electricity production, water-use efficiency, etc) that influence water
 42 extractions. Their models indicate that for the 2050s, areas under severe water stress will include
 43 not only parts of Africa, Central Asia, and the Middle East, but also the western United States.
 44 (Fig. 6.18)

1
2 **Figure 6.18.** Water stress projected for the 2050s based on withdrawals-to-availability
3 ratio, where availability corresponds to annual river discharge (combined surface runoff
4 and groundwater recharge). From Alcamo, Flörke, and Märker (2007).
5

6 Water managers will need to adjust operating plans for storing, diverting, and releasing water as
7 the timing and intensity of runoff changes due to climate change (Bergkamp, Orlando, and
8 Burton, 2003). If these water management adjustments do not keep pace with climate change,
9 water managers will face increasingly severe water and energy shortages due to lessened
10 efficiency in capturing and storing water to supply cities and farms, or to generate electricity.
11

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

26 **6.3.3 Ecosystem Goods and Services Assuming Present Management**

27 This chapter has outlined expectations given future climate projections that include warmer
28 water temperatures for most rivers and changes in flow regimes, with extreme events (floods and
29 droughts) increasing in frequency for many rivers. While the impacts will vary among the WSRs
30 depending on their location, their ability to absorb change—which is largely related to the
31 “wildness” of their watershed—also depends on the management response. If proactive measures
32 to buffer ecosystems (such as those discussed in the next section) are taken, then the
33 consequences may be reduced. The need for these proactive measures should be least for WSRs
34 that are designated “wild” followed by those that are designated “scenic.” Presumably wild rivers
35 are the least affected by human activities that may exacerbate the impacts of climate change.
36 However, as noted earlier, because many WSRs are in reality river *segments* within watershed
37 that may be affected by development or even dams, each designated river must be evaluated to
38 determine the management needs.
39

40 This section describes the impacts to ecosystems assuming “business as usual” in management—
41 *i.e.*, no changes from current practices. The discussion focuses on species and ecological
42 processes, because these two factors influence most of the attributes valued in WSRs: clean
43 water and healthy ecosystems, with flow regimes that support diverse plant and animal
44 assemblages. Even though recreational use of some WSRs is focused primarily on water sports,
45 most users still have a strong preference for the other attributes listed above. Clean and beautiful

1 waterways are only possible if materials entering that water—*e.g.*, nutrients, excess organic
2 matter, etc.—do not interfere with natural biophysical processes or the health of flora and fauna.
3

4 For a given level of “wilderness,” the impacts of climate change on WSRs will depend on how
5 much the changes in thermal and flow regimes deviate from historical and recent regimes (Fig.
6 6.5). Changes outside the historical range of flow or temperature variability may have drastic
7 consequences for ecosystem structure and function (Richter *et al.*, 1997; Poff, Brinson, and Day,
8 Jr., 2002). The impacts will also depend on the rate of change in temperature or discharge
9 relative to the adaptive capacity of species (amount of genetic diversity). Finally, the impacts
10 will depend on the number and severity of other stressors. Thus, the warmer temperatures and
11 drier conditions expected in southwestern rivers may lead to severe degradation of river
12 ecosystems, which will be exacerbated if water withdrawals for consumptive uses increase
13 (Xenopoulos *et al.*, 2005). For example, the Verde River north of Phoenix, Arizona is in a region
14 of the United States that is experiencing increases in population size, and is expected to have
15 reduced rainfall as well as higher winter and summer temperatures under future climates. The
16 Verde is one of the few perennial rivers within Arizona, but its headwaters are an artificial
17 reservoir (Sullivan Lake) and its flows are affected by groundwater pumping and diversions
18 despite being largely in national forest land.
19

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

26 **6.3.3.1 Species-Level Impacts**

27 As the water warms, individual growth and reproductive rates of fish are expected to increase so
28 long as thermal tolerances of any life history stage are not exceeded; typically, eggs and young
29 juveniles are the most sensitive to temperature extremes (Van der Kraak and Pankhurst, 1997;
30 Beiting, Bennett, and McCauley, 2000). Faster growth rates and time to maturation typically
31 result in smaller adult size and, because size is closely related to reproductive output in many
32 aquatic invertebrates (Vannote and Sweeney, 1980), population sizes may decline over time. The
33 spawning time of fish may also shift earlier if river waters begin to warm earlier in the spring
34 (Hilborn *et al.*, 2003). Further, some aquatic species require prolonged periods of low
35 temperatures (Lehmkuhl, 1974); these species may move northward, with local extirpations.
36 However, dispersal to more northern rivers may be restricted by habitat loss, and riverine insects
37 with adult flying stages that depend on vegetated corridors for dispersal may not survive (Allan
38 and Flecker, 1993). For fish, amphibians, and water-dispersed plants, habitat fragmentation due
39 to dams or the isolation of tributaries due to drought conditions may result in local extirpations
40 (Dynesius *et al.*, 2004; Palmer *et al.*, In Press).
41

42 Depending on their severity, climate-induced decreases in river discharge may reduce freshwater
43 biodiversity, particularly if other stressors are at play. Xenopoulos *et al.* (2005) predict up to 75%
44 of local fish biodiversity could be headed toward extinction by 2070 due to the combined effects
45 of decreasing discharge and increasing water extractions. Even if streams do not dry up in the

1 summer, those that experience reductions in baseflow (*e.g.*, in the Southwest) may have stressed
2 biota and riparian vegetation (Allan, 2004). Dissolved oxygen levels may decline, as may critical
3 habitat for current-dependent (rheophilic) species (Poff, 2002). Physiological stress and
4 increased predation resulting from crowding (less depth means less habitat), combined with
5 habitat fragmentation in stream networks (isolated pools), may dramatically reduce survival and
6 constrain dispersal (Poff, 2002).

7
8 Rivers in which future discharge exceeds historical bounds will also experience a loss of species
9 unless they are capable of moving to less-affected regions. Since species life histories are closely
10 tied to flow regime, some species may not be able to find suitable flow environments for feeding,
11 reproducing, or surviving major flood events. Further, with higher flows comes higher suspended
12 sediment and bedload transport, which may interfere with feeding. If sediment deposition fills
13 interstitial spaces, this will reduce hyporheic habitat availability for insects and spawning areas
14 for lithophilic fish (Pizzuto *et al.*, In Press). Whether deposition or net export of these sediments
15 occurs depends on the size of the sediment moving into channels in concert with peak flows (*i.e.*,
16 the stream competency). Particle size and hydraulic forces are major determinants of stream
17 biodiversity (both the numbers and composition of algae, invertebrates, and fish) and excessive
18 bottom erosion is well known to decrease abundances and lead to dominance by a few taxa
19 (Allan, 1995).

20 **6.3.3.2 Impacts on Ecological Processes**

21 Many of the ecological processes that ensure clean water for drinking and for supporting wildlife
22 will be influenced by higher water temperatures and altered flows. Primary production in streams
23 is very sensitive to temperature and flow levels (Lowe and Pan, 1996; Hill, 1996); climate
24 change may thus result in an increase in food availability to herbivorous biota that could support
25 higher abundances and also shift species composition. If riparian plants also grow at faster rates,
26 inputs of leaves and other allochthonous material to rivers may increase. While this could be
27 expected to provide more food for detritivores, this may not be the case if the rate of breakdown
28 of those leaves is higher under future climates. This may occur with higher water temperatures
29 and thus increased microbial growth, or with higher flows that contribute to the physical abrasion
30 of leaves (Webster and Benfield, 1986). Further, allochthonous inputs may represent lower-
31 quality food since plants growing under elevated CO₂ levels may have higher carbon-to-nitrogen
32 ratios, and compounds such as lignin (Tuchman *et al.*, 2002) that reduce microbial productivity
33 (Rier *et al.*, 2002). They also may experience higher leaf decay rates (Tuchman *et al.*, 2003) and
34 detritivore growth rates in streams (Tuchman *et al.*, 2002).

35
36 There is a great deal of uncertainty about how rates of nutrient processing in streams will be
37 influenced by climate change. Dissolved inorganic nitrogen (as NO₃) levels may decrease if rates
38 of denitrification are increased (*e.g.*, by higher temperatures and lower oxygen), which could be
39 important given increasing levels of nitrogen deposition (Baron *et al.*, 2000). On the other hand,
40 if discharge and sediment transport increase, then the downstream movement of nitrogen (as
41 NH₄) and phosphorus (as PO₄) may increase. In short, there is a high degree of uncertainty with
42 respect to how climate change will affect ecological processes. This means that our present
43 ability to predict changes in water quality, and food availability for aquatic biota is limited. To
44 date, few studies have been conducted to simultaneously examine the many interacting factors
45 that are both subject to change in the future and known to influence ecological processes.

1 **6.3.4 Options for Protection Assuming New Management**

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

11
 12 In general, WSRs that are in fairly pristine watersheds with no development and few human
 13 impacts will fare the best under future climates because their natural capacity to adjust is intact.
 14 Even in the face of climate change impacts, rivers surrounded by uninhabited and undeveloped
 15 land may experience shifts in channels—perhaps even a deepening and widening of those
 16 channels—but their provision of ecosystem services may remain intact. The access points for
 17 wildlife or river enthusiasts may need to be shifted and existing trails moved, but largely these
 18 rivers are expected to remain beautiful and healthy. In contrast, rivers in Illinois, which will also
 19 experience increased discharge, may experience serious problems because flooding and erosion
 20 may be exacerbated by development. That said, even some pristine rivers may be negatively
 21 affected. For example, the Noatak River in Alaska is already experiencing very large temperature
 22 shifts because of its fairly high latitude. This could have serious consequences for migrating
 23 salmon and other highly valued species (National Research Council, 2004) (Box 6.4).

24
 25 The question becomes, what is the appropriate management response? Following Palmer et al.
 26 (In Press), we distinguish between *proactive* and *reactive* responses. The former includes
 27 management actions such as restoration, land purchases, and measures that can be taken now to
 28 maintain or increase the resilience of WSRs (*i.e.*, the ability of a WSR to return to its initial state
 29 and functioning despite major disturbances). Reactive measures involve responding to problems
 30 as they arise by repairing damage or mitigating ongoing impacts.

31 **6.3.4.1 Reactive Management**

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

38
 39 The most expensive and serious reactive measures will be needed for WSRs in basins that are
 40 heavily developed or whose water is managed for multiple uses. In areas with higher discharge,
 41 reactive measures may include river restoration projects to stabilize eroding banks or projects to
 42 repair in-stream habitat. Other measures such as creating off-channel storage basins or wetland
 43 creation may be a way to absorb high flow energy. Removing sediment from the bottom of
 44 reservoirs could be a short-term solution to allow for more water storage, perhaps averting dam

1 breaches that could be disastrous. Water quality problems due to high sediment loads or
2 contaminants may appear in WSR reaches downstream of developed (urbanized or agricultural)
3 regions, and these problems are very difficult to cope with in a reactive manner.
4

5 In regions with higher temperatures and less precipitation, reactive projects might include fish
6 passage projects to allow stranded fish to move between isolated river reaches during drought
7 times, replanting of native riparian vegetation with drought resistant vegetation, or removal of
8 undesirable non-native species that take hold. If dams are present upstream of the WSR, flow
9 releases during the summer could be used to save flora and fauna in downstream river reaches
10 that are drying up, and accentuated floods can be managed to avert potentially disastrous
11 ecological consequences of extreme floods.
12

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

21 **6.3.4.2 Proactive Management**

22 Many of the management actions that are needed to respond to the risks of climate change arise
23 directly from changes in the frequency and magnitude of extreme events, in addition to changes
24 in average conditions or baseflow. Anticipating how climate impacts will interact with other
25 ongoing stressors is critical to developing strategies to protect the values of WSRs. Proactive
26 measures that restore the natural capacity of rivers to buffer climate-change impacts are
27 obviously the most desirable actions since they may also lead to other environmental benefits
28 such as higher water quality and restored fish populations. Examples of such measures might
29 include stormwater management in developed basins or, even better, land acquisition around the
30 river or setting back existing levees to free the floodplain of infrastructure, absorb floods, and
31 allow regrowth of riparian vegetation.
32

33 While shifting climate regimes may result in local shifts in species assemblage (Thuiller, 2004),
34 if there are flora and fauna of special value associated with a WSR, then proactive responses to
35 ensure the persistence of these species is needed. This will require detailed understanding of their
36 life histories and ecology. For rivers in regions expected to experience hot, dry periods, planting
37 or natural establishment of drought-tolerant varieties of plants may help protect the riparian
38 corridor from erosion. A focus on increasing genetic diversity and population size through
39 plantings or via stocking fish may increase the adaptive capacity of species. Aquatic fauna may
40 benefit from an increase in physical habitat heterogeneity in the channel (Brown, 2003), and
41 replanting or widening any degraded riparian buffers may protect river fauna by providing more
42 shade and maintaining sources of allochthonous input (Palmer *et al.*, 2005).
43

44 Incorporating the potential impacts of climate change into water management strategies
45 inevitably involves dealing constructively with uncertainty. Enough is now known about the

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

11
12 Legal and institutional barriers exist in many river systems, and will need to be overcome for the
13 adoption of effective management strategies. Water rights, interstate water compacts, property
14 rights, and zoning patterns may all present constraints to effective adaptation strategies. Studies
15 of the Colorado River basin, for example, have found that much of the potential economic
16 damage that may result from climate change is attributable to the inflexibility of the Colorado
17 River Compact (Loomis, Koteen, and Hurd, 2003). The new stressor of climate change, on top of
18 the existing pressures of population growth, rising water demand, land-use intensification, and
19 other stressors, may demand a re-evaluation of the institutional mechanisms governing water use
20 and management, with an eye toward increasing flexibility.

21
22 Along with the management tools described above, a number of other categories of actions and
23 measures can enhance the WSR System's ability to protect the nation's rivers under changing
24 climatic regimes, as described below. Box 6.5 presents a summary list of specific actions WSR
25 managers can take to promote adaptation.

26 27 **Designate More River Corridors as Wild and Scenic**

28 Rivers may be designated as Wild and Scenic by acts of Congress or by the Secretary of Interior
29 upon a state's request. Designation of additional rivers to the WSR program may raise visibility
30 and expand protection to river assets at a time when they are coming under increased human and
31 climatic pressures. Possible candidates for designation include rivers in the Nationwide Rivers
32 Inventory (NRI). The NRI, which is maintained by the National Park Service (updated last in the
33 1980s), includes more than 3,400 free-flowing river segments that are believed to possess at least
34 one outstandingly remarkable value of national significance. By virtue of a 1979 Presidential
35 directive, all federal agencies must seek to avoid or mitigate actions that would affect NRI
36 segments. The WSR System would also benefit from hastening the review of rivers that have
37 already been submitted for designation, but about which no decision has yet been made. For new
38 designations, there is an opportunity to think strategically about climate change impacts when
39 identifying and prioritizing rivers for designation. Climate change may affect the priority order
40 and rationale for designation.

41 42 **Rebalance the Priority of Values used for Designation of WSRs**

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

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

3
4 **Claim, or Purchase, More Water Rights and/or Establish Effective Environmental Flow Programs**
5 **to Secure Ecological Flows**

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

13
14 **Develop and Amend CRMPs to Allow for Adaptation to Climate Change**

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

30
31 **Develop Reservoir-Release Options with Dam Managers**

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

37
38 **Apply Climate Forecasting to Water Management Planning**

39 Climate forecasts can enable water managers to minimize risk and avoid damage to WSR values.
40 The development of scenarios that capture the spectrum of possible outcomes is an invaluable
41 tool for anticipating the ramifications of climate-related hydrological and land-use changes,
42 including reduced snowpacks, greater spring flooding, lower summer flows, and warmer stream
43 temperatures. The utility of forecasting tools, however, depends on the ability to apply their
44 results to water management planning. For instance, the possibility of severe drought occurring
45 in three out of five years implies that river flows may be affected not only by lack of rainfall and
46 runoff, but by increased evapotranspiration from vegetative regrowth after forest fires.
47 Anticipating such flow depletion, and its potential magnitude, is critical to devising plans that

1 mitigate the impacts. For example, warming trends across the Southwest exceed global averages
2 by 50%, providing ample evidence of the importance of planning for reduced water availability
3 and streamflows in the Rio Grande and other southwestern rivers (New Mexico Office of State
4 Engineer and Interstate Stream Commission, 2006).

5 6 **Improve Water Monitoring Capabilities**

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

16 17 **Build Capacity to Offer Technical Assistance**

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

24 **6.4 Case Studies**

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

38
39 There are also key outstandingly remarkable values that the WSR program focuses on. One of
40 those areas is anadromous fish. Box 6.7 provides an overview of potential climate change
41 impacts to anadromous fish and offers management actions that may be taken to lessen those
42 impacts.

1 **6.4.1 Wekiva River Case Study**

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

8
9

10

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

13

14 In 2000, portions of the Wekiva River and its tributaries of Rock Springs Run, Wekiwa¹ Springs
15 Run, and Black Water Creek were added to the National Wild and Scenic Rivers System. The
16 designated segments total 66.9 km, including 50.5 km designated as Wild, 3.4 miles as Scenic,
17 and 13 km as Recreational. The National Park Service has overall coordinating responsibility for
18 the Wekiva River WSR, but there are no federal lands in the protected river corridor.
19 Approximately 60%–70% of the 0.8-km-wide WSR corridor is in public ownership, primarily
20 managed by the State of Florida Department of Environmental Protection and the St. Johns River
21 Water Management District (SJRWMD). The long-term protection, preservation, and
22 enhancement are provided through cooperation among the State of Florida, local political
23 jurisdictions, landowners, and private organizations. The designated waterways that flow through
24 publicly owned lands are managed by the agencies that have jurisdiction over the lands.
25 SJRWMD has significant regulatory authority to manage surface and ground water resources
26 throughout the Wekiva Basin.

27

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

33

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

43

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

1 The WSR management plan is being prepared with the leadership of the National Park Service.
 2 Based on information from the pre-legislation WSR study report (National Park Service, 1999),
 3 and management plans for the state parks (Florida Department of Environmental Protection,
 4 2005) and the SJRWMD (2006a), the priority management objectives for the WSR will likely
 5 include maintaining or improving: water quantity and quality in the springs, streams, and river;
 6 native aquatic and riparian ecosystems; viable populations of endangered and sensitive species;
 7 scenic values; and access and service for recreational users.

8
 9 The Wekiva River was selected for a case study because it provides an example of a spring-fed
 10 WSR system, sub-tropical ecosystems, a coastal location with a history of tropical storms and
 11 hurricanes, and a system in a watershed dealing directly with large and expanding urban and
 12 suburban populations. In particular, the spring-fed systems combined with urban and suburban
 13 land uses require consideration of the relationship between groundwater and surface water and
 14 how they relate to management options in the context of climate change.

15 **6.4.1.1 Current Stressors and Management Methods Used to Address Them**

16 The primary stressors of the Wekiva WSR are:

- 17
- 18 • water extraction for public, recreational and agricultural uses;
- 19 • land conversion to urban and suburban development;
- 20 • pollution, particularly nitrates, via groundwater pathways and surface water runoff; and
- 21 • invasive species.
- 22

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

32
 33 Between 1970 and 1995, agricultural and recreational water use from the aquifer has increased
 34 nearly three fold to 958 million gallons per day (mgpd), with a significant part of the additional
 35 water supporting recreational uses (*i.e.*, golf courses). Over that same period, public (*e.g.*, city)
 36 use of water from the aquifer also increased threefold to 321 mgpd. Projections for the year 2020
 37 are for water extraction for agricultural and recreational uses to barely increase, while extractions
 38 for public use will nearly double (McGurk and Presley, 2002). The St. Johns River, Southwest
 39 Florida, and South Florida Water Management Districts have jointly determined that the Floridan
 40 Aquifer will be at maximum sustainable yield by 2013, and by that date and into the future much
 41 of the water used by people will have to come from alternative sources.

42
 43 Urban development prior to modern stormwater management controls is another stressor on
 44 aquatic systems in the Wekiva Basin. In particular, the Little Wekiva River exhibits extreme
 45 erosion and sedimentation caused by high flows and velocities during major storm events (St.

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

4
5 Declines in spring flows in the Wekiva River Basin are strongly correlated with urban
6 development and ground water extraction (Florida Department of Environmental Protection,
7 2005). Projections based on current practices predict that by 2020 water demand will surpass
8 supply and recharge. By 2010, spring flows may decline to levels that will cause irreparable
9 harm (Florida Department of Environmental Protection, 2005). In response to these projections,
10 the St. Johns River Water Management District (SJRWMD) has declared the central Florida
11 region, which includes the Wekiva River Watershed, a “Priority Water Resource Caution Area”
12 where measures are needed to protect ground water supplies and spring-dependent ecosystems.
13 SJRWMD has developed “Minimum Flows and Levels” (a.k.a., instream flow criteria) for the
14 Wekiva River and Blackwater Creek, and the district has identified minimum spring flows in
15 selected major springs feeding the Wekiva and Rock Springs Run. These are an important
16 regulatory tool to set limits on ground water withdrawals to prevent adverse reductions in spring
17 flow.

18
19 The water management district recommends the following strategies for improving water
20 management (St. Johns River Water Management District, 2006b):

- 21
22
- water conservation;
 - use of reclaimed water; and
 - water resource development, including:
 - artificial aquifer recharge
 - aquifer storage and recovery
 - avoidance of impacts through hydration
 - interconnectivity of water systems.
- 28
29

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

33
34 Water pollution is another significant stressor of the Wekiva WSR. The causes of water pollution
35 are closely related to the water quantity issues discussed above. In particular, unusually high
36 concentrations of nitrates emanating from the springs of the basin are stressing the native
37 ecosystems in the spring runs. Nitrates promote algal blooms that deplete oxygen, shade-out
38 native species, and may negatively affect invertebrate and fish habitat. Nitrates in spring water
39 now may reflect more distant past inputs from agricultural operations and septic systems. The
40 sources of the nitrogen in the springs are animal waste, sewage, and fertilizers (Florida
41 Department of Environmental Protection, 2005), which readily leach to groundwater due to the
42 karstic geology of the basin. Future spring discharges may reflect a newer type of input from
43 reclaimed water application for both landscape irrigation and for direct recharge via rapid
44 infiltration basins that have increased significantly within the past 10–15 years and continue to
45 increase. The management solutions to reduce nitrate pollution include educating the public to
46 use fewer chemicals and apply these with greater care, development and application of

1 agricultural best management practices, and increasing the use of central sewage treatment
2 facilities in place of on-site systems such as septic tanks.

3
4 Recent data suggest that increases in dissolved chlorides in the springwaters may be related to
5 sea level rise and groundwater withdrawals (Florida Department of Environmental Protection,
6 2005). To date, salinity changes in the Wekiva Basin springs are minor and the causes are
7 unclear. Major increases in the salinity (increased chlorides) in the springwater would have
8 significant impacts on the ecosystems of the WSR. Continued monitoring and further research
9 are needed to determine the source of the chlorides (*e.g.*, recharge from polluted surface water or
10 mixing with saltwater from below the Upper Floridan aquifer) and how to manage land and
11 water to limit chlorides in the springflows.

12
13 Exotic plants are a major problem stressing ecosystems in the Wekiva WSR corridor. For
14 example, wild taro (*Colocasia esculentum*) has infested Rock Springs Run and the lagoon area of
15 Wekiwa Springs has hydrilla (*Hydrilla verticillata*), water hyacinth (*Eichhornia carssipes*), and
16 water lettuce (*Pistia stratiotes*). The park managers use a combination of herbicides and manual
17 labor to control invasive plant species (Florida Department of Environmental Protection, 2005).

18
19 Drought-related stress in upland areas has increased the vulnerability of trees to pest species, the
20 Southern pine beetle (*Dendroctonus frontalis*) in particular. Infestations have prompted park
21 managers to clear-cut infested stands and buffers to limit the spread of the beetles. Without these
22 interventions, dead trees would contribute significant fuel, increasing the potential for destructive
23 forest fires.

24 **6.4.1.2 Potential Effects of Climate Change on Ecosystems and Current Management Practices**

25 For Central Florida, climate change models project average temperatures rising by perhaps 2.2–
26 2.8°C and annual rainfall to total about the same as it does today (University of Arizona,
27 Environmental Studies Laboratory, 2007). However, the late summer and fall rainy season may
28 see more frequent tropical storms and hurricanes, overwhelming the current storm water
29 management infrastructure and resulting in periodic surges of surface water with significant
30 pollution and sedimentation loads. More runoff also means less recharge of the aquifer.

31
32 At other times of the year, droughts may be more frequent and of longer duration, leading to
33 water shortages and increased withdrawals from the aquifer, which may reduce spring flows.

34
35 While there is only moderate confidence in predictions of changes in patterns of precipitation,
36 there is a high confidence that it will get warmer. Warmer temperatures over an extended period
37 will change species composition in the WSR corridor. Some native species, particularly those
38 with limited ranges, may no longer find suitable habitat, while invasive exotics, which often
39 tolerate a broad range of conditions, would thrive. Current programs to control invasive species
40 would face new challenges as some native species are lost and replaced by species that favor the
41 warmer climate, particularly for terrestrial species. Where the cold spring waters can moderate
42 water temperature in the streams and river, the current control programs for aquatic invasive
43 species may still be successful in a moderately warmer climate.

1 Climate change scenarios project sea level rising between 0.18–0.59 m by 2099 (IPCC, 2007a).
 2 There are two issues related to potential sea level rise relative to the Wekiva WSR: 1) how would
 3 changes in the tidal reach of the St. Johns River affect the Wekiva, and 2) how might the rising
 4 sea level affect the aquifer that supports the springflows? There are too few data available to
 5 answer these questions.
 6

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

12 **6.4.1.3 Potential for Altering/Supplementing Current Management to Enable Adaptation to** 13 **Climate Change**

14 Future management adaptations for meeting ecosystem goals in the Wekiva WSR should include
 15 monitoring ecosystem health, including water quantity and quality; basin-wide modeling to
 16 protect future management needs; and implementation of management programs in advance of
 17 climatic changes. The water management district and other land management agencies have
 18 robust monitoring programs, though they may not be adequate to understand the complexity of
 19 applying reclaimed surface water in a the karst uplands. Current groundwater monitoring, which
 20 focuses on salinity, may need to be expanded to better understand how nitrates and other
 21 nutrients are transported to the springflows. Increasingly refined models are needed to
 22 understand how water and ecosystems in the Wekiva Basin respond to management.
 23

24 In many ways, it appears that the SJRWMD and local government agencies are beginning to
 25 implement management programs that would be needed to maintain ecological processes in the
 26 Wekiva WSR in a climate change scenario. Aquifer management is widely recognized as among
 27 the most critical tools for ensuring public water supplies and ecological integrity of the Wekiva
 28 WSR. Most of the drinking water in and around the Wekiva Basin is extracted from the Floridan
 29 aquifer—the same water source for the springflows that are essential to ecosystems of the
 30 Wekiva WSR. The Floridan aquifer is a water reservoir that can be managed in ways analogous
 31 to a reservoir behind a dam. Like a dam, with each rain event, to the extent permitted by surface
 32 conditions, the aquifer is recharged; water otherwise runs into streams and rivers, effectively lost
 33 for most public uses and often negatively affecting riverine ecosystems. Different from a dam,
 34 aquifer recharge and replenishment operate in a delayed time frame. This characteristic makes
 35 reversal of any mitigation measures a slow process, and should be considered in adaptation
 36 planning for global climate changes. Recognizing these conditions, programs and plans are in
 37 place to minimize surface runoff and maximize groundwater recharge. Programs include, for
 38 example, minimizing impermeable surfaces (*e.g.*, roofs, driveways, and roads), and holding
 39 surface water in water gardens and artificial ponds.
 40

41 Recharge water must be of sufficiently good quality in order to not adversely affect the WSR
 42 system. Current stormwater management programs, while quite good, are focused on capturing
 43 surface water runoff to prevent it from degrading water quality, but this then “re-routes” poor-
 44 quality water from a surface water load to a ground water load. The sandy soils and karst
 45 geology of the area may result in nitrate-loaded water recharged to the aquifer and then to the

1 springs. There is a great deal to learn about the ultimate effects on groundwater quality of
 2 applying reclaimed water to land surface in the karstic uplands.

3
 4 While the human population in the Wekiva Basin is expected to grow, climate change models
 5 suggest that annual rainfall will remain about the same over the next 100 years, presenting a
 6 challenge for meeting water demand. In response, programs in the basin are under development
 7 to conserve water (reduce water use per person) and to develop “new” water sources (hold and
 8 use more surface water). Similarly, programs are also being planned and implemented to reduce
 9 pollution, including educating the public and commercial users about what, when, and how to
 10 apply chemicals, including nitrate-based fertilizers.

11
 12 Management adaptations to more intense rain events under climate change conditions would
 13 require more aggressive implementation of all these programs, to: maximize recharge of the
 14 aquifer during rain events, minimize withdrawals at all times and particularly during droughts,
 15 minimize pollution of surface water and groundwater, and monitor and prevent salt water
 16 intrusion in the surface water-groundwater-seawater balance system. Considering the importance
 17 of water to local residents and as a factor driving economic development, there is considerable
 18 political will to invest in water management technologies and programs in the Wekiva Basin.
 19 Through this century, current and emerging technologies will likely be adequate for meeting the
 20 water needs for human consumption and ecosystem services in the Wekiva Basin, if people are
 21 willing to make the investment in technologies and engineering and to allocate enough water to
 22 maintain ecosystems.

23 **6.4.2 Rio Grande Case Study**

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

32
 33
 34
 35 **Figure 6.20.** The Wild and Scenic portions of the Rio Grande WSR in New Mexico. Data
 36 from USGS, National Atlas of the United States (2005).

37
 38
 39
 40 **Figure 6.21.** The Wild and Scenic portions of the Rio Grande WSR in Texas. Data from
 41 USGS, National Atlas of the United States (2005).

42
 43 Three different segments of the Rio Grande that total 259.6 miles of stream have been designated
 44 as Wild, Scenic, and Recreational. Part of the 68.2-mile segment of the river south of the
 45 Colorado-New Mexico border was among the original eight river corridors designated as wild

1 and scenic at the time of the system’s creation in 1968. A total of 53.2 miles of this reach are
 2 designated as wild, passing through 800-foot chasms of the Rio Grande Gorge with limited
 3 development. This segment is administered by the Bureau of Land Management and the U.S.
 4 Forest Service (National Wild and Scenic Rivers System, 2007b). About 97% of the land in the
 5 New Mexico WSR management zones is owned and managed by BLM or the USFS.

6
 7 The longest segment of the Rio Grande WSR comprises 195.7 river miles in Texas (National
 8 Park Service, 2004) along the U.S.-Mexico border, with about half of this stretch classified as
 9 wild and half as scenic. This stretch, which was added to the system in 1978, is administered by
 10 the National Park Service at Big Bend National Park for the purpose of protecting the
 11 “outstanding remarkable” scenic, geologic, fish and wildlife, and recreational values (National
 12 Park Service, 2004). Land ownership is evenly divided between private and public (federal and
 13 state) owners on the United States side of the designated river segment.

14
 15 In New Mexico, objectives for managing the WSR include (Bureau of Land Management, 2000):

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

22
 23 In Texas, the resource management goals for the wild and scenic river include (National Park
 24 Service, 2004):

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

32
 33 The Rio Grande WSR was selected for a case study because the distinct segments of the
 34 designated river provide examples of features typical of many rivers in the mountainous and arid
 35 SW. Attributes important to this paper include: significant federal and state ownership of the
 36 streamside in designated segments; an important influence of snowpack on river flow; complex
 37 water rights issues with a great deal of water being extracted upstream of the WSR; primary
 38 competition for water by agriculture; and an international component.

39 **6.4.2.1 Current Stressors and Management Methods Used to Address Them**

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

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

- 1 • Altered Land Use: Land and water use for agriculture, mining operations, and cities is
- 2 leading to declines in water quality due to pollution and sedimentations;
- 3 • Invasive Species: Non-native fish and vegetation are altering ecosystems, displacing
- 4 native species and reducing biodiversity, giant reed and saltcedar are particularly
- 5 problematic in the Texas WSR segment; and
- 6 • Recreational Users: Visitors and associated infrastructure impact the riparian vegetation
- 7 and protected species; subdivision and building on private lands along the Texas and
- 8 Mexico segments threatens scenic values and may increase recreational users' impacts.
- 9

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

22
 23
 24
 25 **Figure 6.22.** Dams and diversions along the Rio Grande (Middle Rio Grande Bosque
 26 Initiative, 2007).

27
 28 Downstream from El Paso, Texas, the channel of the Rio Grande is effectively dry from
 29 diversion for about 80 miles. Because of this "lost reach," the river is more like two separate
 30 rivers than one, with management of the Colorado and New Mexico portion having little effect
 31 on flows downstream of El Paso. In the past, the river in Colorado and New Mexico normally
 32 received annual spring floods from the melting snowpack while the river below Presidio, Texas
 33 received additional flood events in the summer through fall from rains in the Rio Conchos Basin,
 34 Mexico. However, throughout the Rio Grande these natural cycles of annual floods have been
 35 severely disrupted by dams and water extraction.

36
 37 Management of the Texas Rio Grande WSR still depends on flows entering from Mexico—
 38 including the Rio Conchos, which provides 85% of the water to this WSR segment—and which
 39 is managed by the International Boundary and Water Commission according to the Rio Grande
 40 Compact. Instream flows in Texas segments of the WSR have decreased 50% in the past 20
 41 years (National Park Service, 2004). During drought years of the late 1990s and into 2004,
 42 Mexico did not meet its obligations to the United States under the compact and water levels
 43 reached critical lows (Woodhouse, 2005). In 2003, the combination of dams, water extraction
 44 and drought were particularly hard on the river, flow essentially ceased, the river became a series
 45 of pools in Texas WSR segments and the river failed to reach the ocean (Garrett and Edwards, In
 46 Press).

1
2 Inefficient regulation of groundwater contributes to these impacts on the river's flow. The
3 primary source of household water in central New Mexico is groundwater, for which the rate of
4 extraction currently exceeds recharge (New Mexico Office of State Engineer and Interstate
5 Stream Commission, 2006). Aquifers in the region may not be able to meet demand in twenty
6 years, which will further stress an overburdened surface water resource.

7
8 Changes in the flow regime of the river are affecting the channel, the floodplain, and the
9 associated aquatic and riparian ecosystems. In the past 90 years, overall stream flow has been
10 reduced more than 50%, and periodic flooding below Presidio has been reduced by 49%
11 (Schmidt, Everitt, and Richard, 2003). Dams in the lower Rio Grande prevent fish migrations so
12 that Atlantic Sturgeon and American Eel no longer reach the WSR (National Park Service,
13 2007). Where native species were dependent on or tolerant of the periodic floods, the new flow
14 regime is apparently giving an edge to invasive, non-native species (National Park Service,
15 1996). Garrett and Edwards (In Press) suggest that changes in flow and sedimentation, pollution,
16 simplification of channel morphology and substrates, and increased dominance of non-native
17 plant species can explain recent changes in fish diversity and critical reductions and local
18 extinctions of fish species. Giant reed (*Arundo donax*) and salt cedar (*Tamarix* sp.) are
19 particularly problematic as these exotic species invade the channelized river and further disrupt
20 normal sedimentation, thereby reducing habitats critical to fish diversity (Garrett and Edwards,
21 In Press). The problems of dams and irregular flows are complicated by local and international
22 water rights issues, and the ecological health of WSR is only one of the many competing needs
23 for limited water resources.

24
25 To address pollution issues, BLM, USFS, and NPS managers have reduced pollution to the river
26 from their operations by reducing or eliminating grazing and mining near the river, improving
27 management of recreation sites, and increasing education and outreach. However, as with flow
28 regime, most of the water quality problems are tied to decreases in water quantity and discharge
29 from large-scale agricultural, industrial and urban upstream users.

30
31 Federal land managers are making a difference where they can with site-level management. For
32 example, riparian zones are being withdrawn from grazing and mineral leases and are being
33 protected via limited access to sensitive sites and education of backcountry visitors about the
34 values of protected streamside vegetation. Programs are also underway to control erosion in
35 recreation areas and river access points and to improve habitat for protected species (Bureau of
36 Land Management, 2000).

37 **6.4.2.2 Potential Effects of Climate Change on Ecosystems and Current Management Practices**

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

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

1
2 The American Southwest in general, including the Rio Grande watershed, seems likely to
3 experience climate extremes in the form of higher temperature, reduced precipitation (including
4 reduced snowpacks), earlier spring melts, and recurring droughts on top of population growth
5 and other existing stressors (New Mexico Office of State Engineer and Interstate Stream
6 Commission, 2006). While global climate models are inconclusive regarding changes in
7 precipitation for this region, and for the Upper Rio Grande Basin in particular, it seems likely
8 that the projected increase in temperature will result in evaporation rates that more than offsets
9 any possible increase in precipitation (New Mexico Office of State Engineer and Interstate
10 Stream Commission, 2006). In this scenario, the New Mexico WSR segment of the Rio Grande
11 might experience earlier spring floods, with reduced volume and more erratic summer rains
12 (New Mexico Office of State Engineer and Interstate Stream Commission, 2006). Projections of
13 perhaps 5% decrease in annual precipitation for the middle and lower Rio Grande (see Fig. 6.13)
14 combined with higher temperatures (see Fig. 6.12) suggest that annual flows in the Texas WSR
15 segment may be further reduced, and during severe droughts the water levels may decline to
16 critical levels as has been the case in recent years (National Park Service, 2004). Water quality
17 may be further reduced as the shallower water is susceptible to increased warming due to higher
18 temperatures driven by climate change (Poff, Brinson, and Day, Jr., 2002). These conditions
19 would negatively affect many native species and may favor invasive non-native species, further
20 complicating existing programs to manage for native riparian vegetation and riverine ecosystems
21 (National Park Service, 2004; New Mexico Office of State Engineer and Interstate Stream
22 Commission, 2006).

23 **6.4.2.3 Potential for Altering / Supplementing Current Management to Enable** 24 **Adaptation to Climate Change**

25 The incorporation of climate change impacts into the planning and management of the WSR
26 corridors of the Rio Grande is complicated by the river's international character, the numerous
27 dams, diversions, and groundwater schemes that already affect its flow regime, and the multiple
28 agencies involved in the river's management within the WSR corridors as well as upstream and
29 downstream. Sustaining the Rio Grande's wild and scenic values under these circumstances will
30 require planning, coordination, monitoring of hydrological trends, and scenario-based forecasting
31 to help river managers anticipate trends and their ramifications. For example, given the
32 probability of reduced snowpack in the headwaters of the Rio Grande, sustaining flows through
33 the New Mexico WSR corridor will likely depend on coordination among the USFS and BLM,
34 which administer this WSR stretch, the Bureau of Reclamation, which manages upstream water
35 projects (both groundwater and surface water) that influence downstream flows, and owners of
36 local and international water rights. Long standing water rights complicate any predictions of
37 water releases to mimic natural flow regime. In this region, required water deliveries might be
38 met by transferring water rights between watersheds or through credits for future water delivery.
39

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

1
2 Economic incentives are another approach to securing sufficient clean water needed to meet
3 management objectives of the WSR. Recognizing the value of ecological services, one potential
4 measure, for instance, is to purchase or lease water rights for the river. Additionally, technical
5 assistance and incentives could also be provided to users who improve water efficiency, reduce
6 pollution, and release surplus clean water to the river. Water deliveries could mimic natural
7 flows, including scouring floods to build the channel.

8
9 Improving efficiency of agricultural and urban water use and increasing re-use to conserve water
10 and reduce pollution are probably the most cost-effective strategies to make more clean water
11 available in the Rio Grande. If improved water efficiency results in “new” water, the challenge
12 for WSR managers will be to negotiate, purchase or lease water for the river when it is most
13 needed for ecological flows.

14 **6.4.3 Upper Delaware River Case Study**

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

24
25
26
27 **Figure 6.23.** Map of Wild and Scenic stretches in the Delaware River basin. Courtesy of
28 Delaware River Basin Commission (Delaware River Basin Commission, 2007).

29
30 The Upper Delaware Scenic and Recreational River boasts hardwood forests covering over 50%
31 of the river corridor (Conference of the Upper Delaware Townships, 1986). These forests
32 provide lush habitat for diverse fauna including at least 40 species of mammals, such as many of
33 Pennsylvania’s remaining river otters and one of the largest populations of black bear in the
34 state. It is one of the most important inland bald eagle wintering habitats in the northeastern
35 United States. Water quality in the Upper Delaware is exceptional and supports abundant cold-
36 and warm-water fish. As the last major river on the Atlantic coast undammed throughout the
37 entire length of its mainstem, the Delaware provides important habitat for migratory fish such as
38 American eel and America shad. In the upper reaches of the Delaware system, rainbow and
39 brown trout are highly sought by anglers. The river and its surrounding ecosystems provide a
40 beautiful setting for recreation including fishing, boating, kayaking, sightseeing and hiking.

41
42 The Upper Delaware Scenic and Recreational River includes a 55,575 acre ridge-top-to- ridge-
43 top (approx. ½ mile wide) corridor, nearly all privately held. The National Park Service (NPS)
44 has jurisdiction over 73.4 miles of the river, including a “strand” area along its banks (up to the
45 mean high water mark), but owns only 31 acres within the corridor (Conference of the Upper

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

6
 7 The negligible public ownership, complex private ownership, and significant extraction of water
 8 for New York City require that the Upper Delaware be managed as a “Partnership River.” The
 9 National Park Service, the Upper Delaware Council (*e.g.*, local jurisdictions), the Delaware
 10 River Basin Commission (DRBC, which manages the water releases), the Commonwealth of
 11 Pennsylvania, and the State of New York collaborated in preparing the River Management Plan
 12 (Conference of the Upper Delaware Townships, 1986) and collaborate in managing the river.

13
 14 The goals described in the River Management Plan include maintaining or improving water
 15 quality and aquatic ecosystems, providing opportunities for recreation, and maintaining scenic
 16 values of river corridor and selected historic sites. The rights of private land owners are
 17 described in great detail and heavily emphasized throughout the plan, while management actions
 18 essential to maintain ecosystem services are more generalized.

19
 20 The Upper Delaware was chosen as a case study because it exemplifies river ecology for the
 21 northeast and management challenges typical of the region, including a significant human
 22 population, intense water extraction for enormous urban centers, and its status as a “Partnership
 23 River.”

24 **6.4.3.1 Current Stressors of Ecosystems and Management Methods Used to Address Them**

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

31
 32 Water managers in the Delaware Basin are addressing at least four priority issues: (1) provision
 33 of drinking water for major metropolitan areas, (2) flood control, (3) biotic integrity and natural
 34 processes of the WSR, and (4) recreation activities, including coldwater fisheries. New York
 35 City takes about half of the water available in the Upper Delaware River Basin above the
 36 designated WSR. Hence, the primary mechanism remaining to manage the flow regime, water
 37 quality, and river ecology and processes in the WSR is dam management, and the secondary
 38 mechanism is improved surface water management throughout the Upper Basin. Considering the
 39 volume of water extracted, water released from the reservoirs is, overall, significantly below
 40 historic flows. Furthermore, while goals for *annual* average releases are met, they do not always
 41 conform to the periodicity that stream biologists and anglers say are required for native species
 42 and ecological processes. When too little water is released, particularly in the spring and
 43 summer, water temperature increases beyond optimal conditions for many species, and pollutants
 44 are more concentrated. Aquatic invertebrates decline, trout and other species up the food chain

1 are negatively affected and tourism based on river boating and anglers suffers (Parasiewicz,
2 Undated).

3
4 Water is also released from the Upper Delaware reservoirs to help maintain river levels adequate
5 to prevent saltwater intrusion from Delaware Bay up river. During droughts in the past 50 years,
6 the “salt front” has moved up river considerably. This intrusion may play a role in the conversion
7 of upland forest areas to marshes, which could affect adjacent river ecosystems (Partnership for
8 the Delaware Estuary, 2007). The saltwater is problematic for industries using water along the
9 river front and increases sodium in the aquifer that supplies water to Southern New Jersey. Water
10 conservation in the Delaware Basin and New York City has significantly helped address
11 drought-related water shortages.

12
13 Flood control and water quality in the Upper Basin are managed through restoration of stream
14 banks, riparian buffers and floodplain ecosystems and through improved land and water
15 management. The Delaware River Basin Commission sets specific objectives for ecosystem
16 management in the basin (Delaware River Basin Commission, 2004). Land use along the river is
17 regulated by Township (PA) and Town (NY) zoning regulations, which are influenced by state
18 regulations and requirements to qualify for FEMA flood insurance. The NPS and other partners
19 work with the towns and townships to promote, through planning and zoning, maintenance of
20 native vegetation in the floodplain and river corridor and to improve storm water management
21 throughout the watershed.

22
23 The NPS and state agencies also manage river recreation, providing access to boaters and hikers
24 and regulating their impacts. Following recent floods, agencies assisted with evacuation of
25 residents in low-lying flood-prone areas; evacuated their own boats, vehicles, and equipment to
26 higher ground; and mobilized post-flood boat patrols to identify hazardous materials (*e.g.*,
27 propane tanks, etc.) left in the floodway and hazards to navigation in the river channel.

28
29 NPS and others are beginning to work more closely with the National Weather Service to
30 provide them with data on local precipitation amounts, snowpack, and river ice cover, and to
31 coordinate with their Advanced Hydrologic Prediction Service to enable better forecasting and
32 advanced warning to valley residents of flood crests and times.

33 **6.4.3.2 Potential Effects of Climate Change on Ecosystems**

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

1
2 As with any river system, such climate-induced changes in environmental conditions may have
3 serious ecological consequences, including erosion of streambanks and bottom sediments that
4 may decrease the availability of suitable habitat, shifts in the growth rate of species due to
5 thermal and flood-related stresses, and unpredictable changes in ecological processes such as
6 carbon and nitrogen processing (see section 6.3.3).

7 **6.4.3.3 Potential for Altering or Supplementing Current Management to Enable Adaptation for**
8 **Climate Change**

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

18
19 Improved watershed management to reduce aberrant flood events and minimize water pollution
20 is one of the most useful long-term tools for managing river resources in a changing climate
21 (Mid-Atlantic Regional Assessment Team, 2000). Federal, state and local authorities can create
22 incentives and pass ordinances to encourage better water and land use that protect the river and
23 its resources. For example, improved efficiency of water use and storm water management (*e.g.*,
24 household rain barrels and rain gardens, holding ponds), improved use of agrochemicals and soil
25 management, and restoration of wetlands and riparian buffers would combine to reduce severity
26 of floods, erosion damage and water pollution.

27
28 Finally, continual improvements in municipal and household water conservation are among the
29 most promising approaches to manage water in the Delaware River Basin. Populations in and
30 around the Delaware Basin will grow, increasing demand on water supplies and river access for
31 recreational uses. Per capita water use in New York City has declined from more than 200
32 gallons per capita per day around 1990 to 138 gallons per capita per day in 2006 (New York City
33 Department of Environmental Protection, 2006). Water pricing can be use to promote further
34 conservation (Mid-Atlantic Regional Assessment Team, 2000). An important component of this
35 approach is educating the public so that consumers better understand the important role that
36 water conservation plays in protecting river ecosystems and future water supplies.

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6.5 Conclusions

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

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

- Increase monitoring capabilities in order to acquire adequate baseline information on water flows and water quality, thus enabling river managers to prioritize actions and evaluate effectiveness.
- Increase forecasting capabilities and develop comprehensive scenarios so that the spectrum of possible impacts, and their magnitude, can reasonably be anticipated.
- Build flexibility and adaptive capacity into the CRMPs for WSRs, and update these plans regularly to reflect new information and scientific understanding.
- Strengthen collaborative relationships among federal, state, and local resource agencies and stakeholders to ease the implementation of adaptive river management strategies.
- Keep stakeholders informed, concerned, and engaged in what the WSR administering agencies are doing to protect the outstandingly remarkable values of the nation’s rivers as climate change impacts unfold.

1 **6.6 References**

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 - 16 ▪ Kristy Hajny, Niobrara National Scenic River
 - 17 ▪ Mike Huggins, U.S. Fish and Wildlife Service
 - 18 ▪ Quinn McKew, American Rivers
 - 19 ▪ David Purkey, Stockholm Environment Institute-U.S. Center
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 - 21 ▪ Cassie Thomas, National Park Service
- 22
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1 **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

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

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

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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.

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Box 6.4. Climate Change and WSRs in Alaska

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

Potential Effects of Climate Change on Ecosystems and Current Management

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

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

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

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

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

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

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

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Box 6.5. Adaptation Options for Resource Managers**Wild and Scenic Rivers: Adaptation Options for Resource Managers**

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

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Box 6.6. Climate Change, Multiple Stressors and WSRs

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

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

Box 6.7. Migratory Fish

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

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

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

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

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

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2 **6.9 Figures**

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

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1 **Figure 6.2.** Wild and Scenic Rivers in the United States. Data from USGS, National Atlas of the
2 United States (2005).
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Figure 6.3. Selected milestones in the evolution of the Wild and Scenic Rivers system. Adapted from National Wild and Scenic Rivers System website (2007a).

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

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

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1 **Figure 6.6.** Trends in water withdrawals by water-use category. As the population has grown,
2 water has been increasingly withdrawn for public use since 1950 as indicated by total
3 withdrawals (blue line). Water withdrawn for power production and water for irrigation represent
4 largest use followed by water for industrial uses then public supply. From Hutson *et al.* (2004).
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1 **Figure 6.7.** Changes in monthly average river flows on the Delaware River, in the Upper
2 Delaware Scenic and Recreational River segment. Lowered flows in December–July result from
3 upstream depletions for New York City water supply. Increased flows result from upstream
4 reservoir releases during summer months for the purpose of controlling salinity levels in the
5 lower Delaware. Figure based on data provided by USGS (2007).
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Figure 6.8. Location of dams and WSRs in the United States. Data from USGS, National Atlas of the United States (U.S. Geological Survey, 2005; 2006a).

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1 **Figure 6.9.** Photo of scientists standing on the bed of an urban stream whose channel has been
2 incised more than 5 m due inadequate storm water control. Incision occurred on the time scale of
3 a decade but the bank sediments exposed near the bed are marine deposits laid down during the
4 Miocene epoch. Photograph courtesy of Margaret Palmer.
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- 1 **Figure 6.10.** Organization of the WSR system. Adapted from National Wild and Scenic Rivers
- 2 System website (2007a).

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

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1 **Figure 6.12.** Projected temperature changes for 2091-2100 (University of Arizona,
2 Environmental Studies Laboratory, 2007).*
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7 * Note: This figure is provisional, based on securing permission to reprint.

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

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

1 **Figure 6.14.** Median, over 12 climate models, of the percent changes in runoff from United
2 States water resources regions for 2041–2060 relative to 1901–1970. More than 66% of models
3 agree on the sign of change for areas shown in color; diagonal hatching indicates greater than
4 90% agreement. Recomputed from data of Milly, Dunne, and Vecchia (2005) by Dr. P.C.D.
5 Milly, USGS.
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- 1 **Figure 6.15.** Photo of snowmelt in WSR during winter-spring flows. Photo courtesy of National
- 2 Park Service, Lake Clark National Park & Preserve.

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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).

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

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

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- 1 **Figure 6.19.** The Wild and Scenic portions of the Wekiva River. Data from USGS, National
- 2 Atlas of the United States (2005).
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Figure 6.20. The Wild and Scenic portions of the Rio Grande WSR in New Mexico. Data from USGS, National Atlas of the United States (2005).

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1 **Figure 6.21.** The Wild and Scenic portions of the Rio Grande WSR in Texas. Data from USGS,
2 National Atlas of the United States (2005).
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1 **Figure 6.22.** Dams and diversions along the Rio Grande (Middle Rio Grande Bosque Initiative,
2 2007).
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2 **Figure 6.23.** Map of Wild and Scenic stretches in the Delaware River basin. Courtesy of
3 Delaware River Basin Commission (Delaware River Basin Commission, 2007).

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