AFS Policy Statement #32:
STUDY REPORT ON DAM REMOVAL FOR THE AFS RESOURCE POLICY COMMITTEE
(Full Text)

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Introduction

This study report provides background information to support a recommendation by the American Fisheries Society's (AFS) Resource Policy Committee to develop a Dam Removal Policy Statement for consideration by the Governing Board and the full membership. The report is neither a comprehensive nor global review of the ecological, economic, and social costs and benefits of dams. Instead, the report provides the reader with a comprehensive literature review related to dam removal in the United States, with some application to Canada. For this document, a dam is defined as "a bank or mound of earth, or any wall or framework, raised to obstruct a current of water" (Webster's Dictionary 1979) that changes physical or biological conditions of a lotic ecosystem above or below the dam, or obstructs the passage of fish. A dam is considered to be "removed" when the physical blockage is removed from the waterway and stream flow approaches pre-dam conditions. Although this study report and the policy focus on dam removal, some of the following discussion may also apply to dam breaching, which is a partial removal with a different mix of benefits and impacts.

Issue Definition

Dams are dominant elements on many rivers and streams in the United States (Graf 1999). While the largest dams are among the few construction projects that can be identified from space, it is the more than 75,000 dams that exceed six feet in height (USACE 1999a in Appendix 3) that expand this issue to all 50 states. Collectively these dams have the capacity to store nearly 60 percent of the annual U.S. runoff (Graf 1999; Hirsch et al. 1990). In the arid southwest United States, dams on the Colorado River can store four years of typical flow (Andrews 1991). Many smaller dams (estimates range from hundreds of thousands to two million (Naiman and Turner 2000)) influence watersheds and natural resources across the national landscape. As recommended by the Aspen Institute (2002), the U.S. Department of the Interior's Fish and Wildlife Service and Department of Commerce's NOAA Fisheries started in late 2002 a state-by-state inventory of all dams, aiming toward a data base of all listings. Canadian provinces, with the exception of Prince Edward Island, had 455 dams producing hydropower in 2000, including 221 with capacity exceeding 10 MW (Canadian Hydropower Association, 2003).

While this document and the associated policy statement focus on dam removal, the Society recognizes that improved fish passage is often a viable alternative to full removal.

When removal is too contentious, costly, or otherwise prohibitive, a successful passage design may achieve some of the goals. This report does not address fish passage.

Dams have been constructed for many reasons, including electricity generation, mechanical power, irrigation, flood control, drought management, public water supply, navigation, fire protection, industrial cooling, recreation, fishing, wetlands creation (e.g., wildlife flooding in the mid-west in the 1960-70s), non-native species management, and native species protection. These structures have contributed to the economic development of the nation and to the social welfare of its citizens (Schuman 1995; Graf 1999; Heinz Center 2002), but have had ecological impacts on river and riparian ecosystem structure and function. Dam removal is a viable option to restore native or self-sustaining aquatic and riparian ecosystems (cf. Poff et al. 1997; Anonymous 1999), although other options exist and dam removal does not guarantee any particular result.

Amidst this debate, societies continue to construct new dams and operate aging facilities. While dams may provide fewer benefits and more impacts than predicted (Reisner 1986; Pringle 2000; Lemly et al. 2000.), some impacts can be mitigated through dam modification, operating rules, or outright dam removal (cf. Wunderlich et al. 1994; Schuman 1995; NRC 1996; Born et al. 1998; Doyle 1998; American Rivers et al. 1999 in Section 9.3.1 of Appendix 3; Postel 2000). However, each of these "remedial" activities has ecological, economic, and social impacts that also must be considered. Each dam and each removal option represent complex issues that transcend ecology and economics.

An additional consideration in dam removal is the growing number of dams that are obsolete, aging, or dilapidated to the point that they pose significant societal risks (Schuman 1995; Born et al. 1998; Buckley et al. 1998). All dams have a finite life span and eventually will have to be rehabilitated, replaced, or removed.

Water and aquatic resource management in the United States experienced a major shift during the 1990s with implications to public perceptions about dams. Concerns about decreasing biodiversity (Cairns and Lackey 1992; Hughes and Noss 1992; Winter and Hughs 1997; Postel 2000; Naiman and Turner 2000), inability to meet the water quality goals of the Clean Water Act (CWA) (NRC 1996), and general failure to sustain fish populations and fisheries harvests (Williams et al. 1989; Nehlsen et al. 1991; Williams 1997) contributed to developing strategies for ecosystem management. Watershed protection and restoration now complement the historical approaches of point source-, chemical-, and species-specific management (Naiman 1992; Doppelt et al. 1993; Kauffman et al. 1997; Lehman 1997; Roper et al. 1997; Williams et al. 1997; Doyle 1998; Leathery 1998; Pajak 2000).

Dam removal as an option to support watershed restoration focuses on recovery needs for anadromous, catadromous, and potadromous fish passage, spawning and rearing habitat, and ecosystem processes such as sediment and nutrient transport (Wunderlich et al. 1994; NRC 1996; Nemeth and Kiefer 1999). Debate on dam removal has increased since the late 20th century (e.g., Devine 1995; Joseph 1998; Booth 2000; Levy 2000; Aspen Institute 2002).

Watershed and ecosystem objectives also recognize that non-diadromous riverine fishes need passage as well to complete their life histories (Steven Gephard, Connecticut Department of Environmental Protection/Inland Fisheries Division, personal communication). This trend reflects a new awareness of long-term problems for fish populations and their riverine habitats. Reports by American Rivers, Friends of the Earth, and Trout Unlimited document 465 dams that have been removed in the United States since 1912, presumably for safety, watershed restoration, and other purposes (cited in Maclin and Sicchio 1999). At least 123 dams have been removed since 1970 (Heinz Center 2002). The majority of dams that have been removed were small and unsafe, unwanted, or obsolete (Schuman 1995).

Several states have lead the removal movement. Wisconsin has removed more dams than any other state – mostly small mill dams or obsolete hydroelectric dams removed by their owners with oversight from the state Department of Natural Resources (Born et al. 1998). In 1994, Newport #11 Dam on the Clyde River, Vermont, breached after its Federal Energy Regulatory Commission (FERC) license had expired. With a removal recommendation from the Vermont Department of Fish and Wildlife, FERC decided that the dam would not be rebuilt. The dam was completely removed in 1996 to meet state objectives to restore fish habitat. This was the first time FERC recommended removal as a preferred alternatives against the wishes of a dam owner (Maclin and Sicchio 1999). In Maine on November 25, 1997, the Federal Energy Regulatory Commission (FERC) issued an order (81 FERC 61,255) to deny the application for a new license of an existing facility at the Edwards Dam on the Kennebec River, and ordered the licensees to file a plan to decommission the generating facilities and remove the dam. This was done despite the licensees' objections. However, on May 28, 1998, the Lower Dennebed River Comprehensive Accord was filed with FERC. The accord represented a settlement among various parties, including the licensees, state and federal agencies, non-government organizations, and other hydropower facility owners on the Kennebec River regarding the re-licensing of the Edwards Project. The settlement provided for: 1) transferring the license to Maine, which would then, in connection with surrendering the project license, would remove the dam; and 2) resolving disputes regarding fish passage at various upstream projects. FERC approved the settlement in an order issued September 16, 1998 (84 FERC 61,227). Among the species benefited by this action were Atlantic salmon, Atlantic and shortnose sturgeon, and other anadromous fishes (Kennebec Coalition 1999).

Other dam removals intended to restore migratory alosids, striped bass, or sturgeons include: the Quaker Neck Dam removed in 1997-1998 on the Neuse River, North Carolina (Joan Harn, National Park Service, personal communication); six dams on the Naugatuck River, Connecticut (Steve Gephard, Connecticut Department of Environmental Protection/Inland Fisheries Division, personal communication.); more than 100 dams removed in Pennsylvania since the early 1990s (Michael Hendricks, Pennsylvania State Bureau of Fisheries, personal communication); and the Embrey Dam on the Rappahannock River in Virginia in 2004. Studies on the impacts of Quaker Neck Dam (< 6 feet high) before and after its removal document how a low-head dam can substantially affect fish migration, even during periods of high flow when the dam is completely submerged (Beasley and Hightower 2000, Bowman and Hightower 2001).

Many dams have been identified for removal by public and private partnerships. For example, in 2003 the American Rivers' website (see Section 9.1.2) included a list of 57 dams in 16 states to be removed. Among the tallest dams currently designated for removal to restore anadromous fish runs to historical spawning grounds are the Elwha (105 ft) and Glines Canyon (210 ft) dams on the Elwha River, Washington, and the Condit Dam (125 ft) on the White Salmon River, Washington. Hundreds of other dams, ranging from small Colonial-era mill dams in New England and small diversion works on the Great Plains, to large hydroelectric and navigation dams on the lower Snake River, Washington, have been proposed as candidates for removal (Heinz Center 2002). Nemeth and Keifer (1999) pointed out many of the ecological and sociological factors involved in recovery of the spring and summer chinook salmon runs in the Snake River. They called for restoring some level of pre-dam ecosystem function of the lower Snake and Columbia Rivers by providing more natural, free-flowing waters.

Dam removal initiatives and watershed protection approaches frequently conflict with local interests, depending on post-dam water levels and associated watershed uses. Impoundments are often cherished by shore property owners, businesses, and communities for their property-related, recreational, and aesthetic values (Born et al. 1998). Also, issues related to cultural values and historic preservation must be addressed in the decision-making process. As dam removal initiatives proceed, increasing conflict among stakeholders can be expected. Not all parties agree on the best balance of societal values associated with dam removal and restoring rivers to some reasonable semblance of their pre-dam hydrologic regime. In this background document, the AFS focuses on the ecological issues related to dam removal, with a secondary regard to other improvements.

Dam removal raises complex issues regarding sport fish management (Rahel 1997), especially the effects of species introductions in reservoir systems (Lassuy 1995). Fishery managers and citizens took advantage of habitats altered by dams to introduce and manage non-native sport fish, many of which are now very popular among the angling public and contribute to local economies. Dam removal, or even a partial breach, to restore native habitats and species assemblages could cause social, economic, and ecological disruptions that greatly complicate decisions.

As a consequence of physical and biotic alterations, dam removal can not be assured to restore flooded river reaches to the pre-existing natural system in rivers. An additional complication is that fishery managers in the Great Lakes basin and perhaps elsewhere have taken advantage of existing dams and have built small dams to control the spread and reproduction of the invasive sea lamprey (Dodd et al., 2003). While dam removal in the Great Lakes may help restore some native species, it may cause great harm to other native and introduced fishes in tributaries to the Great Lakes (Ellie Koon and Dennis Lavis, U.S. Fish and Wildlife Service Sea Lamprey Management Program, personal communication). Dam removal in the Great Lakes offers complex, but perhaps not unique, challenges. In North Carolina, dam removal could allow catadromous eels and other species infected with parasites to mingle with indigenous populations now inhabiting uninfected upstream waters. Despite that complication, dam removal still offers a major opportunity to improve populations of species such as eels.

These examples offer a glimpse at the debate about perpetuating non-native fisheries and how much manipulation should be used in impounded systems. Lackey (1994), Stanley (1995), and Rahel (1997) noted that the extreme anthropocentric view is that natural resources (e.g., fish) should be managed only for the benefit of people (i.e., the conservation of "valueless" species is wasteful). They contrast this anthropocentric view with the extreme biocentric view that the value of natural resources is not derived from their usefulness to humans, and that such resources should be managed for their own good and protection (i.e., economics is not relevant to conservation). Obviously, few would subscribe to either extreme. And it is likely that there is a continuum of views among AFS members throughout the mid-range of this philosophical spectrum.

In the current regulatory environment, dam removal will continue to be a topic of fierce debate, and AFS will be asked increasingly to articulate a position on the overall issue and perhaps on individual projects. Based on that interest, and with input from a range of knowledgeable members, AFS can best serve the public by developing a policy with technical recommendations to increase the benefits of dam removal on river and riparian ecosystems.

A new policy on dam removal must be developed with close consideration of, and perhaps amendment to existing AFS policy positions of direct relevance to dam removal, including (title followed by author and the year last reviewed for AFS):

1. Policy Statement on Man-induced Ecological Problems (Carter 1979)

2. Policy Statement on Effects of Altered Stream Flows on Fishery Resources (Tyus 1990)

3. Policy Statement on Protection of Threatened and Endangered Species (Kelso 1982)

4. Policy Statement on Strategies for Stream Riparian Area Management (Environmental Concerns Committee 1985)

5. Policy Statement on Cumulative Effects of Small Modifications to Habitat (Burns 1991)

6. Policy Statement Hydropower Development (Tyus and Winter 1992)

7. Policy Statement Biodiversity (Winter and Hughes 1996)

The relationship of a possible policy statement on dam removal to those above is discussed in Appendix 2.

Benefits and Costs of Dams

3.1. Historical Perspectives

Dams have a long history on the Earth's landscape, providing benefits to some of the earliest civilizations. Egyptians built dams upstream from Cairo about 5,000 years ago, largely for agricultural purposes. And western Europeans constructed dams to turn water wheels during the Middle Ages (Smith 1971). In North America, the Hohokam people of present-day Arizona constructed an extensive system of check dams and diversions as early as 300 BC (Gumerman 1991) that persisted till about 1450. Graf (1999) and Collier et al. (1996) provide a concise summary of the evolution of dam building efforts in the United States. They note that widespread, large-structure dam building coincided with development of heavy machinery and the demands of an industrialized society. In the eastern and mid-western states, dam construction supported mill and logging operations. From 1885 to 1940, most of the best dam sites were developed for hydropower. The era from 1945 to 1980 witnessed dams constructed for recreational lake development or municipal and industrial water supplies.

The "golden age" for large dam construction in the United States was between 1935 and 1965 (Thomas 1976; Graf 1999). In the western United States, the Hoover and Grand Coulee Dams were completed before World War II. The Shasta and Friant dams were completed in the 1940s, Glen Canyon Dam in 1963, and the lower Snake River dams in the 1970s. In the east, the 26-dam Tennessee Valley Authority system built in the 1940s initiated an era of building dams and managing reservoirs integrated over an entire river basin (Cullen 1962).

Throughout these decades of dam construction, tribal and public interest in societal values was growing. The Lower Elwha Klallam Tribe opposed construction of Elwha Dam, Washington, in 1910 but was not given a voice in the decision. Likewise, the Skokomish Tribe opposed building of Cushman Dam on the North Fork of the Skokomish River, Washington, circa 1925, but also was denied a voice. The Skokomish's role at Cushman is now formally acknowledged, as recognized by the Federal Energy Regulatory Commission in its June 2004 order for minimum flows as requested by the tribe and others (Hydrowire, 2004). Construction of Hetch Hetchy Dam in Yosemite National Park was widely opposed by environmentalists, including John Muir.

While large dams are being built in developing countries to meet increasing water and power needs (Postel 2000), few sites remain under consideration in the United States, Canada, and western Europe (Collier et al. 1996). In the United States, construction of large federally funded dams has all but ceased due to lack of appropriate sites plus concerns about environmental and social impacts. The trend in the United States and perhaps other developed countries is to increase capacity at existing dams and to construct small hydropower and irrigation dams off stream where potential impacts can be minimized (Wayne Edwards, U.S. Society on Dams, personal communication). Among dozens of life-extension and upgrading projects underway in Canada are the Brilliant Dam and power plant on the Kootenay River, British Columbia and the Sainte Marguerite 3 plant in Quebec (Canadian Hydropower Association, 2003).

As Postel (2000) noted, ecological systems and cultural traditions change over time, ultimately shaping freshwater management strategies. At least 22 federal agencies and scores of state and local agencies share responsibility for some portion of the hydrologic cycle, often with dramatically different perspectives (NRC 1998). Changing attitudes, traditions, and perceptions are increasing conflict among groups interested in dams. As this change and conflict occurs, increased polarization and heated debate can be expected. AFS can not resolve those issues but needs to be mindful of the controversy.

The next three sections summarize the many implications of dams. Relatively few impacts are entirely positive or negative, yielding a complicated analysis of potential effects on the biophysical and ecological environment. AFS recognizes that cultural, legal, historical, and other issues are crucial to sound decisions, but focuses here on the natural sciences that are clearly the Society's strength.

3.2. Impacts of Dams

Until the past century, dam installation was a widely supported method of river management. As a result, American rivers are collectively the most closely controlled hydrologic system of their size in the world (Heinz Center 2002). The benefits of North American dams are appreciable and include public and industrial water supplies, energy production, flood control, water diversion for irrigation, and recreation. The positive and negative effects of dams are debated widely, with proponents and opponents jousting in the literature and along our nation's rivers.

Negative aspects of dam construction and operation are often overlooked, especially long-term economic, social, and ecological effects (Dynesius and Nilsson 1994; Graf 1999; Postel 2000). The secondary impacts of construction or the cumulative impacts of operation warrant special consideration. Once constructed, people tend to overlook alternative solutions to problems such as zoning to keep buildings out of floodplains or using depleted ground water basins for water storage. Ecological and economic factors such as the risk of dam failure or the costs of soil salination (e.g., dust storms, sterilization of agricultural soils) need to be considered when the costs and benefits of dams are balanced.

Among the full suite of impacts, this study report focuses on the often overlooked or underestimated environmental costs. These costs are related not only to the size and design of the dam, but also to its operational strategies. For example, flood control dams maintain low reservoir levels until the onset of each flood season. Water supply reservoirs seek to keep reservoirs full as long as possible. And hydroelectric facilities attempt to minimize spillage so water can pass through turbines to generate electricity.

Each of these strategies has implications for downstream releases, upstream water levels, water temperatures, and the ecological health of the impounded system.

Water resource engineers often seek to optimize dam objectives while minimizing attention to environmental impacts. The size, design, and operational strategies of dams all affect their environmental impacts, which can include permanent land loss, habitat fragmentation, altered energy and nutrient transfers, water level fluctuations, decreased downstream materials transfer, lost river habitats and communities (aquatic and riparian), disturbed fish passage, and pressures from non-native species, among others.

3.2.1. Water Supply

Urbanization requires dependable water supplies for public and industrial needs that are increasingly met by impoundments and diversions. Water is withdrawn by public and private water suppliers and delivered to multiple users for domestic, commercial, and industrial use. Users demand a stable supply of water. Dam-impounded waters ensure this abundance and reliability. In the United States, the quantity of water withdrawn for public water supply during 1990 was an estimated 38,500 million gallons (Mgal)/day (183 gal/day for each person served including residential and industrial usage), a 5 percent increase since 1985. Surface water is the source for about 61 percent of public-supply withdrawals. The tremendous economic growth in the United States since the early 1990s has been supported by a plentiful and reliable supply of water.

Water availability in the United States is considered high (10,000-20,000 cubic meters per year per capita), but supply is predicted to drop to 5-10,000 cubic meters per year per capita by 2015 (NIC 2000) due to a combination of population increase and water consumption rates. Due to their ability to store water, dams are especially critical for water supply during drought conditions. As groundwater supplies continue to decrease, increasing demands on surface water supplies can be anticipated into the middle and latter part of the 21st century (Naiman and Turner 2000; Postel 2000).

In the United States, water consumption has doubled in the last 40 years and, as noted above, is expected to dramatically increase in the future (Postel 2000). In particular, U.S. population growth is expected to increase in those states that already experience severe water-based environmental challenges (Postel 2000). The U.S. Geological Survey (USGS) estimated that industrial water use in 1990 was 19,300 Mgal/day of self-supplied freshwater and 5,190 Mgal/day of public-supplied freshwater. Approximately 80 percent of these needs were derived from surface water. Reservoirs and impounded rivers provide reliable water supplies in to meet daily industrial water supply needs. In the western United States, dam removal could complicate the already complex regiment of water rights. Water stored behind dams has values determined by later release for beneficial use. Decision makers need to evaluate such issues before making removal decisions.

3.2.2. Electricity Production

United States electric power generation, both steam (fossil- and nuclear-fueled) and hydroelectric, heavily depends on an abundant and stable supply of water. Dam-impounded waters ensure this abundance and increase electric system reliability. Hydroelectric power accounts for approximately 10 percent of the total electricity used in the United States, and is produced at approximately 3 percent of the 75,000 large U.S. dams (Schuman 1995; USACE 1999a in Section 9.3.1 of Appendix 3); that ratio is about 70 percent in the Pacific Northwest (USACE 1999a in Section 9.3.1 of Appendix 3). In many mid-western and eastern states, hydropower accounts for 1-5 percent of the electricity produced. Water used for hydroelectric power generation during 1990 was an estimated 3,290,000 Mgal/day. This total represents 2.6 times the average annual runoff in the contiguous United States. (Hydroelectric power use of water exceeds average annual runoff because some water is used several times as it passes through turbines at multiple hydroelectric dams on a river).

Canada is the world's largest producer of hydropower, generating 350 terrawatt-hours per year (Twh/year). Sixty-two percent of all the electricity produced in Canada is in the form of hydropower, which accounts for 97% of Canada's renewable electricity generation. More than 90% of Canadian hydropower is produced in Quebec, Ontario, Manitoba, Newfoundland and Labrador, and British Columbia (Fortin 2002).

For purposes of operating an electrical system reliably hydroelectric power is desirable because it can be brought on line immediately, modulated quickly to follow demand, and is valuable for "ancillary services" such as voltage regulation and control (Pritchard 2000; USACE 1999b in Section 9.3.2 of Appendix 3). Lost hydroelectric power may prompt replacement from fossil-based energy sources (Jereb and Feldman 2000; USACE 1999b in Section 9.3.2 of Appendix 3). Most other forms of electric power generation, such as nuclear and coal-fired, also depend on an abundant and stable water supply for cooling, which is often provided by impounded rivers (USEPA 2000). In the early 1990s, more than 50 percent of the U.S. installed steam-electric stations use cooling water derived from impounded rivers and cooling reservoirs (EEI 1996).

Hydropower produces no air emissions [(except from shallow tropical reservoirs where decaying vegetation releases greenhouse gases) (St. Louis et al. 2000; World Commission on Dams in Appendix 3)], involves no wastes, and utilizes a renewable "fuel." However, as noted below in this Section 3.2), hydropower may create water quality, thermal, sediment, and gas super-saturation problems in impounded rivers when sediments are trapped and water at depth is released intermittently at the surface downstream of a dam. Secondary considerations would include the source of construction material, which is often mined with associated social and environmental issues. Finally, alternating high and low flows associated with "peaking" strategies at hydroelectric dams add cumulative stresses to resident and migratory fish.

3.2.3. Recreation

Dams create waterways that allow managers to expand the variety and amount of recreational opportunities. Dams establish reservoirs that become prime boating and water sport havens. Waters pumped from rivers, often from a reservoir associated with a dam, often provide waters for snow making and other key ingredients to recreational pursuits. Reservoirs can be managed to provide whitewater opportunities immediately downstream by controlling release rates and times. Finally, fisheries in those tailwaters offer increased access to cold- and warm-water fishes throughout the United States. For example, the West Branch of the Farmington River, Connecticut, supports healthier populations of trout and juvenile salmon because of a deep release, minimum flow requirement from a 100-foot water supply dam (Steven Gephard, Connecticut Department of Environmental Protection/Inland Fisheries Division, personal communication). Angling benefits may come at the expense of recreational pursuits such as whitewater or slack water boating.

3.2.4. Flood Loss Reduction

Many dams were constructed to protect citizens and property from the ravages of unpredictable meteorological events. With such protection, land owners and communities tamed floodplains and river valleys that were previously dominated by flood events. Flood control translates into lower societal costs for residential and industrial uses within the floodplain. Many dams designed to control flooding waters also provide recreational opportunities such as boating or fishing, but those benefits are now recognized within the larger water resources community to come at the expense of other natural benefits (see below in this Section 3.2).

3.2.5. Ecosystem Implications

Reservoirs resulting from dams create far more extensive littoral areas than the prior riverine stretches replaced by the reservoirs. The expanded perimeter of such areas often increase opportunities for wetland habitats. Increased edge habitats can support aquatic species such as fish, amphibians, macroinvertebrates, and aquatic vegetation. Such areas also provide refuge for migratory birds and other wildlife. While these ecosystem enhancements are generally incidental to the purposes for which dams were constructed, there are instances when dams have been constructed primarily for the purpose of ecosystem enhancement.

Altered river flow will shift ecological balance downstream of each dam. The more extensive aquatic zones above dams are usually countered by decreased river corridors below each blockage. Water depth, stream channel width, and associated habitats are usually reduced. Water temperatures also change, with impacts dependent on flood regimes from facility operation. Usually, decreased water flow leads to increase water temperatures resulting in a different mix of plant and animal species below the dam. The new ecosystem characteristics may lead to shifts away from native species. These impacts can be translated down river systems to their mouths. Estuarine health can be affected by altered river flow, slightly higher salinities during low flow periods, lower sediment load as materials accumulate behind dams, and shifts in microchemistry that can be translated into food chain impacts from algae and plankton on up to the fishes and birds. See also Section 3.2.9 below.

3.2.6. Permanent Loss of Productive Land

Inundation of fertile cropland above dams is a potentially serious threat to food production and human displacement. While this concern is greatest in populous countries like China and Bangladesh, smaller-scale impacts occur in flooded valleys throughout North America. Also, reduced seasonal flooding, which normally replenishes soil nutrients in river floodplains or stimulates plankton production and fisheries on continental shelves, adversely affects food production in countries where food is most needed (e.g., Aswan Dam, Egypt). Decreasing amounts of important riparian habitat has serious implications for terrestrial species that require such habitats to complete their life history; for aquatic species that spawn in seasonally flooded areas often sacrificed by dams; and for the recruitment of large woody debris to river systems.

3.2.7. Water Level Fluctuations

Depending on location (tributary vs. mainstem), design (pumped storage vs. conventional), intended use (flood control vs. water supply), and operational strategy (peaking at hydropower facilities), water levels in reservoirs or downstream from dams may vary substantially over short periods of time (Naiman and Turner 2000). Such fluctuations have the potential to adversely affect fish spawning, seasonal availability of habitat, development of aquatic and terrestrial macrophytes, riparian vegetation growth, and bottom dwelling organisms populations within the impoundment (Rood and Mahoney 1995; Braatne et al. 1996; Naiman and Turner 2000; Wildhaber et al. 2000; Galat et al. 2001). Recreation (e.g., boat ramps) and aesthetic values (e.g., extensive mucky or flooded shoreline) also can be significantly impacted by fluctuating water levels. In areas that have few topographical changes, such as Michigan's lower peninsula, dams have been built on the "best" fish habitat, e.g., riffle or rapids (Trautman 1957).

3.2.8. Upstream Energy and Nutrients Transfer

Dams may prevent nutrient and energy exchange from larger downstream systems to upstream areas by stopping or reducing fish passage. Larkin and Slaney (1997), Willson et al. (1998), Cederholm et al. (1999, 2000), Gresh et al. (2000) and Bilby et al. (2001) document the importance of energy and nutrients expressed as fish from the Pacific Ocean to the entire inland system. Similar processes have been noted for Atlantic Ocean watersheds with alosid migrations (Durbin et al. 1979; Garman and Macko 1998; MacAvoy et al. 2001) and for inland ecosystems (Hall 1972). Many watersheds now considered impoverished might improve if this important ecosystem function were restored through improved fish passage or dam removal.

3.2.9. Loss of Downstream Materials Transport

Dams are well known for disrupting the downstream passage of sediments, nutrients, and large woody debris. Dams trap these materials, prevent their normal processing by rivers, and cut off transport to larger downstream water bodies. Unintended sedimentation behind dams reduces the useful operation and life of dams; changes the characteristics of the reservoir (e.g., limits boating due to shallows); prevents sediment from replenishing downstream riparian, estuary, and ocean beach habitats; and causes scouring downstream of dams. By serving as settling basins, reservoirs may retain sediments, nutrients, and organic debris that are important for maintaining downstream fish, invertebrate, and plant communities (Petts 1980; USEPA 1989; Tyus 1999). Perhaps no where has this impact been noticed more than the Mississippi River drainage basin and delta, where dams, diversions, and channelization limit sediment delivery and starve downstream wetlands.

Trapped sediment behind dams and levees commonly reduces spawning gravel beds below dams, especially when there is no source to replenish them downstream. For example, salmon depend on loose gravel for spawning; when the gravel is captured behind a dam, the stream below may lose its gravel and become too armored for effective spawning (Raymond 1988). The river substrate downstream of both the Elwha and Glines Canyon dams has coarsened and armored, contributing to the decline of chinook salmon listed under the Endangered Species Act (ESA). The Elwha River estuary has been reduced in size, and nearshore beaches have steepened and receded, all contributing to a decline in fish habitat (NPS 1996). In addition, large woody debris transport has been reduced, resulting in a less diverse river community below the dams. Large woody debris helps to retain salmon carcasses and their nutrients (Cederholm and Petersen 1985).

Impeded flow can also have subtle effects on water chemistry that can affect downstream ecology. For example, dams can trap sediments and reduce silica transport to estuaries. A silica deficit can depress diatom productivity and shift species diversity toward algae, perhaps with secondary impacts on planktivorous species in the food chain (Cooper 2003). In agricultural regions, silica increases from farming (Colman and Bratton 2003) could be ameliorated by dams.

3.2.10. Loss of River Habitats and Communities

Dam construction may lower biodiversity and reduce riparian habitat throughout the watershed. Decreased habitats, fewer native flora and fauna, and more non-native plants and animals, are often common in altered rivers (Bain et al. 1988; Burns 1991; Dynesius and Nilsson 1994; Moyle et al. 1998; Tyus 1999; Janssen et al. 2000; Naiman and Turner 2000; Postel 2000; Pringle 2000; Pringle et al. 2000; Freeman et al. 2001; Bowen et al. 2003). In the United States, The Nature Conservancy reported that 67 percent of freshwater mussels are at risk, along with 51 percent of crayfish, 40 percent of amphibians, and 37 percent of freshwater fish (Stein and Flack 1997). Although risk is generated by human activities such as recreational fishing (bait releases) and shipping (ballast waters), an important threat to these species is hydrologic changes such as dams that alter river flow, its frequency and duration, raise water temperature, narrow the floodplain, change sedimentation, and degrade habitat (Postel 2000; Bowen et al. 2003).

Dams significantly alter flow regimes so that riparian and flood plain habitats become degraded or disappear (Bain et al. 1988; Dynesius and Nilsson 1994; Tyus 1999; Naiman and Turner 2000; Postel 2000; Janssen et al. 2000; Shields et al. 2000). River and floodplain ecology are inextricably linked, and restoring the ecological integrity of rivers depends on natural hydrographs prevented by dams (Galat and Frasier 1996; Galat and Lipkin 2000; Postel and Richter 2003). In the west, a high percentage of endangered vertebrate and plant species depend on riparian areas. Cottonwood trees, which support listed species in the western United States, are a classic example of the ecological impacts of dams since they depend on overbanking flow for recruitment and population viability (Auble et al. 1994). In extreme cases, rivers and lakes may dry up. In California, dams and other decisions affecting water supply permitted Owens Lake in the Owens Valley to dry up completely and nearly resulted in the loss of Mono Lake, a unique and important ecosystem (Roos-Collins 1994).

3.2.11. Disturbance of Passing Fish

Fish passing downstream and upstream through power-generating dam turbines can be damaged physically, and this damage can cause death or increased vulnerability to predation (FERC 1995; Coutant and Whitney 2000). The additive effects of this impact can be especially problematic for migratory fishes that may pass multiple dams (AFS 1985; Raymond 1988; Burns 1991; Bates 1993). Although passage rates may be acceptable at a single dam, the cumulative effect of multiple dams can threaten long-term survival of a species (Burns 1991; NRC 1996; USACE 1999).
Part of the passage problem is movement through reservoirs in which juvenile out-migrating fish are vulnerable to resident predators (NRC 1996). This is of particular concern with out-migrating salmon smolts in the Pacific Northwest that may pass through a number of impoundments with northern pike minnows and other resident predators (Raymond 1988; OTA 1995; NRC 1996).

In addition, the act of downstream passage by juvenile salmonids involves both active and passive swimming. Those fish that emerge from the gravel and immediately migrate to saltwater at very small size (e.g., pink and chum salmon) use currents as a transport mechanism, but dams slow water velocities. Pink salmon typically do not feed in freshwater and move rapidly to saltwater upon emergence, as early as the first night after emergence (Miller and Brannon 1981). That species may suffer starvation and high mortality within the slow water of a single reservoir (FERC 1993).

Migration cues may be lost for both upstream and downstream passage due to the change from a river environment to an impoundment (NRC 1996). Non-diadromous (river) fish also may be harmed by dams that prevent access to habitat needed for different life history functions, such as spawning, nursery, foraging, and over-wintering areas and seasonal thermal refugia (Schlosser 1991; Fausch and Young 1995; OTA 1995; NRC 1996; Schmutz and Jungwirth 1999; Bunt et al. 2001; Fausch et al. 2002).

3.2.12. Lost Energy and Societal Impacts

Electricity lost from energy-producing dams must be replaced to minimize impacts that would ripple through society. That major issue can be reduced by focusing removal on the thousands of dams that block fish but add little or no energy to the grid. Where energy production is valued, perhaps some dam removal goals can be achieved by adding fish passage facilities instead of pursuing complete removal.

3.3. Costs and Benefits of Dams

Some aspects of dam operation have both benefits and costs, thereby bridging the preceding two sections. Environmental concerns, the focus of this study report, include flood management, navigation, irrigation, water quality, fish and wildlife, reservoir and river recreation, habitat fragmentation, and non-native species.

3.3.1. Flood Management

The U.S. Army Corps of Engineers operates more than 500 dam and reservoir projects, many of which are managed for flood control (USACE 1998), although there are unintended consequences. One complex example is the Auburn and Folsom Dam debate on the American River near Sacramento, California. While the flood control concept could be designed to reduce threats in a flood-prone and densely populated region, the levee and dam system would compromise efforts to maintain ecosystem health throughout the San Francisco Bay delta region and specific efforts to restore listed species such as salmonids to their historic ranges.

Detailed information on flood control management can be obtained from the Corps and the Federal Emergency Management Agency (FEMA) web sites (see Appendix 3). While dams cannot completely control floods, when properly designed and operated, they can protect life and property, especially if downstream development is managed appropriately. Since dams were completed in the Connecticut River Valley after the flood of 1955 (Steven Gephard, Connecticut Department of Environmental Protection/Inland Fisheries Division, personal communication), no floods have occurred like the ones that killed 108 people and crippled Hartford in 1927, 1936, and 1938 (Leuchtenburg 1953). Similar results have been noted in the Catawba River (North Carolina, South Carolina), the Yazoo River (Mississippi), and a number of other systems in the United States.

Unfortunately, dams encourage people to live in downstream floodplains, increasing the potential for disaster if they fail, as happened to Saint Francis Dam (1928) and Williams Hill Dam (1963) in southern California, and to Teton Dam (1976) in Idaho. In the western United States, many dams are built on geologic discontinuities, or faults, where earthquakes may occur (Mount 1995). Multiple small dam failures pose other threats, as in 1994 when Tropical Storm Alberto caused more than 200 small dams to fail, killing three in Georgia (FEMA 1994 in Appendix 3).

3.3.2. Navigation

Locks and dams have expanded navigation to "inland" ports and eased distribution of bulk commodities worth billions of dollars annually. This transit has reduced on-road congestion and pollution. In the United States, approximately 25,000 miles of inland waterways support navigation, hauling 622 million tons of cargo in a typical year. The U.S. Department of Transportation estimated that direct operating revenues in 1996 for inland waterways exceeded $3 billion (USDOT 1996 in Appendix 3).

The indirect national economic benefits of inland waterway navigation have not been estimated; however, their magnitude can be envisioned from one study. For the 1994 navigation season (April through October), the St. Lawrence Seaway Corporation found that system-wide benefits included nearly 50,000 jobs, $2.2 billion in personal income, $1.9 billion in total revenue for firms engaged in handling and transporting cargo through the system, $101.7 million in state and local taxes, and $155.8 million in federal taxes (SLSC 1994 in Appendix 3). Seaway shipping totaled 38 million metric tons of cargo in 1996, approximately 6 percent of the total goods transported through all U.S. inland waterways.

Inland navigation systems, including dams and locks, often block natural movements of water and fish, and may degrade species, valuable fisheries, and other ecological values (Junk et al. 1989). For example, the upper Mississippi River system of engineered waterworks supports miles of navigable channels yet restricts the natural ebb and flow of flood waters that nurture habitats, with major impacts to native fishes.

Dams that impact fish populations and associated industries represent a significant negative economic impact. More economic benefit is generated by sport fishing than from commercial navigation on the Mississippi River. That revenue stream may be compromised by dams and related facilities such as locks.

The U.S. Army Corps of Engineers analyzed the effects of breaching Snake River dams on commodities transportation in the Pacific Northwest (see USACE 1999c in Section 9.3.2 of Appendix 3). For grain, the most important commodity affected, the USACE estimated an increase in transportation, storage, and handling costs amounting to $34 million annually, or an average for the region of 26.6 cents per bushel. If dams were removed and commodities would need to be moved by railroads rather than barges, infrastructure improvements costing from $210 million to a high of $535 million, would be needed. In contrast, Lansing (1998 in Section 9.3.2 in Appendix 3) reported that "[r]iver transportation on the lower Snake is expensive and heavily subsidized. Although river shippers pay only $1.23 per ton to go from Lewiston, Idaho to Kennewick, Washington, taxpayers and electric ratepayers pay an additional $12.66. The total cost to ship one ton of goods on the lower Snake is $13.89. In comparison, rail costs only $1.26."

According to Taxpayers for Common Sense (see Section 9.3.2 in Appendix 3), "[a] second, smaller cost to federal taxpayers is that they subsidize the full cost of maintaining and operating the navigation system on the lower Snake River, an estimated $35 million per year. According to the Congressional Budget Office (see Section 9.3.2 in Appendix 3), barge navigation receives the highest percentage of subsidy of any form of freight transportation in the United States, including rail and highway. On the lower Snake River, waterway users pay none of the waterway costs, even though they are loud voices for keeping the dams." Similar economic challenges cloud the future use of the St. Lawrence as a seaway to the Great Lakes and other waterway systems.

3.3.3. Irrigation

Water temporarily stored in reservoirs and diverted for irrigation has stimulated agricultural development in arid western states. Indeed, the regional economies of many important agricultural areas, such as the San Joaquin Valley of California, are dependent upon irrigation water. Crops grown on irrigated lands are valued at nearly $70 billion a year – about 40 percent of the total value of all crops sold in the United States. The quantity of water withdrawn for irrigation in the United States is an estimated 180 cubic kilometers per year, with surface water the source of about 63 percent of irrigation withdrawals. The nine western water-resources regions (excluding Hawaii and Alaska) accounted for 90 percent of the total water withdrawn for irrigation in the United States during 1990 (See USGS in Section 9.3.2 in Appendix 3).

Globally, Postel (1998) estimated that the volume of irrigation water annually available to crops will have to increase by 2050 cubic kilometers over current demand to meet agriculture needs in the year 2025, the equivalent of the annual runoff of 24 Nile Rivers or 110 Colorado Rivers. Approximately 40 percent of the world's food comes from the 17 percent of the world's cropland that is irrigated. This dependence on irrigated land is expected to increase in the future because of limited opportunities to expand rain-fed crop production (Postel 2000). Based on such intensive use, agricultural irrigation in arid areas often increases salinity beyond human tolerance, a reason (along with deforestation and climate change) frequently given for the collapse of early civilizations in the Middle East and elsewhere. Salinity increases are due to high evaporation associated with impounded rivers and open-conduit systems (see also Section 3.2 above). Thus, the important present-day benefits of irrigation made possible by dams may have severe long-term consequences.

3.3.4 Water Quality and Sedimentation

Impoundments can serve as large treatment basins (USEPA 1989). Suspended sediments and nutrients in particular can often be reduced as a result of physical, chemical, and biological processes occurring in reservoirs, although toxic compounds that accumulate in reservoir sediments ultimately have to be dealt with to extend or end a dam's operational life (EPRI 2000a). Small impoundments are constructed to retain storm water and reduce erosion, but may also raise water levels with implications to streambank vegetation, winter ice scour, and increased erosion. Nutrients retained within a reservoir can be incorporated in plankton that subsequently cascade downstream where they can increase downstream productivity of invertebrates and fishes.

On the other hand, the ability of impoundments to provide water treatment and sediment removal is often reduced over time as they fill up with sediment, particularly small impoundments (Morris and Fan 1998). Sediments remaining in impoundments are frequently one of the major management challenges facing removal decisions and concerns following dam removal (Heinz Center 2002). The quantity of sediment and the potential for increased downstream sedimentation vary greatly with dam size, the geography and hydrologic characteristics of the basin, and other factors (Poff and Hart 2002).

River impoundments alter water quality within the impoundment, and those impacts can be passed downstream depending on outlet depth and design (AFS 1985; USEPA 1989; Tyus 1999; EPRI 1990; USDOE 1994). In surface release impoundments, the downstream temperatures may be higher than natural temperatures. For hypolimnetic releases, the downstream temperatures may be significantly colder than historical temperatures and may be accompanied by lower dissolved oxygen (USEPA 1989). Another potential effect of hypolimnetic releases is the "summer cool, winter warm syndrome," or a seasonal shift in, and dampening of, temperature extremes that can restructure biological communities. Specifically, above normal winter temperatures in temperate rivers can have negative impacts on aquatic insects and native fishes (Ward and Stanford 1979). Lesser, but still important, variability may occur in nutrient transport, suspended sediment, and dissolved metals (Tyus 1999).

Gas supersaturation from hypolimnetic releases, or from excessive voluntary or uncontrolled spill at hydro projects, can have serious effects on fishes and downstream biotic communities (NOAA National Marine Fisheries Service 1995). In the Columbia River system in the 1960s, an involuntary spill caused substantial, documented losses of adult salmon and steelhead attributed to gas bubble trauma (GBT) (Westgard 1964; Beiningen and Ebel 1970; Ebel and Raymond 1976). The bulk of the research on GBT has been conducted on direct acute lethal effects of gas bubble trauma on juvenile fishes (Pauley and Nakatani 1967; Newcomb 1974; Weitkamp and Katz 1980).

The exact nature of the relationship between sublethal exposures to gas super-saturation and the ultimate success of migration and unimpaired reproduction are poorly known. Disrupted physiology during spawning migrations can pre-dispose fish to invasion by fungal and other pathogens (Smith 1988). Eye abnormalities were described in lake trout exposed to very low levels (100.5 percent total gas pressure) of gas super-saturation for an extended time (Krise and Smith 1993). Gas super-saturation has been shown to be a significant fish stressor at sublethal levels, depressing growth in lake trout (Krise 1993).

3.3.5. Fish and Wildlife

Reservoirs provide excellent habitat for some species of fish and wildlife. Operational strategies for dams can be altered to provide stable water levels for spawning and recruitment of reservoir fish stocks, or to provide flow downstream to optimize spawning by target species (AFS 1985; EPRI 2000b). Reservoir fluctuations often are used to control non-native vegetation and fishes, to concentrate forage fishes, or to create a dynamic aquatic-terrestrial transition zone (Hall 1971). Sometimes downstream flows are managed to provide opportunities for fishing and other water-based recreational activities (Hyra 1978; AFS 1985; Bates 1993; EPRI 2000b). In particular, hypolimnetic releases can support cool-water sport fisheries (e.g., tailwater fisheries for trout) that would otherwise not be available in warm-water regions.

The quality, quantity, and timing of water releases below dams are important ecological considerations (Petts 1980; AFS 1985; Cushman 1985; Bain et al. 1988; Tyus 1990; Moyle et al. 1998; EPRI 2000b). Reservoirs typically dampen and homogenize the flow regime, as well as alter natural flow seasonality (NRC 1996; Naiman and Turner 2000). During natural periods of low flow (e.g., winter in the Green River, Utah; summer in the Illinois River), biota may suffer from elevated or fluctuating base flow (Muth et al. 2000). While historically most emphasis has been on maintaining some minimum flow (Weisburg and Burton 1993), research has also addressed biodiversity below dams under the "natural flow paradigm" (Poff et al. 1997) and the "range of variability approach" (Richter et al. 1996). Rapid changes in flow can disrupt downstream ecological processes and strand fish and wildlife (AFS 1985, Tyus 1990).

Successful spawning of indigenous fish and maintenance of diversity of native mollusks are two concerns closely tied to flows downstream from impoundments (Allan and Flecker 1993; Vaughn and Taylor 1999). Native mollusk diversity decreases closer to dams. Increased diversity in undammed downstream waters appears to be related to increased habitat complexity and a more natural flow regime due to tributaries that promote higher diversity of fish required by mollusks to support their parasitic glochidia larvae (Vaughn and Taylor 1999).

Altered flow regimes also may favor non-native species, furthering declines of native species (Poff et al. 1997; Tyus 1999; Levine 2000). Other concerns related to downstream flows include maintaining natural geomorphic processes in streams and rivers (Graf 1996; Tyus 1999; Shields et al. 2000; Hurst et al. 2000). Depending upon whether one's view of fishery management is primarily anthropocentric or biocentric, views on the relative values of fisheries and fishes in reservoirs versus rivers and streams may be quite different.

Dams have fragmented all large rivers in the United States (Graf 1999) and the northern third of the world (Dynesius and Nilsson 1994). Habitat fragmentation adversely impacts indigenous aquatic and terrestrial species that require unfragmented habitat for migration, reproduction, nursery, or wintering habitat (National Research Council 1996). In some instances, isolating various habitat components of a species can have serious implications on the long-term survival of that species (AFS 1985; Bates 1993; OTA 1995; Jager et al. 2000). This concern is the basis for efforts aimed at improving fish passage at dams or at total dam removal.

Habitat fragmentation is one of the causative factors in the drastic decline of salmon in the northwestern United States (Raymond 1988; Bates 1993; NRC 1996; USACE 1999). Snake River salmon runs decreased seven-fold in the past 20 years despite attempted recovery techniques using trucks and barges to transport fish past the dams (USDOC 1995). Other factors besides dams (e.g, ocean conditions, deforestation, development) play important roles in the decline and may be responsible for some of the population increases observed near the turn of the 20th century. Habitat fragmentation has also been implicated as a contributor to the decline of Pacific northwest sturgeon stocks (Cochnauer et al. 1985) and lake sturgeon in the Great Lakes basin (Auer 1996).

Dams and habitat fragmentation also isolate river segments and their biota. Plant and animal movements are interrupted or affected by dams and the unnatural habitats they create. Dam construction can isolate migratory populations from spawning and rearing tributaries, and cause the loss of many fluvial populations (Thurow et al. 1988; Hilderbrand and Kershner 2000). Dams also can obstruct movements and completion of life histories of anadromous and potadromous fishes (those that migrate within a river system). However, in some cases, these isolated segments have provided refugia for species of special concern, such as cutthroat trout. And impassable barriers have been used to assure that non-native salmonids are kept out of areas with native salmonids because nonnative trout have reduced the viability of populations of native species (Grifffth 1988; Varley and Gresswell 1988; Kruse et al. 2000).

The consequences of restricted range are debated in the literature, as population fragmentation can occur both from migration barriers and from genetic introgression of non-native species through hybridization. Alternatively, breaching dams can reestablish and reconnect river habitat and provide for recovery of diadromous fishes (Anonymous 1999).

Since the 1990s, dam removal has gained favor as an antidote to habitat fragmentation. Great Lakes states have removed more than 100 small inland dams (<5 meters high) to restore fish to historical ranges and to restore more favorable stream conditions for native fish such as brook trout and smallmouth bass. Many of these removals have been grass-roots efforts led by citizen groups and implemented by local governments, with assistance from state and federal agencies and non-profit organizations (Maclin and Sicchio, 1999).

Several federal programs provide funding support for grass-roots efforts to restore fish habitat and improve fish passage. The NOAA Community-based Restoration Program supported 53 dam removal and fish passage projects between 1996 and 1999, and well over 100 total through 2002. These projects have improved access to hundreds of kilometers of stream habitat for anadromous and potadromous fish. Salmonids, herring, alewife, and shad have benefited the most from these projects (Lenhart 2003).

3.3.6. Reservoir and River Recreation

Dams have helped support the burgeoning demand for water-based recreation, such as boating, including power, sail and rowing, fishing, swimming, camping, and picnicking. Recreation assessment and planning play a large role in the re-licensing of hydroelectric facilities. Licensees' reported a total of 103.6 million recreation user days at FERC-licensed hydropower projects in 1996. This information, which comes from the FERC Form 80, includes 86.4 million recreation user days and 17.2 million recreation user nights. There are 1,782 federal dams that each impound more than 50 acre-feet of water; 500 of these dams have more than 1,000 surface acres. These facilities support about 900 million visits a year and generate more than $44 billion in economic impacts (see USDOI web site in Section 9.2 of Appendix 3). In some cases on dammed or free-flowing rivers, the economic benefits of recreational boating exceed the benefits of power (see American Rivers website listed under Section 9.3.2.).

Dam construction may create reservoirs, de-watered downstream reaches, or decrease river-based recreation such as white water boating and stream angling. River-based recreation also provides substantial economic benefits, particularly from direct, indirect, or induced effects on local economies (Moore and Siderelis 2003). Case studies and methodologies for evaluating these benefits associated with dam removal and improved stream flows are available from the U.S. Fish and Wildlife Service (USFWS), Division of Economics (see Section 9.3.2 of Appendix 3). "Conversion of riverine areas to reservoirs has previously been judged beneficial because of the recreational opportunities afforded by fishing for game fish in reservoir and tailwater environments. Whereas such reservoir fisheries were once rare and natural streams abundant, the decline of natural streams has proceeded at an alarming rate. In addition, the long-term maintenance of an acceptable level of reservoir sport fishing has proven to be an expensive venture because of the need for intensive, long-term management practices. These practices include put-and-take stockings, poisoning and restocking, and other management procedures" (Tyus and Winter 1992).

The U.S. Army Corps of Engineers studied the recreational benefits provided by dams in Idaho’s lower Snake River and the impacts associated with breaching (USACE 1999d in Section 9.3.2 of Appendix 3). Regarding sport fishing on reservoirs in the system, a 1997-1998 survey estimated a total of more than 111,000 angling trips and nearly 500,000 hours of angling effort would be foregone with dam removal. Although the numbers remain unpublished, the USACE (1999d in Section 9.3.2 of Appendix 3) estimated that river recreation activities would exceed those currently offered by reservoir recreation activities, assuming restoration of anadromous salmon runs.

In the late 1990s, the estimated annualized present value of the economic benefits of restored river recreation exceeded reservoir recreation activities by $28 million per year to as much as $306 million per year with a middle estimate of $66 million per year (USACE 1999d in Section 9.3.2 of Appendix 3). As noted above, it is clear that fishery management philosophy (anthropocentric or biocentric) will influence views of the relative recreational merits of reservoir vs. river and stream fisheries. Aesthetic benefits must also be considered, but were absent in the aforementioned studies and in this study report due to the narrow focus of both reports.

3.3.7. Non-native Species

As the global economy becomes more interconnected and goods are transported between regions with greater ease, the movement of non-native species has also increased. The Great Lakes region offers compelling evidence of how species can become established, often with significant ecological implications. More than 140 non-native species have become established in the Great Lakes basin mostly by ballast water introductions, including the Chinese mitten crab, Eurasian ruffe, sea lamprey, zebra mussel, spiny waterflea, and round goby. Dams that alter natural hydrology may create and maintain river conditions favorable for non-native species.

Temporary and permanent dams also can play a role in allowing or preventing non-native species to gain a place in new systems. Dams can provide integrated control of non-native species by preventing access to new habitats or to spawning grounds. Hundreds of dams on Great Lakes tributaries, including 61 barriers built or modified by the Great Lakes Fishery Commission, prevent sea lampreys from reaching suitable spawning areas in tributary streams (Klar and Schleen 2001). Restoring the connectivity of some Great Lakes tributaries without regard to the continued exclusion of sea lampreys could be devastating to the continued control of this non-native pest. In some rivers, non-natives have gained access via water control structures.

Sea lamprey control is the cornerstone of an estimated $4 billion Great Lakes fishery for native and introduced species. About 200 tributaries are treated with lampricide to kill sea lamprey larvae, while hundreds of other tributaries do not require repeated, expensive chemical treatment because barriers block lamprey movements (Dennis Lavis and Ellie Koon, U.S. Fish and Wildlife Service, personal communication). However, this positive benefit comes at a cost. There are fewer fish species above than below lamprey barriers, fish community similarity above and below barriers is less than in control streams without dams, and movement of non-jumping species is restricted by barrier dams (Dodd et al., 2003 see BILD website in Section 9.3.2 in Appendix 3).

Planned introductions are one of the most commonly accepted management strategies for realizing the full potential of altered aquatic habitats produced by dams. Highly prized fisheries, such as tailwater trout fisheries in the southeastern United States, are dependent upon the altered conditions from dam construction and operation. One objective during some re-licensing or dam refurbishment projects has traditionally been to maximize these non-native fisheries rather than to return the community to a more natural structure, thereby complicating the public interest review associated with relicensing decisions.

Experience in non-dam situations offers insights into the unintended introduction of fish pathogens. Species or strains not endemic to isolated reaches of a river system can be introduced with the free movement of species after a barrier is removed or modified, thereby exposing native populations and any new migrants to risks of transmission (Anderson et al. 2000). Studies in Oregon seek to determine the risks to native populations of trout from Myxobolus cerebralis (the etiologic agent of whirling disease), which is carried by migrating salmon and steelhead that might stray into uninfected rivers. Also in the Pacific northwest, the infectious hematopoietic necrosis virus (IHNV) was successfully transmitted from free-ranging kokanee in the Deschutes River to a hatchery population of steelhead trout and to free-ranging chinook salmon. In Montana, similar concerns have been raised for populations of bull trout above dams on the Clark Fork River (James Peterson, Montana Wildlife and Parks, personal communication). In the Iron River, Wisconsin, a 50-foot high, former FERC-licensed dam is being removed and replaced with a 3-foot lamprey barrier that will continue protection of the Iron River National Fish Hatchery from diseases borne by Great Lakes salmonids (Dennis Lavis and Ellie Koon, U.S. Fish and Wildlife Service, personal communication).

The Political and Regulatory Context

4.1. Size of Dam and Regulatory Authority

From a political perspective, dams fit into three categories: 1) those that are regulated by the federal government, e.g., Federal Energy Regulatory Commission-licensed projects; 2) those that are federally owned, e.g., by the U.S. Army Corps of Engineers, DOI/Bureau of Reclamation, Tennessee Valley Authority; and 3) those that are neither owned nor regulated by the federal government, e.g., state owned. Federal facilities can be further divided into three categories: 1) built and regulated by federal entities (USACE, U.S. Bureau of Reclamation, Tennessee Valley Authority, etc.); 2) built by non-federal entities that often with technical or cost-sharing assistance from federal agencies; and 3) privately-built.

The U.S. Department of Agriculture has assisted in the construction of more than 10,000 dams, most of which are located in the upper reaches of watersheds, and used for flood control and watershed protection. But the number of dams owned by the federal government is fairly small. According to the National Inventory of Dams (USACE 1999a in Appendix 3), the federal government owns only three percent (i.e., about 2,250 dams) of the 75,137 dams that measure six feet or more in height. Of the 2,259 dams primarily used for hydropower (federal and non-federal), a large number are operated by the federal government or regulated by the FERC. The bottom line is that more than 70,000 dams that measure six feet in height or more are neither regulated by the FERC nor owned by the United States (USACE 1999a in Section 9.3.1 of Appendix 3). Some of those dams are regulated by state agencies; others are not regulated.

Most of the 87 largest dams (those storing one million acre-feet or more) are publicly owned. Their authorization, financing, and construction are defined in the federal legislation that specifies their primary uses, requiring that any alternative uses must occur within that framework. In the past, enabling legislation often has focused on flood control or navigation for USACE dams, or on water storage and delivery for dams of the USBR. Often these large structures have legislatively-mandated multiple uses in addition to their primary purposes. Re-engineering or operational changes to benefit downstream areas and purposes that are not explicitly part of the Congressional authorization for a dam are on uncertain policy terrain (Heinz Center 2002).

Most medium size dams that store 10,000 to 1,000,000 acre-feet of water are owned by private companies or cooperatives interested in irrigation, water supply, hydroelectric power, or direct waterpower uses (e.g., saw mills) (Heinz Center 2002). Non-federal hydropower projects on public waterways are licensed by the FERC for periods of 30 to 50 years. During the next 14 years (January 2004-January 2015), about 200 FERC-licensed facilities will be up for license renewal, thereby affecting thousands of river miles and many fish populations. Also, as of July 2002, developers held preliminary permits for 274 sites to evaluate the hydroelectric potential of a possible facility.

Dams not federally owned or FERC-regulated may fall within state jurisdiction, depending on size. While a small number of dams that measure six feet in height or higher produce hydroelectric power, most were built and are operated for purposes such as irrigation, recreation, water supply, flood control, and fire protection. States generally possess regulatory authority over these dams, at least for dam safety, and have the authority to make dam removal decisions, although in some cases federal approval might be required for certain dam removal actions (e.g., Clean Water Act section 404 permit regulating dredge and fill activities in the nation's waters). Dams that measure six feet in height or less often are unregulated, even for dam safety purposes, and have not been inventoried in many places. But removal still may require federal or state approval (J. Harn, National Park Service, personal communication).

Lastly, there is the issue of obsolete and abandoned dams. There are many small, low-head dams that no longer serve their useful purpose but continue to impact river and stream resources. Some of these have been abandoned, with no owner to take responsibility for mitigating the damages associated with the projects or to assume liability for the safety of the structure. These dams usually become wards of the state.

4.2. Relevant Laws and Regulations

Many legal issues are associated with dam removal. Such decisions often are made in the context of a regulatory hearing. Once a decision has been made, federal, state, and local permits are required to physically remove the dam. In addition to decisions about whether or not and how to remove a dam, decisions also must be made about potential restoration measures. Because many of the laws that apply to dam removal focus on environmental protection, they often are not easily adapted to the environmental restoration activities associated with dam removal and may actually discourage restoration efforts (Bowman 2001). One exception is the Pennsylvania Department of Environmental Protection "restoration waiver" authorization process that facilitates removal of unwanted dams to restore streams (Michael Hendricks, Pennsylvania Bureau of Fisheries, personal communication). Waivers are coordinated with the commonwealth's Bureau of Waterways and Engineering in an efficient, one-step process with the Department of Environmental Protection. Pennsylvania's approach accounts for the long-term ecological benefits of dam removal while acknowledging short-term impacts.

For hydropower facilities, Section 10(j) of the Federal Power Act (FPA) provides the primary regulatory context. The FPA requires that each hydroelectric license issued by the FERC include conditions based on recommendations received from the U.S. Fish and Wildlife Service, NOAA's National Marine Fisheries Service, and state fish and wildlife agencies for the protection, mitigation, and enhancements of fish and wildlife resources affected by a hydropower project. It provides that, whenever the FERC believes that any recommendation is inconsistent with the purposes and requirements of Part 1 of the FPA, or other applicable law, the FERC and the agency shall attempt to resolve any such inconsistency, giving due weight to the recommendations, expertise, and statutory responsibilities of such agency. Section 18 provides another important mandate. That FPA section empowers the U.S. Fish and Wildlife Service and NOAA's National Marine Fisheries Service to prescribe fishways that must be incorporated into licenses to reduce the effects of dams on river systems.

The Electric Consumers Protection Act (ECPA) of 1986 dramatically altered the re-licensing process for hydroelectric plants in the United States (Harrell 1996), by requiring the FERC to give equal consideration to power and development purposes and to environmental and other non-developmental values, including "energy conservation, protection, mitigation of damage to, and enhancement of, fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and preservation of other aspects of environmental quality" (16 U.S.C. B797e).

Additional legislative and administrative changes have led to terms for many new licenses being set through settlement agreements and collaborative efforts between the license applicant, resource agencies, states and other stakeholders, subject to FERC approval. A few recent settlements have included provisions to remove uneconomical (re: the costs of meeting re-licensing requirements) dams either in the near-term or the future (e.g., Wisconsin Electric in Wisconsin1 and Michigan; Condit Dam in Washington). With deregulation of the electricity industry and increased operational costs, facilities that are marginally economic may become candidates for decommissioning or removal, or may become orphan dams that are wards of the state. Cushman Dam in Washington is one such example (Hydrowire 2004).

It is also important to note that re-licensing of a hydroelectric facility by the FERC allocates public trust resources (river and stream habitat) for private or public use for an extended period. Each license application offers the opportunity for society to decide whether keeping the dam is an appropriate use of resources and whether the dam should be removed. Although it is very rarely exercised, the FERC, under certain circumstances, considers removal to be a viable alternative during the re-licensing process.

An additional consideration affecting all dams on the National Inventory of Dams is the 1976 Safety of Dams Act that requires periodic inspections of all dams in the country (Heinz Center 2002). Currently, 25% of all U.S. dams are more than 50-years old; by 2020, that figure will reach 85%. Inspections carried out by state agencies and reported to the USACE and FEMA show that 14% of all dams in the country are rated as "high hazard," with an additional 18% rated as "significant hazard" (Heinz Center 2002). Such dams have a high probability of loss of life or property if they fail, with associated ecological implications.

While most states have established programs to monitor and ensure dam safety, in some states not all dams are covered. The degree to which states regulate non-safety aspects of these dams also varies, with some states having no mechanism or process in place to regulate their environmental impacts or to make dam removal determinations (see ASDSO in Section 9.2 of Appendix 3).

Whether designed to generate power or some other purpose, dam construction has many intersections with the Endangered Species Act (ESA), Clean Water Act (CWA), the National Environmental Policy Act (NEPA), Coastal Zone Management Act, National Historic Preservation Act, the Wild and Scenic Rivers Act, Federal Power Act, Magnuson-Stevens Fishery Conservation and Management Act (M-SFCMA), Atlantic Coastal Fishery Cooperative Management Act, and with treaty-protected rights of Native Americans. For example, imperiled species in western U.S. watersheds often bring ESA into regulatory debates on dams. Recovery of some listed species hinges on actions involving dams, and the CWA stipulates that it is national policy to restore and maintain the biological, chemical, and physical integrity of rivers, a task that may involve modification or removal of dams.

The ESA has some bearing on most dam removals (Bowman 2001). Section 7 prohibits federal actions that jeopardize the continued existence of listed species, or that destroy or adversely affect critical habitat. Section 9 prohibits all persons from taking (e.g., harming) any listed species. The Act also requires the USFWS and NOAA's National Marine Fisheries Service to develop and implement recovery plans for the conservation and survival of threatened and endangered species. No dams have been removed under ESA authority, but the presence of listed species at a dam (particularly fish) has been an important factor in decisions to remove dams (e.g., Saeltzer Dam, Clear Creek, California). In fact, the restoration of threatened and endangered Pacific salmon populations was the primary purpose of the four dam removals in the Pacific northwest in 2000-2001 (Bowman 2001) and was an important consideration in debates for other dams continuing in 2003.

Many permits may be necessary to remove a dam (Bowman 2001). At the federal level, most dam removals require a CWA Section 404 permit issued by the U.S. Army Corps of Engineers for dredging a navigable waterway. To obtain Corps approval requires that the action result in no net loss of wetlands and in minimal adverse impacts, that there be no practicable alternatives to dam removal, and that the action is in the public interest. To obtain these permits may require a NEPA review and the preparation of an environmental impact statement. A Rivers and Harbors Act permit is issued with the CWA 404 permit if there is no adverse impact of dam removal on interstate navigation. If the dam is FERC-regulated and the license term has not expired, the owner must receive a "license surrender approval."

The Corps or the FERC may need to conduct additional consultations with the USFWS or NOAA's National Marine Fisheries Service regarding the presence of endangered or threatened species in the project area, with NOAA's National Marine Fisheries Service regarding project impacts on any fishery management plan developed by a regional fishery management council under the auspices of the Magnuson-Stevens Fishery Conservation and Management Act, or regarding compliance with the National Historic Preservation Act. State permits required before a dam removal can proceed may include Waterway Development, Dam Safety, Water Quality Certification, Coastal Zone Management Act Certification, State Environmental Policy Act review, National Historic Preservation review, and Resetting of the Floodplain. Municipalities require permits for demolition and building (Bowman 2001).

Because environmental laws in the United States focus primarily on protection, the legal system has not kept up with the evolution of public interest in environmental restoration. Whereas deviation from the status quo is the goal of restoration efforts such as dam removal, the CWA and ESA focus on recovery and maintaining the status quo. Thus, the goals of dam removal often are at odds with otherwise good environmental protection laws. Dam removal is sometimes accomplished in spite of laws designed to protect lotic resources, often when decisions are based on economic rather than ecological factors (e.g., FERC licensing) (Bowman 2001). A critical question for the near future is how to permit restoration projects within the current legal framework while fully considering the environmental impacts of restoration projects.

Although debate often casts social and economic benefits against environmental goals, dams may offer important compromise instruments with socioeconomic and environmental benefits (Heinz Center 2002). For example, through improved FERC licensing processes, new and renewed licenses are being established through settlement agreements between hydropower operators and resource agencies. Some view these agreements as providing for increased flows to protect fish and wildlife, riparian corridors, river-based recreation, and other non-developmental values in ways that are compatible with continued hydropower production [e.g., Wisconsin Shores (Wisconsin) and Deerfield (Deerfield River, Massachusetts) settlements in Pritchard 2000]. Others see the settlements only as ways to continue dam operation while providing minimal mitigation of impacts to fish and wildlife.

In Canada, the provinces regulate dams through either Environment or Water Acts. The Water Branch of the respective provincial governments usually regulates private dams at the provincial level through the Water Rights or Water Resources Administration Acts. Currently, there are no national standards or requirements for dam construction or removal. The federal government only gets involved in these issues when there are Environmental Impact or Fisheries Act issues, and they can condition the operation or removal of dams under these acts.

Removal Guidelines

5.1. Physical Conditions

Engineering for dam removal continues to evolve. To assist the hydropower industry in assessing economic and regulatory issues, the American Society of Civil Engineers published guidelines on the retirement of dams and hydroelectric facilities (ASCE 1997). The removal of small, low-head dams is usually straightforward and involves wrecking balls, backhoes, hydraulic hammers, heavy equipment, explosives, or a combination of these tools. With those basic skills in the 1950s, the California Department of Fish and Game was able to remove 24 small (<30 ft high) dams from the Klamath River basin at a total cost of about $3,000 (Handley and Coots 1953). Retirement of the Edwards Dam (Maine) required construction of a temporary earthen dam to permit access to the main structure. When the main structure was breached, the temporary dam washed out, and the remaining parts of the original dam were removed (Heinz Center 2002). "Engineering for dam removal continues to evolve. To assist the hydropower industry in assessing economic and regulatory issues, the American Society of Civil Engineers published guidelines on the retirement of dams and hydroelectric facilities (ASCE 1997). The removal of small, low-head dams is usually straightforward and involves wrecking balls, backhoes, hydraulic hammers, heavy equipment, explosives, or a combination of these tools. With those basic skills in the 1950s, the California Department of Fish and Game was able to remove 24 small (<30 ft high) dams from the Klamath River basin at a total cost of about $3,000 (Handley and Coots 1953). Retirement of the Edwards Dam (Maine) required construction of a temporary earthen dam to permit access to the main structure. When the main structure was breached, the temporary dam washed out, and the remaining parts of the original dam were removed (Heinz Center 2002)."

The logistics and costs for dam removal grow exponentially with size. A number of traditional engineering approaches have been proposed, but they have not been used yet for removing large dams (USACE 1999b in Section 9.3.1 of Appendix 3). Complicating the removal of dams are considerations related to how to provide interim fish passage during the course of a multi-year dam deconstruction, how to weigh the temporary costs of increased sediment loads versus the long-term benefits of dam removal, and how to remove or stabilize the volume of sediments that have accumulated in the reservoirs (ASCE 1997). These sediments also shorten dam life and may be laden with elevated levels of contaminants (EPRI 2000a). All of these issues must be addressed on a case-by-case basis during the environmental impact analysis phase of each dam deconstruction project.

5.2. Impact Assessment

Dam removal can have significant impacts to entire biological communities within the impounded areas and downstream. It is important to understand how changing flows associated with dam operation and removal will affect river ecosystems, including channel formation and maintenance, sediment transport, fish passage, riparian communities and wildlife. Recently geomorphologists and hydrologists have concentrated on understanding the downstream physical impacts of dams (cf. Graf 1996; Poff and Hart 2002). Typically dams reduce flood flows, increase low flows, decrease the annual and inter-annual variation in flow, and increase the short-term variability in flow. Attempts to define ecological impacts of these operations and provide downstream habitat for organisms led to the development of the "instream flow incremental methodology" (IFIM) and other techniques for determining flow needs of fish and other aquatic organisms (Reiser et al. 1989; Gillian and Brown 1997). IFIM, however, has limited usefulness due to its narrow focus on physical habitat as the determinant of biological productivity (Van Winkle et al. 1997) and fundamental weaknesses of the models themselves (Castleberry et al. 1996; Williams 1996; Kondolf et al. 2000).

To bolster the utility of IFIM as a decision-support system, the Electric Power Research Institute (EPRI) developed procedures for individual-based modeling (IBM) to address instream flow issues (Van Winkle et al. 1996). While IFIM relies on habitat suitability curves, IBMs use with a mechanistic representation of the processes underlying fish growth, survival, and reproduction (Van Winkle et al. 1993). EPRI (1999) has more recently reviewed the conceptual approaches to IBMs and has developed a software package for IBMs of stream fish. Such models can predict the cumulative effects of base flow, temperature, extreme flows, angler harvest and food production on fish growth, survival, and reproduction.

More recently, new conceptual models, such as the "natural flow paradigm" (Poff et al. 1997) and the "range of variability analysis" (Richter et al. 1996), have been developed to emphasize the range and timing of flow variation for entire communities of river (including riparian) species, rather than the population-level responses of one or a few game fish species. EPRI (2000b) and Annear et al. (2002) provide a comprehensive review of the approaches discussed above, as well as new tools involving decision theory for determining instream flow needs.

"Ecosystem diagnosis and treatment," a method for assessing watershed health in relation to salmon ecology, has been developed and used in the Pacific northwest (see Mobrand Biometrics in Appendix 3). This method uses salmon as the diagnostic or indicator species in a watershed. It attempts to look at ecosystem quality from a salmon's perspective and to recommend remediations that would move the system from its present state to an ideal state for salmon life history and production.

Along with IFIM, "qualitative observation" is a common instream flow method. This approach is mentioned infrequently in the technical literature, but is discussed in detail in EPRI (2000b) and Annear et al. (2002), where it is referred to as demonstration flow assessment. It appears to have arisen for hydropower relicensing at sites where other, more formalized approaches were believed to be inappropriate, subject to bias, or too expensive. It typically involves observation of several alternative instream flow rates by representatives of the various hydroelectric facility relicensing stakeholders and selection of a rate that appears to optimize instream management goals.

EPRI (2000b) discusses the advantages and disadvantages of this approach. The key advantages are that it is inexpensive and quick. The main disadvantage is that it can be regarded as too subjective because it relies on opinions rather than quantitative modeling. In contentious proceedings, this approach may not provide sufficient evidentiary support. But EPRI (2000b) notes that this disadvantage could be somewhat overcome if formal practices of decision theory and analysis were incorporated in the qualitative protocols. Flow regimes developed by this method have been successfully defended and have become the basis for stream management (e.g., Moyle et al. 1998).

The developing areas of watershed modeling and community indices may prove to be valuable tools for making decisions about dam removal. The "watershed analysis risk management framework" (WARMF) (Chen et al. 1997) has proven to simulate hydrology and water quality accurately in a number of systems, and likely would be particularly helpful in predicting flow regimes and water quality in a "no dam" scenario. The consensus module of WARMF allows for input by stakeholders to develop a river management plan.

The sociological implications of dam removal demand serious consideration, and this can probably be best addressed through a consensus tool such as the WARMF. Also, community indices are in varying degrees of development and will likely prove useful in the quest to examine community impacts in addition to impacts on target species. The "Index of biotic integrity" (IBI) (Karr 1981) has been validated for wadeable and non wadeable streams. The "reservoir fish assemblage index" (Jennings et al. 1995; Hickman and McDonough 1996) is in the latter stages of development and may be followed by an index for tailwaters.

The U.S. Environmental Protection Agency also has a web site dedicated to providing up-to-date information on the Agency's efforts to develop national bio-criteria and bio-assessment methods (see USEPA in Section 9.3.2 of Appendix 3).

5.3. Decision-making

While the science documenting the impacts of dam operation is mature, that associated with dam removal decision-making is only emerging. The fundamental scientific questions about dam removal are (Heinz Center 2002):

1) Can the physical system dynamic be restored?

2) Can the biological integrity return to sustainable levels?

Dam removal may return streams to previous conditions. Sediment loads behind dams and altered channel dimensions downstream may not automatically return to previous states (Heinz Center 2002). Rehabilitation of watershed level processes such as sediment, large wood, and water transport is most critical. If these processes are repaired, it is likely that waterway ecology will improve, although other watershed developments could influence efforts to restore natural ecological functions. In addition to the engineering and scientific challenges of evaluating dam removal, a challenge will be to quantify and resolve economic and sociological considerations.

While there is an increasing number of scientific research initiatives regarding dam removal, there has been a lack of efforts to synthesize the scientific findings with social science and public policy (Johnson and Graber 2002). Increased application of social science and decision-making principles to dam removal may lead to outcomes that favor more sustainable ecosystems and greater public benefits in the long term. Johnson and Graber (2002) suggest that scientists can address this need by conducting more applied research, disseminating those findings, and actively communicating with decision-makers.

While some waterway uses such as hydroelectric power, flood control, and drinking water are highly quantifiable, others, such as water quality, biodiversity management, endangered species, and existence values are more difficult to quantify.

Despite the complexities of the decision-making, there are dam removal success stories (Maclin and Sicchio 1999). For example, the removal of the Woolen Mills Dam in West Bend, Wisconsin has converted a formerly eutrophic millpond into a park area with a stream supporting a smallmouth bass population (Maclin and Sicchio 1999). This dam, which powered a sawmill and woolen mills and later was converted to hydroelectricity, had become nonfunctional and unsafe by 1980. Removal eliminated a public safety hazard, provided 61 acres of prairie and wetland which were planted with native vegetation, and restored a rock-bottomed portion of the Milwaukee River with riffles, pool and rapids, providing excellent smallmouth bass habitat.

Edwards Dam on the Kennebec River in Maine was removed in 1999. Since then, water quality has improved dramatically and Atlantic salmon, shad, and alewife returned for the first time in 160 years. Mayflies and other aquatic insects, along with fish returns (striped bass, alewife, shads, sturgeons) have attracted ospreys, kingfishers, and bald eagles. Removal also increased river recreation, fishing opportunities, and economic benefits to the local economy. Alphonso Dam on Evans Creek, Oregon, was removed by the U.S. Bureau of Land Management in 1999. For a cost of $55,000, removal enabled the threatened coho salmon and other fish species to migrate up the East Fork of Evans Creek for the first time in 100 years and reach an additional 12 miles of spawning and rearing habitat. According to American Rivers (see Section 9.3.1), dam removal has increased annually from 19 in 1999 to 57 in 2003.

The factors to be considered in a proposed dam removal are many and the stakeholders are numerous. Any decision on dam removal will certainly have to be on a site-by-site basis with a foundation in science and a full and objective consideration of ecological, engineering, maintenance, safety, economic, legal, and sociological factors. From a purely fisheries point of view, all stakeholders must participate to determine benefits and costs of ensuing from altering river ecosystems by retaining or removing dams.

Remaining Issues

Decisions about dam removal should involve all vested interests based on a wide array of issues. The AFS recognizes that complicated issues require that dam removal be considered on a case-by-case basis, but benefiting from information such as this study report and its numerous citations to provide a basis that extends beyond individual decisions. We can generalize about the biological impacts of dams, but we cannot generalize about decisions to remove or retain individual dams. Each dam will stand or fall based on a comprehensive review of biological and non-biological factors. The latter include economic, social, cultural, and legal issues, which have received minimal attention in this study report.

The AFS's role in dam removal must follow the principles that formed the basis of previous policy statements. These principles are embodied in the Proposed Policy Statement on Dam Removal (Appendix 4), as supported by this document.

This technical review and the Society's policy statement address a complex issue. Hence, it is fair to say that each contributor to (or reviewer of) this document might prefer to alter some words and implications. For that reason, and based on geographic or technical reasons, not every statement is supported by consensus. Despite those differences, the Resource Policy Committee as constituted by different members since 1999 supports this technical report and the policy statement. Some reviewers believe that the AFS should not develop a policy statement on dam removal.

The dam removal movement reflects changing values in our society. The Resource Policy Committee believes the AFS must address this issue. The Society's Governing Board can move "forward" by developing a new policy statement on dam removal or by deciding not to develop a policy. In either event, the decision should be published in Fisheries, noting that the AFS Resource Policy Committee reviewed the issue in detail and recommended that a policy statement be developed. The policy statement should be accompanied by this technical document to provide support and justification.

Contributors to This Document

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Appendices

9.1. Appendix 1. Organizations with Position Papers on Dam Removal

9.1.1. American Fisheries Society Subunits

Idaho Chapter: The Idaho Chapter passed a resolution with a 92% approval regarding the role of dams in Snake River salmon and steelhead recovery (June 24, 1999). The resolution stated that the four lower Snake River dams are a significant threat to the continued existence of remaining Snake River salmon and steelhead stocks. The Chapter stated that for recovery in their native ecosystem, one biologically required action is to eliminate or greatly reduce impacts to salmon and steelhead from the four lower Snake

River dams by removing, breaching or bypassing the dams, or otherwise allowing the lower Snake River to flow freely. The Chapter concluded that in conjunction with actions to allow the lower Snake River to flow freely, action to address detrimental impacts to habitat from harvest or from hatcheries likely will be required.

Michigan Chapter: The Michigan Chapter unanimously passed a resolution on dam removal on March 5, 2001, stating that dams alter the physical, chemical, and biological aspects of water quality; often restricting the movement, distribution, and exchange of genetic materials of fish and other aquatic organisms. They also found that dam removal or breaching of dams has proven to be an effective means of restoring aquatic ecosystems. The Chapter "supports the concept of dam removal where net positive environmental impacts and ecosystem restoration and rehabilitation are expected." It encouraged the Michigan Department of Natural Resources and the American Fisheries Society (the parent society) to develop comprehensive policy statements regarding the removal of dams where ecosystem restoration is likely.

North Pacific International Chapter: The North Pacific International Chapter passed a resolution in support of removal of the Elwha and Glines Canyon Dams on the Elwha River, Washington.

Oregon Chapter: The Oregon Chapter unanimously passed a resolution on "Snake River Salmon and Steelhead Recovery" on February 17, 2000. The position of the Oregon Chapter is that the four lower Snake River dams are a significant threat to the continued existence of Snake River salmon and steelhead stocks. The Chapter noted that if society wishes to restore these salmonids to sustainable, fishable levels a significant portion of the lower Snake River must be returned to a free-flowing condition by breaching the four lower Snake River dams, and that this action must happen soon. The Chapter further recommended that substantive actions to address detrimental impacts associated with harvest management, hatchery practices, and habitat alteration will be required of all concerned people.

Western Division: The Western Division of the American Fisheries Society adopted a resolution on July 13, 1999, regarding dam removal that is very similar to the Idaho and Oregon Chapter resolutions.

Wisconsin Chapter: The Wisconsin Chapter adopted a resolution on dam removal on January 5, 2000. Key elements of the resolution were: 1) dams on rivers restrict movement, distribution and exchange of genetic material of fish and other aquatic organisms; 2) dams have deleterious effects on the physical, chemical and biological aspects of water quality; 3) removal or breaching of dams are effective means of restoring lotic aquatic ecosystems; and 4) the AFS parent society is encouraged to develop comprehensive policy statements regarding the removal of dams where ecosystem restoration is likely.

9.1.2. Other Agencies or Organizations with Position Papers or Investigative Efforts

American Rivers: American Rivers does not have a specific policy on dam removal, but it is a partner in Hydropower Reform Coalition that does have a policy (see below). American Rivers formally opposes dams that "don't make sense" (see www.amrivers.org). See August 19, 2003, posting for information on removals scheduled for 2003.

American Society of Civil Engineers (ASCE): The ASCE has published a document, "Guidelines for Retirement of Dams and Hydroelectric Facilities." See EWRI below in this Section 9.1.2 for a paper on dam removal.

Aspen Institute: Aspen is an international, nonprofit, and educational institute that addresses a wide range of policy issues in a timely manner. Institute projects seek to improve mutual understanding and, where possible, achieve agreement regarding challenging policy issues through "an intentional, value-based method of dialogue" among participants representing diverse values, perspectives, and opinions.

Aspen's Program on Energy, the Environment and the Economy conducted a two-year dialogue on a variety of dam and river issues raised by the idea of dam removal. Twenty-six invited individuals participated in eight three-day meetings over the two years. They represented wide-ranging, relevant expertise, including: dam safety; ownership; construction; operation; removal and modification; federal, state, and local government regulation and permitting; tribal issues; hydropower generation and dam licensing; engineering; aquatic biology; water supply; fish and river management and restoration; and resource management, policy, planning, and conservation.

The objective of the dialogue was for participants "to express, inform, and integrate their values, knowledge and understanding, and to create new thinking to guide policy and practice around the issues of dams and rivers." The dialogue culminated in a 68 page report, "Dam Removal: A New Option for a New Century," published by the Aspen Institute in late 2002.

The intentions of the dialogue and report were largely accomplished. Although participants held extremely diverse perspectives and values, they were able to reach agreement on ten premises that were the basis for 13 recommendations. This included agreement that, "Dam removal can be a reasonable approach to meeting a variety of economic, ecological, water resource management, public safety, and owner objectives." Also repeatedly emphasized was that every dam and river is unique so it is not appropriate to address every dam in the same manner. In particular, this premise means that the scale and scope of "analysis necessary to consider the dam removal option properly varies from case to case and….needs to be commensurate with the scale of the project and scope of the project's impacts."

The recommendations comprehensively address the full range of issues associated with dam removal so this option "can be integrated effectively into river resources management, and removal decisions and implementation can be successful." Each recommendation is accompanied by proposed actions necessary to implement it.

The last two sections of the report, Priority Issues When Considering Dam Removal and Lessons Learned in the Implementation of Dam Removal, make the document a very practical guide for considering the dam removal option. The selected references in the report are current and enhance the reports usefulness and practicality.

Electric Power Research Institute (EPRI): EPRI is a non-profit scientific organization, primarily funded by U. S. energy producers. EPRI's primary focus is to provide scientific information to support policy and regulatory debates. EPRI does not have a formal or informal policy on dam removal. However, as part of its Hydropower Relicensing Environmental Issues research program, EPRI gathers and assembles scientific information on dam removal and project decommissioning issuesfor its members and for the benefit of public decision-making.

Environmental and Water Resources Institute: This unit of the American Society of Civil Engineers (listed separately above) produced a white paper on dam removal. See http://www.ewrinstitute.org/pdf/whitepaperdamremoval1.pdf

Friends of the River: This organization has a detailed policy statement which can be summarized by their words: "dam removal is not necessarily a quick and easy fix for blocked rivers and degraded ecosystems, but it is proving to be an exciting one with much promiseY[for]Ythe 21st century. (FOR, 1999).

Heinz Center: The H. John Heinz III Center for Science, Economics and the Environment is a non-profit institution dedicated to improving scientific and economic foundations for environmental policy. The Center fosters collaboration between industry, environmental organizations, government, and academia. The Heinz Center conducted a study of the economic, environmental, and social impacts of decommissioning dams in the U.S. The study was designed to "establish a method or process by which users may balance a complex set of goals [physical, biological, social, economic] in considering dam removal," as well as considering political opportunities and constraints. Specific objectives of the study to identify outcomes of dam removal, indicators of such outcomes that are measurable, and useful data sources. The study was performed with representatives of academia, government, environmental groups, and industry. The report is listed in the literature cited section of the study report.

Hydropower Reform Coalition: The HRC has a policy on dam decommissioning in the FERC relicensing process (http://www.amrivers.org/hydropowertoolkit/damdecommissioningpolicy.htm). The policy concludes that the vast majority of dams regulated by the FERC are profitable, safe, and have environmental impacts that can be adequately mitigated through changes in dam operations. But some other FERC-regulated dams either are uneconomic or marginally economic, have safety problems that may be costly to repair, or have environmental impacts that outweigh the dam's benefits. In these situations, dam decommissioning, either through license surrender or mandatory through FERC-ordered decommissioning, may be a viable alternative. The HRC believes the FERC must adopt new policies and practices to respond to the need for removal of dams that don't make sense. These policies involve consideration of dam decommissioning at relicensing, consideration of removal at license surrender, funding of dam decommissioning and removal, and dam owners' obligations in the absence of a national dam decommissioning insurance fund.

Instream Flow Council: IFC is a non-profit organization of state and provincial fish and wildlife agencies whose mission is to improve the effectiveness of instream flow programs to conserve aquatic resources. The Council has issued several statements on dam removal, with an emphasis on how instream flow program can support removal or modification.

Izaak Walton League: While the Izaak Walton League has no policy on dam removal, sections of other policies and resolutions bear on the issue. A 1997 resolution supports increasing commitment of state and federal resources to the study and removal of dams and other artificial barriers to fish migration. The IWL also stresses limiting the impact of dams and irrigation withdrawals by installing ladders, screens and other fish passage facilities, controlling water flows to maximize fish passage, protecting spawning habitats, and rejecting dams that would diminish fish runs or limit recovery.

National Hydropower Association: The National Hydropower Association has a policy on Dam Decommissioning and Removal (http://www.hydro.org/policy/sustain_dam.asp?t1=index.asp&n1=Policy+%26+Advocacy&t2=legislative.a sp&n2=Legislative+Issues). The NHA believes that dams are not simply a remnant of the past; they continue to play an important role in our future. The NHA, "recognizes the fact that maintaining some hydro dams, once their full public benefit is weighed against environmental and other social needs, may no longer be prudent," but believes that, "when all benefits are considered, dam removal will occur only in rare instances." They believe the "real issue in dam removal is whether all of the benefits of a dam are appropriately weighed against the real, not subjective or hopeful gains." The NHA calls for decisions to remove dams to be a slow, cautious, and deliberative process. The Association believes that, "Smart policy dictates that dam removal should be considered a last resort when there is no other means to address the environmental consequences of the impoundment and all of the project benefits have been appropriately weighed." The NHA policy concludes by calling for stakeholders to work together to "develop a rational national policy that can both protect and preserve our waterways and the infrastructure within them."

Trout Unlimited: On streams and rivers of importance to wild salmonids, TU supports the removal of dams unless such removal will damage the upstream ecosystem (e.g. by allowing upstream movement of harmful native or non-native species, including pathogens) (TU 1997).

U.S. Society on Dams: The USSD has no policy on dam removals. Its Committee on Dam Decommissioning is responsible for: 1) developing information that can be used to respond to inquiries that come to USSD on decommissioning of dams; 2) establishing a forum where members of USSD and other interested parties can discuss issues related to the decommissioning of dams; 3) creating and maintaining a state of the art body of accurate information on the decommissioning of dams; 4) preparing and maintaining a USSD position paper on decommissioning of dams for inclusion on the USSD World Wide Web home page; and 5) establishing guidelines for possible national use in determining the "why, when, and how" to decommission dams. A draft policy paper is at http://www.ussdams.org/c_decom.html

9.2. Appendix 2. Current AFS Policy Statements Related to Dam Removal

The AFS has already instituted several policy statements of direct relevance to the issue of dam removal. These include the following, listed by the primary authors and the date written or last reviewed:

· AFS Policy Statement on Hydropower Development (Tyus and Winter 1992)

This policy recognizes the negative impacts of altered stream flows on stream fishery resources. It recommends that instream fishery flows be implemented with water storage projects. One of the potential positive impacts of dam removal is enhanced instream fishery flows. The analysis of aquatic resource impacts and/or benefits associated with dam removals may depend on habitat evaluation procedures and research efforts supported by this policy. Similarly, the recommended national and international stream fish programs to evaluate stream ecosystems could include the evaluation of or need for dam removal.

· AFS Policy Statement on Effects of Altered Stream Flows on Fishery Resources (Tyus 1999)

This resource policy recognizes the impacts that hydropower development has had on major North American river systems. These impacts have occurred through the loss of free-flowing reaches by dams and impoundments. The comprehensive fisheries plans and management objectives and standardized impact assessment procedures proposed by the hydropower development policy are applicable to dam removal evaluations. The licensing agency fund recommended in this policy to cover removal and restoration assumes that dam removal will occur. This funding would financially support the dam removal policy.

· AFS Policy Statement on Cumulative Effects of Small Modifications to Habitat (Burns 1991)

This resource policy addresses the accumulation of local or small project impacts and their potentially serious regional and/or global impacts on fisheries. The policy recommendations include full disclosure of impacts during planning, a common framework of assessment methods, disclosure by regulators, research on habitat improvement and mitigation. These recommendations apply to and are reflected in the dam removal policy through the recommendations of consideration of consensus tools to include all stakeholders and the encouragement of the science of dam removal.

· AFS Policy Statement on Man-induced Ecological Problems (Carter 1979)

This resource policy recognizes that human population growth and the related increased use of resources has been at the expense of aquatic and other natural resources. The policy recommends tests on a local or watershed basis to determine if, after a short-term benefit has been realized, it is practicable to restore the area to its original function. This recommendation would apply to dams and their removal.

· AFS Policy Statement on Protection of Threatened and Endangered Aquatic Species (Kelso 1982)

This policy addresses the need for protection of threatened and endangered aquatic species habitat as well as the species themselves. The policy identifies the need to define critical habitat and the need to characterize the magnitude of anthropogenic impacts on aquatic systems that can cause further declines of aquatic species. Dams and their impacts have been shown to lead to the decline of aquatic species and to their listing as threatened or endangered. The AFS policy on the protection of listed aquatic species is related to and supports the policy on dam removal through the recommendation to support the evaluation and conservation of functional relationships between aquatic organisms and their environment, and through the support for research to determine habitat requirements, causes for decline, characteristics of critical habitat, and activities detrimental to the species and its habitat. This information is needed in the evaluation of a dam removal and any related threatened and endangered aquatic species.

· AFS Policy Statement on Biodiversity (Winter and Hughes 1997)

The policy statement on biodiversity recognizes the value and loss of biodiversity at the genetic, stock, species, assemblage, ecosystem and landscape levels. Dams have led to this loss through fragmentation of rivers and riverine systems. The biodiversity policy is related to and supports the dam removal policy through the following recommendations: national policies on biodiversity, education on management, protection and restoration of altered ecosystems, emphasis of restoration of ecosystem processes, monitoring of species and ecosystems, research on the environment to support biodiversity, and social science research on how people manage and value their natural resources.

9.3. Appendix 3. Web Site References on Dam Removal as of December, 2003.

9.3.1. Issue Definition

U.S. Army Corps of Engineers. 1999a. Water Control Infrastructure: National Inventory of Dams 1998-1999. U.S. Army Topographic Information Center, Alexandria, VA, (http://crunch.tec.army.mil/nid/webpages/nid.cfm)

American Rivers, Friends of the Earth and Trout Unlimited. 1999. Dam Removal Success Stories: Restoring Rivers through Selective Removal of Dams that Don=t Make Sense, (http://www.amrivers.org or www.americanrivers.org)

American Rivers and International Rivers Network. 2004. Beyond Dams: Options and Alternatives. 80pp. (Www.americanrivers.org or www.irn.org)

9.3.2. Benefits and Costs of Dams

The benefits of dams in the U. S. are appreciable, (http://www2.privatel.com/~uscold.index.html)

Public Water Supply

Surface water was the source for about 61% of public-supply withdrawals, (http://water.usgs.gov/watuse/wups.html)

As groundwater supplies continue to drop, increasing demands on surface water supplies can be anticipated into the middle and latter part of the 21st century, (http://water.usgs.gov/ogw/gwrp/stratdir/issues.html)

Industrial Water Supply

Approximately 80% of these needs are derived from surface water, (http://water.usgs.gov/watuse/wuin.html)

Electricity

Hydroelectric power accounts for approximately 10% of the total electricity used in the U.S., (http://www.inel.gov/national/hydropower/more.htm)

Hydroelectric power use of water exceeds average annual runoff because some water is used several times as it passes through multiple hydroelectric dams on a river, (http://water.usgs.gov/watuse/wuhy.html)

From the electric utility perspective, hydroelectric power is desirable because it can be brought on line immediately, modulated quickly to follow demand, and is valuable for "ancillary services" such as voltage regulation and control,

(USACE 1999a,b, http://www.nww.usace. army.mil/html/offices/pl/er/reports.htm, http://www.inel.gov/national/ hydropower/more.htm)

Removal of hydroelectric power may result in replacement power coming from air polluting, fossil-based energy sources, (http://www.nww.usace.army.mil/html/offices/pl/er/reports.htm)

Hydroelectricity has the environmental advantages that it produces no air emissions (but see www.dams.org for another viewpoint), involves no wastes to be managed, and utilizes a renewable "fuel," (http://www.inel.gov/national/hydropower/more.htm, http://www.hydro.org)

Loss of Riverine Communities

In general, construction of large dams has resulted in decreased biodiversity and reduced riparian habitat, (http://www.dams.org)

Loss of Downstream Transport of Materials

Conditions in the Elwha River, WA watershed, (http://www.nps.gov/olym/elwha/home.htm)

Flood Control

Detailed information on flood control management can be obtained from the USACE (http://www.wrsc.usace.army.mil/) and the Federal Emergency Management Agency (FEMA) (http://www.fema.gov/)

In 1994, Tropical Storm Alberto caused the failure of over 200 small dams and 3 deaths in Georgia, (http://www.fema.gov/MIT/damsafe/about.htm)

Navigation

The U. S. Department of Transportation estimated that direct operating revenues in 1996 for inland waterways exceeded $3 billion, hauling 622 million tons of cargo, (http://www.dot.gov/)

For the 1994 navigation season (April through October), the St. Lawrence Seaway Corporation found that system-wide benefits included nearly 50,000 jobs, $2.2 billion in annual personal income, $1.9 billion in total annual revenue for firms engaged in handling and transporting cargo through the system, $101.7 million in state and local taxes each year, and $155.8 million in federal taxes each year, (http://www.dot.gov/slsdc/reports/ 96anrep.html)

More detailed information on the navigation and transportation economics of the federally maintained, 465-mile-long Columbia-Snake Inland Waterway can be found in USACE (1999c, http://www.nww.usace.army. mil/html/offices/pl/er/reports.htm)

Lansing (1998) also discusses the economics of river transportation on the lower Snake River, (http://www.onrc.org/wild_oregon/salmonriver98.html)

Taxpayers for Common Sense report on the true costs of freight transport in the U.S., (http:www.net/main.html). Another article on this issue can be found at, (http://www.oregonlive.com/news/99/07/st072519.html)

Irrigation

The nine western water-resources regions (excluding Hawaii and Alaska) accounted for 90% of the total water withdrawn for irrigation during 1990, (http://water.usgs.gov/watuse/wuir.html)

Reservoir and River Recreation

Five hundred of these federal dams have more than 1000 surface acres, (National Recreation Lakes Study Commission, Reservoirs of Opportunity, Executive Summary, June 1999, (www.doi.gov/nrls)

Case studies and methodologies for evaluating these benefits associated with dam removal and improved stream flows are available from the USFWS Division of Economics (Industrial Economics, Inc., Economic Analysis for Hydropower Project Relicensing: Guidance and Alternative Methods, October 1998; http://www.indecon.com/pdf/hydroeco.pdf)

The estimated annualized present value of the economic benefits of restored river recreation exceed reservoir recreation activities by at least $28 million per year to as much as $306 million per year with a middle estimate of $66 million per year, (USACE 1999d, Lower Snake River Sport Fishery Use and Value Study. Walla Walla District, Portland, OR. http://www.nww.usace.army.mil/html/ offices/pl/er/reports.htm#lsr_edocs).

Non-native Species

Barrier dams for sea lamprey control in the Great Lakes basin have mixed ecological impacts, (BILD 2000, Biological Impacts of Low-head Barrier Dams, http://www.axelfish.uoguelph.ca/research/BILD.htm).

9.3.3. The Political and Regulatory Context

9.3.3.1. Size of Dam and Regulatory Authority

The U.S. Department of Agriculture assisted in construction of more than 10,000 dams mostly in the upper reaches of watersheds and mostly for flood control and watershed protection, (http://www.ftw.nrcs.usda. gov/pl566/agingwater/infra.html)

The bottom line is that over 70,000 of the 75,137 dams 6 feet high or higher are neither regulated by the FERC nor owned by the U.S., (http://crunch.tec.army.mil/ nid/webpages/nid.cfm)

9.3.3.2. Relevant Laws and Regulations

The states generally possess regulatory authority over these dams and would have the authority to make dam removal decisions, although in some circumstances federal approval might be required for certain dam removal actions, (http://www.amrivers.org/template2.asp?cat=2&page=190&id=1345&filter=10)

Currently, 25% of all U.S. dams are more than 50 years old and by the year 2020, that figure will reach 85%, (http://www. asce.org/govnpub/issue_brief/issbrfdm.html)

Further information on this issue can be obtained from the Association of State Dam Safety Officials, ASDSO, 606-257-5140, (http://www.damsafety.org/ndsp.cfm)

In addition, as the electricity market becomes deregulated, there is a chance that smaller hydroelectric projects may become uneconomical to operate and may be surrendered or abandoned, (http://www.amrivers.org/template2.asp?cat=2&page=2678&id= 16488&filter=10)

Examples include the Wisconsin Shores Settlement, http://cips.ferc.fed.us/Q/CIPS/HYDRO/P/P-1759.00H.TXT, and the Deerfield Settlement, http://cips.ferc.fed.us/Q/CIPS/HYDRO/P/P-2323.00D.TXT

9.3.4. Removal Guidelines

9.3.4.1. Physical

The removal of small, low-head dams is usually straight-forward and involves wrecking balls, backhoes, hydraulic hammers, heavy equipment, explosives, or a combination of these tools, (http://www.amrivers.org/ template2.asp?cat=2&page=2678&id= 16488&filter=10)

9.3.4.2. Impact Assessment

The U. S. Environmental Protection Agency also has a web site dedicated to providing up-to-date information on the Agency's efforts to develop national biocriteria and bioassessment methods, (http://www. epa.gov/OST/biocriteria/)

Mobrand Biometrics has developed the Ecosystem Diagnosis Treatment methodology that uses salmon as the indicator species for the ecosystem. By comparing existing conditions to ideal conditions, management recommendations can be made, (http://www.edthome.org/overview.htm)

9.4. Appendix 4: Proposed AFS Policy Statement on Dam Removal

The American Fisheries Society (AFS) recognizes that dams and associated aquatic communities provide many important societal benefits but that river blockages may cause adverse environmental impacts and societal costs. The net costs and benefits of dams should be compared to traditional values that were affected by altered habitat and ecology. AFS believes that dam removal can be a legitimate alternative to mitigate the adverse environmental effects of dams and their operation. Decisions about dam removal should rely on the best available scientific information give full, objective consideration to local costs and benefits and broader, regional considerations. The AFS supports dam removal when it is determined that both: 1) the benefits of dam removal outweigh the costs associated with societal, cultural, environmental, economic, engineering, and technical issues; and 2) dam removal is the best approach to restore fish habitat and the fish populations and fisheries they supported. Removal decisions should be selected with full stakeholder involvement.

When deemed to be the preferred alternative, dam removal should minimize impacts to aquatic and riparian resources. The AFS recognizes that adverse impacts to fisheries and impounded ecosystems are an unavoidable consequence of dam removal, but a well-designed removal can minimize short-term impacts. Over the longer term, removal is often warranted where temporary impacts are outweighed by the long-term benefits of dam removal. When the decision to preserve or rebuild a dam is made, effective and efficient fish passage facilities should be included at the structure to mitigate dam-induced fragmentation of the river ecosystem and resulting impacts to aquatic communities.

Implement this policy statement on dam removal, the AFS recommends that agencies, industry sectors, environmental interests, and others:

1. Develop a North American inventory and supporting database (location, dimensions, ownership, age, etc.) on public and private dams that is accessible to all stakeholders;

2. Organize workshops and symposia focused on science associated with the benefits and costs of dam removal;

3. Include all stakeholders from the beginning in the analysis of the ecological, economic, and sociological impacts of a specific dam removal;

4. Where warranted by project scope and applicable guidelines, use decision tools to quantify ecological, economic, cultural, and other values of river and riparian ecosystems above and below each dam;

5. Recognize long established water laws and the implications of dam removal on senior water rights;

6. Where cost and benefit analyses are conducted, consider scientific uncertainty and risk assessments;

7. Use accumulated knowledge to inform adaptive management processes in dam removal evaluations and projects, e.g., apply knowledge gained from past dam removal studies and projects to increase the success of future projects; and,

8. For non-power dams, encourage public and private entities to establish monetary funds, both project-specific and pooled, to support informed decision-making regarding dam removal, dam repair, and/or implementation of fish passage, mitigation, and enhancement measures. For federally licensed hydropower dams, follow agency guidance and licensing processes that encourage licensee to pay for fish passage and other mitigation.