

# CHAPTER FOUR: ALTERATION OF FRESHWATER SYSTEMS

## Introduction

Freshwater riverine and riparian habitats located in the northeastern coastal United States provide important habitat for the growth, survival, and reproduction of diadromous fishes and are critical to maintaining healthy estuarine ecosystems. Some of the diadromous fish (species that migrate between freshwater and saltwater for specific life history functions) inhabiting the Northeast include Atlantic salmon (*Salmo salar*), striped bass (*Morone saxatilis*), alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), American shad (*Alosa sapidissima*), rainbow smelt (*Osmerus mordax*), Atlantic sturgeon (*Acipenser oxyrinchus*), shortnose sturgeon (*Acipenser brevirostrum*), and American eel (*Anguilla rostrata*). Not only are diadromous fishes subject to environmental impacts in the marine environment, but they also encounter dams, pollution, effects of urbanization, and habitat changes in freshwater (Moring 2005). In addition, some forage species that are important prey for marine fisheries depend upon freshwater habitats for portions of their life cycle. The health and availability of freshwater systems and the preservation and maintenance of associated functions and values are vital to the diversity, health, and survival of marine fisheries.

Free flowing rivers, ponds, and lakes act as migratory corridors, spawning, nursery, and rearing areas and provide forage and refuge for life stages of these species. Riverine and riparian corridors, and palustrine and lacustrine wetlands provide important functions and values for resident and migratory fish, freshwater mussels, reptiles, amphibians, and insects (Chabreck 1988). Riparian corridors provide shade, nutrients, and habitat enhancing debris in riverine systems (Bilby and Ward 1991), which are essential elements necessary for these aquatic resources to thrive. In addition to supporting aquatic resources, freshwater wetlands perform important and broad ecological functions by reducing erosion, attenuating floodwater velocity and volume, improving water quality by the uptake of nutrients, and reducing sediment loads (Howard-Williams 1985; De Laney 1995; Fletcher 2003). Freshwater habitats are intricately connected to terrestrial and coastal ecosystems, making them vulnerable to a wide array of anthropogenic disturbances that can alter the functions, values, quantity, and accessibility of freshwater wetlands used by migratory fish (Beschta et al. 1987; Naiman 1992).

Biological, chemical, and physical threats to freshwater environments from terrestrial and aquatic sources have led to habitat fragmentation and degradation (Bodi and Erdheim 1986; Wilbur and Pentony 1999; USEPA 2000; Kerry et al. 2004). In particular, nonfishing activities, such as mining, dredging, fill placement, dam construction and alterations of hydrologic regimes, thermal discharges, and nonpoint source pollution have degraded and eliminated freshwater habitats (Zwick 1992; Wilbur and Pentony 1999; Hanson et al. 2003). Examples of nonpoint source pollution include urban stormwater and agricultural runoff (e.g., petroleum products, metals, pesticides, fertilizers, and animal wastes). Refer to the Coastal Development and Agriculture and Silviculture chapters for more detailed discussion on nonpoint source pollution. The federal Clean Water Act (CWA) has eliminated certain types of disposal activities, limited fill activities, and otherwise resulted in improved protection of the nation's wetlands and waterways. Despite these and other regulations to protect aquatic habitat, anthropogenic impacts continue, dramatically affecting fish habitat, including prey species and fisheries (Wilson and Gallaway 1997; Bodi and Erdheim 1986; Hanson et al. 2003; Ormerod 2003; Kerry et al. 2004).

## Dam Construction and Operation

The history and effects of dam construction on passage and habitat is well documented (Larinier 2001; Heinz Center 2002). Among the major identified causative factors of the population demise of Atlantic salmon, dam construction and operation may be the most dramatic (NEFMC 1998; Parrish et al. 1998; USFWS and NMFS 1999). In the United States, 76,000 dams have been identified in the National Inventory of Dams by the US Army Corps of Engineers and the Federal Emergency Management Agency (Heinz Center 2002). This number may be as high as 2 million when small-scale dams are included (Graf 1993). Dam construction and operation in the northeastern United States have occurred for centuries to provide power generation, navigation, fire and farm ponds, reservoir formation, recreation, irrigation, and flood control. Important for the local economy when originally constructed, today many of these structures are obsolete, unused, abandoned, or decaying. Fish passages in any given river system may not be consistent or effective throughout, limiting the ability for Atlantic salmon and many other migratory and resident species to reach necessary habitat. Sections 18 and 10j of the Federal Power Act require fish passage and protection and mitigation for damages to fish and wildlife, respectively, at hydroelectric facilities.

The effects of dam construction and operation on fisheries and aquatic habitat include: (1) complete or partial upstream and downstream migratory impediment; (2) water quality and flow patterns alteration; (3) thermal impacts; (4) alterations to the floodplain, including riparian and coastal wetland systems and associated functions and values; (5) habitat fragmentation; (6) alteration to sediment and nutrient budgets; and (7) limitations on gene flow within populations.

### *Impaired fish passage*

The construction of dams with either no fish passage or ineffective passage was the primary agent of the population decline of US Atlantic salmon (USFWS and NMFS 1999; NEFMC 1998). By 1950, less than 2% of the original habitat for Atlantic salmon in New England was accessible because of dams (Buchsbaum 2005). Dams physically obstruct passage and alter a broad range of habitat characteristics essential for passage and survival. Without any mechanism to get around a dam, there is no upstream passage to spawning and nursery habitat. Fish that gather at the base of the dam will either spawn in inadequate habitat, die, or return downstream without spawning. The presence of a fish passage structure does not necessarily ensure access to upstream habitat. Even with a structure in place, passage is contingent on many factors, including water-level fluctuations, altered seasonal and daily flow regimes, elevated temperatures, reduced water velocities, and discharge volumes (Haro et al. 2004).

Safe, timely, and effective downstream passage by fish is also hindered by dams. The time required for downstream migration is greatly increased because of reduced water flows within impoundments (Raymond 1979; Spence et al. 1996; PFMC 1999). This delay results in greater mortality associated with predation and the physiological stress associated with migration. Downstream passage for fish is hindered or prevented while passing over spillways and through turbines (Ruggles 1980; NEFMC 1998) and by entrainment or impingement on structures associated with a hydroelectric facility. Dadswell and Rulifson (1994) reported on the physical impacts observed in fish traversing low-head, tidal turbines in the Bay of Fundy, Canada, which included mechanical strikes with turbine blades, shear damage, and pressure- and cavitation-related injuries/mortality. They found 21-46% mortality rates for experimentally tagged American shad passing through the turbine.

Fragmentation of aquatic habitat caused by dams can result in a loss of genetic diversity and spawning potential that may make populations of fish more vulnerable to local extirpation and extinctions, particularly for species functioning as a metapopulation (Morita and Yamamoto 2002).

### *Altered hydrologic, salinity, and temperature regimes*

Dams and dam operations alter flow patterns, volume, and depth of water within impoundments and below the dam. These hydrological alterations tend to increase water temperatures, stratify the water column, and decrease dissolved oxygen concentrations in the water impoundments. Projects operating as “store and release” facilities can drastically affect downstream water flow and depth, resulting in dramatic fluctuations in habitat accessibility, acute temperature changes, and overall water quality. Although large, impounding dams have the ability to alter the hydrology of large segments or entire rivers, smaller, run-of-the-river dams that do not contain impoundments generally have little or no ability to alter downstream hydrology (Heinz Center 2002).

Reductions in river water temperatures are common below dams if the intake of the water is from lower levels of the reservoir. Stratification of reservoir water not only affects temperature but can create oxygen-poor conditions in deeper areas and, if these waters are released, can degrade the water quality of the downstream areas (Heinz Center 2002).

By design, dams often reduce peak flows as flood control measures. However, reductions of peak flows can decrease the physical integrity of the downstream river because the floodplains (including side channels, islands, bars, and beaches) are not as extensively connected to the river (Heinz Center 2002). In addition, dams can also reduce low flows during periods of drought and when dam operators reduce water releases in order to maintain water levels in the impoundments (Heinz Center 2002).

Dams with deep reservoirs have high hydrostatic pressures at the bottom and can force atmospheric gases into solution. If these waters are released below the dam, either by water spilling over dams or through turbines, it can cause dissolved gas supersaturation, resulting in injury or death to fish traversing the dam (NEFMC 1998; Heinz Center 2002).

Tidal fresh habitat is limited to a narrow zone in river systems where the water is tidally influenced, yet characteristically fresh (i.e., < 0.5 ppt salinity). This narrow habitat type may be altered or lost because of dam construction and operations.

### *Alteration of stream bed and stream morphology*

The construction of a dam fragments habitat, altering both upstream and downstream biogeochemical processes and resulting in a wide array of direct and indirect cumulative impacts (Poff et al. 1997; Heinz Center 2002). Multiple habitat variables are affected by dams, principally streambed properties (Spence et al. 1996), the transport of sediments and large woody debris (Spence et al. 1996; PFMC 1999), and overall stream morphology.

Dams typically reduce peak flows as a flood control measure and can reduce low flows when water releases are reduced to save water during drought. As the range of flows in the river are decreased, the width of the active portion of the watershed is reduced and the river channel shrinks (Heinz Center 2002).

### *Altered sediment/large woody debris transport*

Dams affect the physical integrity of watersheds by fragmenting the lengths of rivers, changing their hydrologic characteristics, and altering their sediment regimes by trapping most of the sediment entering the reservoirs and disrupting the sediment budget of the downstream

landscape (Heinz Center 2002). Because water released from dams is relatively free of sediment, downstream reaches of rivers may be altered by increased particle size, erosion, channel shrinkage, and deactivation of floodplains (Heinz Center 2000).

Large woody debris (LWD) and other organic matter are often removed from rivers containing dams, as well as for other reasons, such as aesthetics, road and bridge maintenance, and commercial and recreational uses. Organic debris provides habitat for a variety of aquatic organisms, such as Atlantic salmon, by promoting habitat complexity, including the formation of pool and riffle complexes and undercut banks (Montgomery et al. 1995; Abbe and Montgomery 1996; Spence et al. 1996). Removing organic debris may change the structure, function, and value of the river system. From a broader perspective, removal of LWD from a river system disrupts a link between the forest and the sea (Maser and Sedell 1994; NRC 1996; Collins et al. 2002; Collins et al. 2003).

### ***Riparian zone development and alteration of wetlands***

Riparian wetlands may be lost to water level increases upstream and flow alterations downstream of the dam. Generally, the greater the storage capacity of a dam, the more extensive are the downstream geomorphological and biological impacts (Heinz Center 2002). Lost wetlands result in a loss of floodplain and flood storage capacity, and thus a reduced ability to provide flood control during storm events. A healthy riparian corridor is well vegetated, harbors prey items, contributes necessary nutrients, provides LWD that creates channel structure and cover for fish, and provides shade, which controls stream temperatures (Bilby and Ward 1991; Hanson et al. 2003). When vegetation is removed from riparian areas, water temperatures tend to increase and LWD is less common. The result is less refuge for fish, fundamental changes in channel structure (e.g., loss of pool habitats), instability of stream banks, and alteration of nutrient and prey sources within the river system (Hanson et al. 2003). Riparian zone development can be considered a secondary effect of dam construction. Residential, recreational, and commercial development may result from the associated impoundment.

### ***Changes to native aquatic communities***

Impoundments can concentrate predators and disease carrying organisms and disrupt fish development, thereby altering the community structure at various trophic levels and potentially changing the natural habitat and fishery dynamics of the aquatic habitat. In addition, the loss of wetlands by the increased impoundment level and reduction of freshwater input and sediments below the dam can have potentially serious impacts on both fish and invertebrate populations (NEFMC 1998).

Impoundments also create an opportunity for nonnative species to become established. Common carp (*Cyprinus carpio*), northern pike (*Esox lucius*), and walleye (*Sander vitreus*) are a few examples. These species have the ability to dramatically alter local habitats and aquatic communities. In some instances, introduced species such as smallmouth bass (*Micropterus dolomieu*) become managed as a sport fish to the exclusion of native species. Over time, these introduced species become accepted as part of the “natural” condition. Like the changes associated with creating an impoundment, these introduced species can change the community dynamics of the riverine system.

## *Conservation measures and best management practices for dam construction and operation (adapted from Hanson et al. 2003 and PFMC 1999)*

1. Avoid the construction of new dam facilities, where possible.
2. Retrofit existing dams with efficient and functional upstream and downstream fish passage structures.
3. Construct and design facilities with efficient and functional upstream and downstream adult and juvenile fish passage which ensures safe, effective, and timely passage.
4. Construct dam facilities with the lowest hydraulic head practicable for the project purpose. Site the project at a location where dam height can be reduced.
5. Consider all upstream passage types, including natural-like bypass channels, denil-type and vertical slot fishways, Alaskan steppass, fishlifts, etc. Volitional passage is preferable to trap and truck methods.
6. Downstream passage should prevent adults and juveniles from passing through the turbines and provide sufficient water downstream for safe passage.
7. Operate facilities to create flow conditions that provide for passage, water quality, proper timing of life history stages, and properly functioning channel conditions, and to avoid strandings and redd (i.e., spawning nest) dewatering. Run-of-river, such that the volume of water entering an impoundment exits the impoundment with minimal fluctuation of the headpond, is the preferred mode of operation for fishery and aquatic resource interests. Water flow monitoring equipment should be installed upstream and downstream of the facility. Generally, fluctuations in headpond water levels should be kept between 6 and 12 inches.
8. Coordinate maintenance and operations which require drawdown of the impoundment with state and federal resource agencies to minimize impacts to aquatic resources.
9. Use seasonal restrictions for construction, maintenance, and operations of dams to avoid impacts to habitat during species' critical life history stages (e.g., spawning and egg development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
10. Develop water and energy conservation guidelines for integration into dam operation plans and into regional and watershed-based water resource plans.
11. Encourage the preservation of LWD, whenever possible. If possible, relocate debris as opposed to removing it completely. Remove LWD only to prevent damage to property or threats to human health and safety.
12. Address the cumulative impacts of past, present, and foreseeable future development activities on aquatic habitats by considering them in the review process for dam construction and operation.
13. Consider the removal of a dam when it is feasible (see the following section on dam removal).

## **Dam Removal**

A number of factors may be considered in determining the efficacy of removing a dam, including habitat restoration, safety, and economics (Babbitt 2002; Heinz Center 2002). Dam removal provides overall environmental benefits to freshwater habitats and aquatic resources. The recovery of some anadromous species, such as Atlantic salmon and rainbow smelt, may be dependent on targeted dam removals, principally those dams blocking passage to high quality spawning and rearing habitat. Dam removal reconnects previously fragmented habitat, allowing the natural flow of water, sediment, nutrients, and the genetic diversity of fish populations and reestablishes floodplains and riparian corridors (Morita and Yokota 2002; Nislow et al. 2002).

The Heinz Center (2002) provides a thorough overview of environmental, economic, and social issues to consider when evaluating dam removal. Because there are a number of concerns and interests surrounding dams and their use, the overall benefits of dam removal must be weighed against all potential adverse impacts. It is important to bear in mind that although the removal of a dam may reverse most of the undesirable changes, it is unlikely to restore completely the natural conditions because of other dams on the river and the other anthropogenic effects on streams, such as channel control and land use management (Heinz Center 2002).

For many local residents, the impoundments created by these dams define a way of life for the community. Changing the existing conditions may not necessarily be perceived as good for all parties. For example, an impoundment may contain stocked game fish which provide recreational opportunities for the community. Dam removal may eliminate these species or bring about interactions with formerly excluded diadromous species. However, because dams alter sediment and nutrient transport processes and raise water levels upstream of the structure, dam removal can result in short and long-term impacts upstream and downstream.

The effects of dam removal on fisheries and aquatic habitat include: (1) release of contaminants; (2) short-term water quality degradation; (3) flow pattern alteration; (4) loss of benthic and sessile invertebrates; and (5) alterations of the riparian landscape and associated functions and values.

### *Release of contaminated sediments and short-term water quality degradation*

Dam removal typically results in an increased transfer of sediments downstream of the dam, while the spatial and temporal extent of sediment transfer depends on the size of the dam and total sediment load. Sediments accumulated behind dams can bind and adsorb contaminants that when remobilized after the removal of a dam have the potential to adversely affect aquatic organisms including the eggs, larvae, and juvenile stages of finfish, filter feeders, and other sedentary aquatic organisms (Heinz Center 2002). For example, a reduction in macroinvertebrate abundance, diatom richness, and algal biomass has been attributed to the downstream transport of fine sediments previously stored within a dam impoundment (Thomson et al. 2005). However, as fine sediment loads are reduced and replaced by coarser materials in the streambed, macroinvertebrate and finfish assemblages should recover from the disturbance (Thomson et al. 2005). Dam removal can impact overall water quality during and after the demolition phase, although these are typically temporary effects that generally do not result in chronic water quality degradation (Nechvatal and Granata 2004; Thomson et al. 2005).

### *Flow pattern alteration*

Dam removal generally changes downstream conditions by increasing the water and sediment discharges which tend to decrease channel gradients and increase stream depths and widths (Heinz Center 2002). In addition, flood events may increase; reactivate the floodplain; and reconnect side channels, islands, bars, and beaches. Reconnecting and increasing the active floodplain may help reduce low flow conditions in a river. Removal of a dam restores the natural timing of peak and low flows, which have important consequences for the biological components of the ecosystem. For example, seed production among native trees and spawning migrations of anadromous fish species often coincides with peak flows in the spring (Heinz Center 2002).

### *Loss of benthic and sessile invertebrates*

As discussed above, remobilized sediments after the removal of a dam have the potential to adversely affect aquatic organisms including benthic and sessile invertebrates. However, although

water quality often is degraded immediately following removal, the abundance and diversity of aquatic invertebrates should increase as the sediment budget and hydrology of the river approaches a natural equilibrium (Heinz Center 2002).

### *Alteration of wetlands*

Lowering the water level will alter the wetland structure upstream of the old dam site and the associated wildlife assemblage. Lowering of impoundments can result in the alteration of existing wetlands (Nislow et al. 2002). As water levels recede, fringing wetlands may be lost while new wetlands are formed along the new riparian border. Newly exposed stream banks may need armoring or other erosion control methods to protect them. The history of the project, geomorphology of the watershed, and location in the river system, among other factors, will dictate the types of environmental issues dam removal will present. Geomorphic effects of downstream sediment transport may have long-term implications (Pizzuto 2002). However, many of these impacts are short-term, dissipating with time as the river system comes to a natural equilibrium (Bushaw-Newton et al. 2002; Thomson et al. 2005).

### *Conservation measures and best management practices for dam removal (adapted from Hanson et al. 2003)*

1. Conduct a comprehensive evaluation of the historic and existing hydrology, hydraulics, and sediment transport prior to the decision to remove a dam to assess possible adverse and cumulative effects of the removal of the structure on the watershed. Dam removal assessments should adopt a watershed scale of analysis.
2. Conduct an assessment of the biotic component of the effected area, particularly if anadromous fish restoration is one of the objectives of the dam removal. For example, the assessment may include characterization of the historic distribution and abundance of fish species, their various life history habitat requirements, and their limiting environmental factors. The assessment should also evaluate the predicted physical and chemical conditions following dam removal to determine if additional restoration may be necessary.
3. Conduct sufficient testing to evaluate the type, extent, and level of contamination upstream of the dam prior to the decision to remove a dam. Contaminated sediments, if extensively present, may require mechanical or hydraulic removal prior to the removal of the dam.
4. Conduct sufficient evaluation of the streambed within the impoundment to plan for any necessary streambed modifications.
5. Consider the possible necessity for removal of the dam in stages to control the release of sediments, if sediments are expected to be released downstream.
6. Schedule dam removal during the less sensitive time of year for aquatic resources, particularly outside the expected migratory period. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
7. Plan for revegetating the newly exposed stream bank with native vegetation.
8. Establish a contingency plan in the event that the stream channel needs modification (addition of riffle and pool complex, added features to create habitat complexity, meanders, etc.) to facilitate fish passage and habitat functions.
9. Establish a monitoring protocol to evaluate success of the restoration for fish passage and utilization.
10. Conduct outreach to the public to provide an understanding of the benefits of dam removal.

## Stream Crossings

Stream crossings are characterized as any structure providing access over a stream, river, or other water body for transportation purposes (e.g., roads, utilities). The feasibility of effective fish passage at stream crossings may be complex. Land ownership, utility crossing, flood protection for low-lying properties, and safety along the transportation corridor must be considered. Unfortunately, many transportation corridors interact and interfere with fisheries corridors (i.e., streams and rivers). These transportation corridors require structures for crossing rivers, streams, and other water bodies. If improperly designed, stream crossings can alter, degrade, fragment or eliminate aquatic habitat and potentially impede, or eliminate, passage for resident and migratory species (Evans and Johnston 1980; Belford and Gould 1989; Clancy and Reichmuth 1990; Furniss et al. 1991; USGAO 2001; Jackson 2003). Until recently, the primary concerns related to designing these structures were cost, designed load capacity, and hydraulics. Furthermore, common practice for repairing deficient structures often resulted in maintaining inadequate stream crossing conditions (e.g., “slip-lining” with smaller diameter pipe, lining of culvert with concrete, or replacing the structure in-kind).

Some American states and Canadian provinces have recognized the concerns relating to fish passage and stream crossings. For example, the Maine Department of Transportation and Commonwealth of Massachusetts Riverways Program, among others, have independently published guidelines for addressing fish passage at stream crossings (MEDOT 2004; MRP 2005). These and similar documents provide extensive information regarding fish and aquatic organism passage, habitat continuity, and wildlife passage requirements for environmentally-sound and safe transportation across streams, rivers, and other waterbodies.

The construction, maintenance, and operation of roadways at stream crossings can also affect aquatic habitats by increasing rates of erosion, debris slides or landslides and sedimentation, introduction of exotic species, and degradation of water quality (Furniss et al. 1991; Hanson et al. 2003). However, the focus of this chapter is the design and operation of the fish passage structure. Refer to the Coastal Development chapter in this report for information pertaining to impacts associated with roadways and vehicular traffic at stream crossings.

### *Impacts to fish passage*

Improperly designed stream crossings can block fish and aquatic organism passage in a variety of ways, including: (1) perched culverts constructed with the bottom of the structure above the level of the stream effectively act as a dam and physically block passage; and (2) hydraulic barriers to passage are created by undersized culverts which constrict the flow and create excessive water velocities (Evans and Johnston 1980; Belford and Gould 1989; Furniss et al. 1991; Jackson 2003). Smooth-bore liners made from high density plastic help meet the goal of passing water and protecting roadways from flooding, but they greatly increase flow velocities through the passage. Conversely, oversized culverts with large, flat bottom surfaces reduce water depth. Insufficient water depths may also be another hydraulic impediment to passage (Haro et al. 2004). In situations where water velocities are not physically limiting and water depths are sufficient, the impediments to passage may be a lack of resting pools. Many stream crossings, particularly longer culverts, are placed over wide stretches of river. Fish may not be capable of burst speeds and sustained swimming throughout the length of the crossing. Under such conditions, migrating fish are unable to reach spawning habitat.



## *Alteration of hydrologic regimes*

Undersized and/or improperly placed stream crossings can also affect water quality. Undersized structures can act as dams, impounding water and increasing water temperature. In extreme cases, if flows are sufficiently reduced and the impounded area deep enough, increased surface temperatures can create thermal stratification and reduce dissolved oxygen. In addition, as water flows through the structure the temperature of the water can rise, affecting aquatic organisms downstream. Undersized culverts can also cause flooding upstream of the crossing, affecting upland and riparian habitat.

## *Conservation measures and best management practices for stream crossings*

1. Design stream crossings for the target finfish species and various age classes. Other aquatic species, such as amphibians, reptiles, and mammals, should also be considered in the designs, as they play a role in healthy ecosystems.
2. Design structures to provide safe and timely passage to minimize injury and limit excessive predation.
3. Design and install new structures in a manner not to interfere with fish and aquatic organism passage and that complies with all applicable regulations.
4. Design structures to provide sufficient water depth and maintain suitable water velocities for target species during the migration season. Consider seasonal headwater and tailwater levels and how variations in them could affect passage of all aquatic life stages. Design considerations may include constructing a low flow channel, weir structure, energy dissipation pools, and designing structures for bank full width.
5. Consider the presence of nonnative, invasive aquatic species in fish passage design for stream crossings, particularly where the crossing may present an existing barrier to passage.
6. Design the structure to maintain or replicate natural stream channel and flow conditions to the greatest extent practicable. An open bottom arch or bridge is preferred. The structure should be able to pass peak flows in accordance with state and federal regulations. Ensure sufficient hydrologic data have been collected.
7. Bury culverts and pipes sufficiently to replicate a natural streambed. Doing so will also provide habitat functions, such as resting pools and reduced water velocities for longer structures.
8. Match the gradient of the stream crossing with the natural stream channel grade. Perched culverts should be removed, wherever practicable.
9. Maintain or stabilize upstream and downstream channel and bank conditions if the stream crossing structure causes erosion or accretion problems. Use of native vegetation should be required for erosion control and sediment stabilization.
10. Ensure the location and overall design of the fish passage structure and the stream crossing are compatible with local stream conditions and stream geomorphology.
11. Ensure that materials for the fish passage structure are nontoxic to fish and other aquatic organisms. Pressure treated lumber should be avoided.
12. Develop construction design and methods for repairing and replacing stream crossings that take into account fish passage requirements.
13. Conduct in-water construction activities during a time of year that would have the least environmental impacts to aquatic species (e.g., low flow seasons). Temporary diversions and coffer dams may be suitable alternatives with proper planning. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.

14. Address the cumulative impacts of past, present, and foreseeable future development activities on aquatic habitats by considering them in the review process for stream crossing projects.

## **Water Withdrawal and Diversion**

Freshwater is becoming limited because of natural events (e.g., droughts), increasing commercial and residential demand of potable water, and inefficient use. Freshwater is diverted for human use from groundwater, lakes, and riverine environments or is stored in impoundments. The withdrawal or impoundment of water can alter natural current and sedimentation patterns, water quality, water temperature, and associated biotic communities (NEFMC 1998). Natural freshwater flows are subject to alteration through water diversion and use and modifications to the watershed such as deforestation, dams, tidal restrictions, and stream channelization (Boesch et al. 1997). Water withdrawal for freshwater drinking supply, power plant cooling systems, and irrigation occurs along urban and agricultural areas and may have potentially detrimental effects on aquatic habitats. Increased water diversion is associated with human population growth and development (Gregory and Bisson 1997). Water diversion is not only associated with water withdrawal and impoundment, but it also represents water discharges, which alter the flow and velocity and have associated water quality issues (Hanson et al. 2003). Water withdrawal in freshwater systems can also affect the health of estuarine systems. Refer to the Physical Effects: Water Intake and Discharge Facilities and Coastal Development chapters for additional information on the affects of water withdrawal on estuarine systems.

The effects of water withdrawal and diversion on freshwater fishery habitat can include: (1) entrainment and impingement; (2) impaired fish passage; (3) alteration of flow and flow rates, and processes associated with proper flows; (4) degradation of water quality (e.g., water temperature, dissolved oxygen) associated with proper water depth, drainage, and sedimentation patterns; (5) loss and/or degradation of riparian habitat; and (6) loss of prey and forage.

### *Entrainment and impingement*

The diversion of water for power plant cooling and other reservoirs results in entrainment and impingement of invertebrates and fishes (especially early life-history stages of fish) (NEFMC 1998). Fish and invertebrate populations may be adversely affected by adding this source of mortality to the early life stage which often determines recruitment and strength of the year-class. Important habitat for aquatic organisms around water intakes may become unavailable for recruitment and settlement (Travnichek et al. 1993).

### *Impaired fish passage and altered hydrologic regimes*

Water diversion and the withdrawal or discharge of water can result in a physical barrier to fish passage (Spence et al. 1996). Excessive water withdrawal can greatly reduce the usable river channel. Rapid reductions or increases in water flow, associated with dam operations for example, can greatly affect fish migratory patterns. Depending on the timing of reduced flows, fish can become stranded within the stream channel, in pools, or just below the river in an estuary system.

### *Water quality degradation*

The release of water with poor quality (e.g., altered temperatures, low dissolved oxygen, and the presence of toxins) affects migration and migrating behavior. The discharge of irrigation water into a freshwater system can degrade aquatic habitat (NRC 1996) by altering currents, water quality, water temperature, depth, and drainage and sedimentation patterns. Both water quantity and quality

can greatly affect the usable zone of passage within a channel (Haro et al. 2004). Altered temperature regimes have the ability to affect the distribution; growth rates; survival; migration patterns; egg maturation and incubation success; competitive ability; and resistance to parasites, diseases, and pollutants of aquatic organisms (USEPA 2003). In freshwater habitats of the northeastern United States, the temperature regimes of cold-water fish such as salmon, smelt, and trout may be exceeded leading to extirpation of the species in an area. Some evidence indicates that elevated water temperatures in freshwater streams and rivers in the northeastern United States may be responsible for increased algal growth, which has been suggested as a possible factor in the diminished stocks of rainbow smelt (Moring 2005).

### *Release of contaminants*

Irrigation discharges are often associated with contaminants and toxic materials (e.g., metals, pesticides, fertilizers, salts, and nutrients) and possibly introduced pathogens, all of which stress the habitat and aquatic organisms (USEPA 2003). Studies evaluating pesticides in runoff and streams generally find that concentrations can be relatively high near the application site and soon after application but are significantly reduced further downstream and with time (USEPA 2003). However, some pesticides used in the past (e.g., dichlorodiphenyl trichloroethane [DDT]) are known to persist in the environment for years after application.

Soil transported from irrigated croplands and rangelands usually contains a higher percentage of fine and less dense particles, which tend to have a higher affinity for adsorbing pollutants such as insecticides and herbicides (Duda 1985; USEPA 2003). In addition, irrigation water has a natural base load of dissolved mineral salts, and return flows convey the salt to the receiving streams or groundwater reservoirs. If the amount of salt in the return flow is low in comparison to the total stream flow, water quality may not be degraded to the extent that aquatic functions are impaired. However, if the process of water diversion and the return flow of saline drainage water is repeated many times along a stream or river, downstream habitat quality can become progressively degraded (USEPA 2003).

### *Siltation and sedimentation*

Water diversions can alter sediment and nutrient transport processes (Christie et al. 1993; Fajen and Layzer 1993), which can hinder benthic processes and communities. Suspended sediments in aquatic environments can reduce the availability of sunlight to aquatic plants, interfere with filtering capacity of filter feeders, and clog and harm the gills of fish (USEPA 2003). Increased suspended sediments may degrade or eliminate spawning and rearing habitats, impede feeding, negatively affect the food sources of fishes, severely alter the aquatic food web, and thus negatively affect the growth and survival of diadromous fish. Fine sediments are potentially detrimental to Atlantic salmon development and survival during all life stages. For example, sediments can fill interstitial spaces, embedding the substrate and preventing oxygenated water from reaching the incubating eggs within redds and inhibiting the removal of waste metabolites; eliminate refuge utilized by fry and parr to avoid predators; create a homogeneous environment which can lead to lower fish densities; reduce macroinvertebrate abundance; and decrease the depth and area of pools utilized by juveniles and adults (Danie et al. 1984; Fay et al. 2006). In addition, Breitburg (1988) found the predation rates of striped bass larvae on copepods to decrease by 40% when exposed to high turbidity conditions in the laboratory.

## ***Loss of wetlands and flood storage***

Healthy riparian corridors are well vegetated, support abundant prey items, maintain nutrient fluxes, provide LWD that creates channel structure and cover for fish, and provide shade, which controls stream temperatures (Bilby and Ward 1991; Hanson et al. 2003). Riparian wetland vegetation can be affected by long-term or frequent changes in water levels caused by water withdrawals and diversions. Removal of riparian vegetation can impact fish habitat by reducing cover and shade, by reducing water temperature fluctuations, and by affecting the overall stability of water quality characteristics (Christie et al. 1993). As river and stream water levels recede because of withdrawals, fringing wetlands may be lost and armoring or other erosion control methods may be needed to protect newly exposed stream banks. The results are less refuge for fish, fundamental changes in channel structure (e.g., loss of pool habitats), instability of stream banks, and alteration of nutrient and prey sources within the river system (Hanson et al. 2003). The changes to the natural habitat caused by irrigation water discharges can potentially lead to large-scale aquatic community changes. Changes in flow patterns may affect the availability of prey and forage species. In conjunction with anthropogenic watershed changes, water diversions and associated riparian impacts have been associated with the increase in some harmful algal blooms (Boesch et al. 1997), which further impact an array of aquatic habitat characteristics. Lost wetlands correlate to a loss of floodplain and flood storage capacity, and thus a reduced ability to act as flood control during storm events.

For additional information on water diversion impacts, refer to the Physical Affects: Water Intake and Discharge Facilities, Chemical Affects: Water Discharge Facilities, and Agriculture and Silviculture chapters in this report.

## ***Conservation measures and best management practices for water withdrawal/ diversion (adapted from Hanson et al. 2003)***

1. Design projects to create flow conditions adequate to provide for passage, water quality, proper timing for all life history stages, and avoidance of juvenile stranding and redd (i.e., spawning nest) dewatering, as well as to maintain and restore properly functioning channel, floodplain, riparian, and estuarine conditions.
2. Use seasonal restrictions to avoid impacts to habitat during species' critical life history stages (e.g., spawning and egg development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
3. Establish adequate instream flow conditions for anadromous fish.
4. Design intakes with minimal flows to prevent impingement/entrainment (e.g.,  $\leq 0.5$  feet per second).
5. Screen water diversions on fish-bearing streams, as needed.
6. Design thermal discharges such that ambient stream temperatures are maintained or a zone of passage is provided to maintain suitable temperatures for fish passage.
7. Incorporate juvenile and adult fish passage facilities on all water diversion projects.
8. Whenever possible, contaminants and sediments should be removed from water discharge prior to entering rivers and other aquatic habitats.
9. Address the cumulative impacts of past, present, and foreseeable future development activities on aquatic habitats by considering them in water withdrawal project review processes.

## Dredging and Filling

The dredging and filling of riparian and freshwater wetlands directly remove potentially important habitat and alter the habitat surrounding the developed area. Expansion of navigable waterways is associated with economic growth and development and generally adversely affects benthic and water-column habitats. Routine dredging is required to maintain the desirable depth as the created channel fills with sediment. Direct removal of riverine habitat from dredge and fill activities may be one of the biggest threats to riverine habitats and anadromous species (NEFMC 1998).

Dredge and fill activities in riverine and riparian habitats can affect fisheries habitat in a number of ways, including: (1) reducing the ability of the wetland to retain floodwater; (2) reducing the uptake and release of nutrients; (3) decreasing the amount of detrital food source, an important food source for aquatic invertebrates (Mitsch and Gosselink 1993); (4) converting habitats by altering water depth or the substrate type (i.e., substrate conversion); (5) removing aquatic vegetation and preventing natural revegetation; (6) hindering physiological processes to aquatic organisms (e.g., photosynthesis, respiration) caused by increased turbidity and sedimentation (Arruda et al. 1983; Cloern 1987; Dennison 1987; Barr 1993; Benfield and Minello 1996; Nightingale and Simenstad 2001); (7) directly eliminating sessile or semimobile aquatic organisms via entrainment or smothering (Larson and Moehl 1990; McGraw and Armstrong 1990; Barr 1993; Newall et al. 1998); (8) altering water quality parameters (i.e., temperature, oxygen concentration, and turbidity); (9) releasing contaminants such as petroleum products, metals, and nutrients (USEPA 2000); (10) reducing dissolved oxygen through reduced photosynthesis and through chemical processes associated with the release of reactive compounds in the sediment (Nightingale and Simenstad 2001).

Filling wetlands removes productive habitat and eliminates the important functions that both aquatic and many terrestrial organisms depend upon. For example, the loss of wetland habitats reduces the production of detritus, an important food source for aquatic invertebrates; alters the uptake and release of nutrients to and from adjacent aquatic and terrestrial systems; reduces wetland vegetation, an important source of food for fish, invertebrates, and water fowl; hinders physiological processes in aquatic organisms (e.g., photosynthesis, respiration) because of degraded water quality and increased turbidity and sedimentation; alters hydrological dynamics, including flood control and groundwater recharge; reduces filtration and absorption of pollutants from uplands; and alters atmospheric functions, such as nitrogen and oxygen cycles (Mitsch and Gosselink 1993).

### *Flood storage capacity*

Impervious surfaces decrease the capacity of a watershed to absorb pulses of freshwater input (e.g., heavy rain, snowmelt). Similarly, stormwater drain systems decrease the storage by directing water directly into a nearby wetland or river system. The rate and volume of stormwater runoff from land into rivers and streams is greater in watersheds with high percentages of impervious surface cover and extensive drainage systems, which reduce the stormwater storage capacity (American Rivers 2002). Measurable adverse changes in the physical and chemical environment were observed when the impervious cover exceeded 10-20% of the land cover (Holland et al. 2004). Flashy, high-velocity pattern of flows and associated pulse of contaminants from upland sources can have long-term, cumulative impacts on freshwater wetlands and riverine, estuarine, and marine ecosystems. As development continues throughout the region, the ability to minimize loss of flood storage capacity and mitigate consequences of increasing coverage of

impervious surfaces will be significant planning issues (American Rivers 2002). Refer to the Coastal Development chapter for additional information on stormwater runoff and nonpoint source pollution.

Impacts associated with dredging and filling of aquatic habitats and wetlands are discussed in greater detail in the Offshore Dredging and Disposal Activities, Marine Transportation, and Coastal Development chapters of this report.

### *Conservation measures and best management practices for dredging and filling (adapted from Hanson et al. 2003)*

1. Avoid the filling of wetlands and riparian habitat whenever possible. Ensure proposed dredge and fill projects in wetlands are water-dependent.
2. Utilize best management practices (BMPs) to limit and control the amount and extent of turbidity and sedimentation. Standard BMPs may include constructing silt fences, coffer dams, and operational modification (e.g., hydraulic dredge rather than mechanical dredge).
3. Require the use of multiple-season biological sampling data (both pre- and post-construction) when appropriate to assess the potential and resultant impacts on habitat and aquatic organisms.
4. Test sediment compatibility for open-water disposal per the US Environmental Protection Agency (US EPA) and US Army Corps of Engineers requirements for inshore and offshore, unconfined disposal.
5. Plan dredging and filling activities to avoid submerged aquatic vegetation and special aquatic sites. This may include the placement of pipes for hydraulic dredging and anchoring of barges and other vessels associated with the dredging project.
6. Design the dredge footprint to avoid littoral zone habitat, and appropriate buffers should be in place to protect these areas from wind driven waves and boat wakes.
7. Schedule dredging activities when the fewest species and least vulnerable life stages are present. Appropriate work windows can be established based on the multiple season biological sampling. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
8. Reference all dredging projects in a geographical information system (GIS) compatible format for long-term evaluation.
9. Identify sources of sedimentation within the watershed that may exacerbate repetitive maintenance activities. Implement appropriate management techniques to control these sources.
10. Address cumulative impacts of past, present, and foreseeable future dredging operations on aquatic habitats by considering them in the review process.

## **Mining**

Most modern mining operations in the northeast US region involve bulk mineral commodities (aggregates such as sand, gravel, and crushed stone), but the region has a long history of mineral mining for mica, feldspar, copper, iron, gold, silver, and coal, as well as peat (Lepage et al. 1991; Boudette 2005; VADMME 2007). While some mineral mining continues in this region, many operations have ceased entirely (Lepage 1991). Some of these abandoned mines have become a source of groundwater or surface water contamination and have been identified by the US EPA's Superfund Program (USEPA 2007) and other nonfederal programs for cleanup. Currently, the US EPA Superfund Program lists cleanup sites on the Susquehanna River in Pennsylvania from coal mining and tributaries leading to East Penobscot Bay in Maine and the Connecticut River in Vermont from copper and other metal mining.

Few active mining sites in the northeast US region currently affect fishery resources as they generally are not located adjacent to or in rivers that support diadromous fish. In addition, because access for diadromous fish to historic spawning grounds has been adversely affected by dams and poor water quality throughout the region (Moring 2005), the potential adverse effects of mining operations on these species have been reduced in recent times. Nonetheless, some sand and gravel extraction projects occur within rivers and their tributaries of the northeast US region. Although limited information is available on this subject, it appears the number of active sand and gravel operations that may adversely affect diadromous fish in the northeast US region is relatively small compared to other regions of the United States. However, considering the potential direct and indirect effects from historic and current mining activities on long-term water quality and health of diadromous species, a brief discussion on this topic is warranted in this section.

Mining within riverine habitats may result in direct and indirect chemical, biological, and physical impacts to habitats within the mining site and surrounding areas during all stages of operations (NEFMC 1998). On-site mining activities include exploration, site preparation, mining and milling, waste management, decommissioning and reclamation, and abandonment. Mining operations often occur in urban settings or around existing or historic mining sites; however, mining in remote settings where human activity has caused little disruption and aquatic resources are most productive may cause significant impacts (NRC 1999). Existing state and federal regulations have been established to restrict various environmental impacts associated with mining operations. However, the nature of mining will always result in some alteration of habitat and natural resources (NRC 1999).

Some of the impacts associated with the extraction of material from within or near a stream or river bed include: (1) disruption of preexisting balance between sediment supply and transporting capacity, leading to channel incision and bed degradation; (2) increased suspended sediment, sediment transport, turbidity, and gravel siltation; (3) alteration in the morphology of the channel and decreased channel stability; (4) direct impacts to fish spawning and nesting habitats (redds), juveniles, and prey items; (5) alteration of the channel hydraulics during high flows caused by material stockpiled or left abandoned; (6) removal of instream roughness, including LWD; (7) reduced groundwater elevations and stream flows caused by dry pit or wet pit mining; and (8) destruction of the riparian zone during extraction operations (Pearce 1994; Packer et al. 2005). In addition, structures used in mining extraction and transportation often cause additional impacts to wetland and riverine habitats (Starnes and Gasper 1996). Other impacts include fragmentation and conversion of habitat, alteration of temperature regimes, reduction in oxygen concentration, and the release of toxic materials.

### *Mineral mining*

Although there is a long history of mining in the northeast region of the United States, few active mineral mining operations remain that are located in or adjacent to streams or rivers in this region, and even fewer mineral mining operations occur in streams and rivers utilized by diadromous fish. Nonetheless, mineral mining has occurred in the northeast US region in the past, as evidenced by a number of completed and ongoing remediation sites in areas that have supported or historically supported diadromous fish (USEPA 2007). A brief discussion on the potential impacts to aquatic habitats is provided below.

The effects of mineral mining on riverine habitat depend on the type, extent, duration, and location of the mining activity. Surface mining typically involves suction dredging, hydraulic mining, panning, sluicing, strip mining, and open-pit mining. Surface mining has a greater potential impact on riverine habitat than does underground or shaft mining, depending on other aspects of the

mining activities, including processing and degree of disturbance (Spence et al. 1996; Hanson et al. 2003). Elimination of vegetation, topographic alterations, alteration of soil and subsurface geological structure and alteration of surface and groundwater hydrologic regimes are potential effects of surface mining (Starnes and Gasper 1996). Soil erosion and sediment runoff may be the greatest impact of surface mining, contributing a greater sediment load per area of disturbance compared with other activities because of the degree of soil, topographic, and vegetation disturbance (Nelson et al. 1991).

### *Sand and gravel mining*

Sand and gravel are the most valuable and extensively exploited nonfuel mineral resources in the eastern US region and are mined in all states from Virginia to Maine (Bolen 2007). According to Starnes and Gasper (1996), sand and gravel extraction is the least regulated of all mining industries, and approximately 80% of this resource is extracted under jurisdiction of state and local laws only. These authors state that sand and gravel mining is “widely used in large US rivers and can increase the sediment bed load through resuspension, physically eliminate benthic organisms, and destroy fish spawning and nursery areas, all of which ultimately change aquatic community composition” (Starnes and Gasper 1996); however, they do not identify specific rivers that are affected or state whether the rivers support diadromous fish species. The Virginia Department of Mines, Minerals and Energy states, “Sand and gravel are extracted from coastal sand pits, river terraces or dredged from the rivers themselves” (VADMME 2007). In 2005, over 15,000 tons of sand were mined from two operations along the Roanoke River in Virginia (VADMME 2007). In addition, a dredge and fill permit was granted by the US Army Corps of Engineers to allow sand extraction in the St. John River, ME, for use in road sanding operations (USACE 2005). Although sand and gravel mining may not be a significant threat to diadromous fish in the northeast US region at this time, at least some activity is currently taking place, and any increase in activity represents potential future threat.

Gravel and sand mining operations can involve wet-pit mining (i.e., removal of material below the water table); dry pit mining on beaches, exposed bars, and ephemeral streambeds; or subtidal mining. Impacts associated with sand and gravel mining in riverine environments are similar to mineral mining impacts and include: turbidity plumes and resuspension of sediment and nutrients, removal of spawning habitat, and alteration of stream channel morphology. These physical perturbations often lead to alteration of migration patterns, physical and thermal barriers to upstream and downstream migration, increased fluctuation in water temperature, decrease in dissolved oxygen, high mortality of early life stages, increased susceptibility to predation, and loss of suitable habitat (Packer et al. 2005). For information pertaining to impacts associated with mining and dredging in marine habitats refer to the chapter on Offshore Dredging and Disposal Activities.

### *Peat mining*

Peat is mined in the United States primarily for horticultural and industrial purposes, including a filtration medium to remove toxic materials and a fuel/oil absorbent (Jasinski 2007). Peat mining occurs in a number of states in the northeast US region, although at relatively small scales. In Maine, at least one peat mining operation exists in the Narraguagus River watershed, which burns mixtures of peat and wood chips to generate electricity (Lepage et al. 1991; USFWS and NMFS 1999).

The impacts associated with peat mining include the release of contaminants (i.e., peat fiber, arsenic residues, and other toxic chemicals), siltation, increased stormwater runoff from roads and



other unvegetated areas, and altered hydraulic flow regimes (NEFMC 1998; USFWS and NMFS 1999). Peat mining has been associated with acidic conditions in eastern Maine watersheds, such as Narraguagus River, and has been identified as a potential contributor to Atlantic salmon declines (USFWS and NMFS 1999).

### *Alteration of stream bed and stream morphology*

Surface mining can alter channel morphology by making the stream channel wider and shallower and removing the natural sediment load. Consequently, the suitability of stream reaches as rearing habitat may decrease, especially during summer low-flow periods when deeper waters are important for survival. Gravel bar skimming or “scalping,” which involves the removal of the surface from gravel bars without excavating below the low water flow level, can significantly impact aquatic habitat (Packer et al. 2005). Bar skimming creates a wide, flat cross section in the stream channel, which eliminates confinement of the low flow channel. A reduction in pool frequency may adversely affect migrating adults that require holding pools (Spence et al. 1996). Changes in the frequency and extent of bedload movement and increased erosion and turbidity can also remove spawning substrates, scour redds, result in a direct loss of eggs and young, or reduce their quality by deposition of increased amounts of fine sediments. These changes can affect the early life stages of Atlantic salmon, which exhibit an affinity for specific habitat types (Fitzsimons et al. 1999; Hedger et al. 2005). Extraction of sand and gravel in riverine ecosystems can directly eliminate the amount of gravel available for spawning if the extraction rate exceeds the deposition rate of new gravel in the system. Gravel excavation also reduces the supply of gravel to downstream habitats. The extent of suitable spawning habitat may be reduced where degradation reduces gravel depth or exposes bedrock (Spence et al. 1996). Associated with stream morphology alterations are resultant increased temperatures from a reduction in summer base flows; altered width to depth ratios; decreased riparian vegetation; decreased dissolved oxygen concentration as water temperatures increase; decreased nutrients from loss of floodplain connection and riparian vegetation; and decreased food production (e.g., loss of invertebrate prey populations) (Spence et al. 1996).

### *Sedimentation and siltation*

Sedimentation effects of mining may be immediate or delayed. During gravel extraction, for example, fine material can travel long distances downstream in the form of turbidity plumes. Silt can also be released during peat mining operations (USFWS and NMFS 1999). Sedimentation may be a delayed effect because gravel removal typically occurs at low flow when the stream has the least capacity to transport fine sediments out of the system. Increased sedimentation results when the spring freshet inundates an extraction area that is less stable than before mining operations. The extent and duration of sedimentation and siltation is likely to be higher than normal as unstable sediment washes freely into the system during higher rates of flow, acting as a migratory barrier to anadromous fish, such as Atlantic salmon, and increasing entrainment of sediment in downstream habitat. The result can be a degradation or loss of spawning and rearing habitat within the system (Spence et al. 1996).

### *Release of contaminants*

Peat mining can negatively impact diadromous fish, including Atlantic salmon, from the discharge of low pH water containing peat silt and dissolved metals and pesticides (USFWS and NMFS 1999). However, only one peat mining operation has been identified on the Narraguagus

River in Maine, and monitoring efforts at the site suggests that impacts are being controlled (USFWS and NMFS 1999).

Although current mineral mining operations in the northeast region of the United States are not a significant threat to rivers supporting diadromous fish, the effects of historic mining operations continue to be remediated (USEPA 2007). Harmful or toxic materials can be released directly from mining operations, including processing and machinery. Mining can introduce high levels of metals, sulfuric acid, mercury, cyanide, arsenic, and processing reagents into waterways. Water pollution by metals and acids is associated with mineral mining because ores, rich in sulfides, are commonly mined to extract gold, silver, copper, zinc, and lead (NRC 1999). In combination with anoxic conditions, sulfur-containing sediments can create additional levels of toxicity in addition to acid conditions (Brouwer and Murphy 1995). The improper handling or discharge of tailings and settling ponds can result in a direct loss of living aquatic resources as a result of decreased water quality and increased concentration levels of toxic substances. Locating settling ponds in unstable or landslide prone upland sites makes them prone to dangerous, instantaneous releases of large quantities of toxins. Groundwater and surface water may be incidentally contaminated by leaching of toxic substances from upland settling ponds.

*Conservation measures and best management practices for mining (adapted from Hanson et al. 2003 and Packer et al. 2005)*

1. Use upland aggregate sources before beginning any mining activities in active channels or floodplains.
2. Avoid mining operations in rivers and streams identified as important migratory pathways, spawning, and nursery habitat for anadromous fish.
3. Conduct a thorough assessment and characterization of aquatic resources, sediments, and potential sources of point and nonpoint contaminants prior to gravel removal.
4. Design, manage, and monitor sand and gravel mining operations to minimize potential direct and indirect impacts to riverine habitat if operations cannot be avoided. This includes, but is not limited to, migratory corridors, foraging and spawning areas, and stream/river banks.
5. Minimize the spatial extent and the depth of mine extraction operation to the maximum extent practicable.
6. Schedule necessary in-water activities when the fewest species and least vulnerable life stages are present. Seasonal restrictions should be used to avoid impacts to habitat during species critical life history stages (e.g., spawning and egg development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
7. Identify upland or off-channel (where channel will not be captured) gravel extraction sites as alternatives to gravel mining in or adjacent to rivers and streams identified as important pathways for anadromous fish, if possible.
8. Utilize best management practices to avoid spills of dirt, fuel, oil, toxic materials, and other contaminants. Prepare a spill prevention plan and maintain appropriate spill containment and water repellent/oil absorbent cleanup materials on the project location.
9. Treat wastewater (e.g., acid neutralization, sulfide precipitation, reverse osmosis, electrochemical, or biological treatments) and recycle onsite to minimize discharge to streams. Treat wastewater before discharge for compliance with state and federal clean water standards.
10. Reclaim mining wastes that contain contaminants such as metal, acids, arsenic, or other substances if leachate could enter aquatic habitats through surface or groundwater.

11. Use best management practices to minimize opportunities for sediment to enter streams and waterways. Methods such as contouring, mulching, silt curtains, and settling ponds should be part of the operations plan. Monitor turbidity during operations and alter operations if turbidity levels reach or exceed a predetermined level.
12. Address the cumulative impacts of past, present, and foreseeable future development activities on aquatic habitats by considering them in mining project review processes.

## **Emerging Issues for Freshwater Systems**

### *Endocrine disruptors, pharmaceuticals, and nanoparticles*

Growing concerns have mounted in response to the effects of endocrine-disrupting chemicals on humans, fish, and wildlife (Kavlock et al. 1996; Kavlock and Ankley 1996). These chemicals act as “environmental hormones” that may mimic the function of the sex hormones androgen and estrogen (Thurberg and Gould 2005). One of the sources of endocrine disrupting compound is the effluent of residential and commercial wastewater treatment facilities, as well as agricultural runoff (USGS 2002). Some of the chemicals shown to be estrogenic include polychlorinated biphenyl (PCB), dieldrin, DDT, phthalates, and alkylphenols (Thurberg and Gould 2005), which have had or still have applications in agriculture and may be present in irrigation water. Metals have also been implicated in disrupting endocrine secretions of marine organisms, potentially disrupting natural biotic processes (Brodeur et al. 1997). Adverse effects include reduced or altered reproductive functions, which could result in population-level impacts. Refer to the Chemical Effects: Water Discharge Facilities chapter for more information on endocrine disruptors. In addition to endocrine disrupting compounds, recent studies have found municipal wastewater effluent entering streams and rivers containing human and veterinary pharmaceuticals, including antibiotics and natural and synthetic hormones (USGS 2002).

Other recent concerns are the release of substances referred to as nanoparticles into the aquatic environment. Nanoparticles, such as fullerenes (e.g., 60-carbon molecules often referred to as “buckyballs”) may have great potential for use in the pharmaceutical, lubricant, and semiconductor industries, as well as applications in energy conversion. However, the micro-fine particulate waste generated from the production and use of nanoparticles may adversely affect the distribution, feeding, ecology, respiration, and nutrient regeneration of microorganisms, such as bacterivorous and herbivorous protozoa, protists, and phagotrophic or mixotrophic microalgae (Colvin 2003).

### *Harmful algal blooms*

Impervious surfaces and stormwater drain systems can increase the rate and volume of stormwater runoff into rivers and streams. This direct flushing of water generates large pulses of runoff into rivers and streams, carrying with it nutrients and a wide-range of pollutants that flow into estuaries and coastal areas. Nutrient-rich waters have been associated with harmful algal blooms (HABs), which can deplete the oxygen in the water during bacterial degradation of algal tissue and can result in hypoxic or anoxic “dead zones” and large-scale fish kills in rivers, estuaries, and coastal areas (Deegan and Buchsbaum 2005; MDDNR 2007). For example, HABs have been responsible for fish kills in the freshwater portions of the Potomac River in Virginia and the Corsica River in Maryland, as well as in the Potomac and Chesapeake Bay estuaries (MDDNR 2007). HABs affecting Gulf of Maine waters have resulted in shellfish bed closures and mortalities to endangered marine mammals (NOAA 2008; WHOI 2008). While the causes of HABs in coastal waters of New England are unclear, large pulses of freshwater rivers and streams in the region as a

result of elevated rainfall and snowmelt in the spring are being examined as contributing factors in creating conditions favorable for algal growth (NOAA 2008). Refer to the Coastal Development and Introduced/Nuisance Species and Aquaculture chapters for more information on HABs.

### *Introduced and nuisance species*

Introductions of nonnative nuisance species are a significant threat to freshwater and coastal ecosystems in the United States (Carlton 2001). Nonnative species may be released intentionally (i.e., fish stocking and pest control programs) or unintentionally during industrial shipping activities (e.g., ballast water releases), aquaculture operations, recreational boating, biotechnology, or from aquarium discharge (Hanson et al. 2003; Niimi 2004). For example, increased competition for food sources between the invasive exotic zebra mussel (*Dreissena polymorpha*) and open-water commercial and recreational species have altered the trophic structure in the Hudson River estuary, NY, by withdrawing large quantities of phytoplankton and zooplankton from the water column, thus increasing competition with planktivorous fish (Strayer et al. 2004). Refer to the Introduced/Nuisance Species and Aquaculture chapter for information on introduced and nuisance species.

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