Chapter A8: Impingement & Entrainment by Waterbody Type

Introduction

The environmental impacts of cooling water intake structures (CWISs) are closely tied to the biological productivity of the waterbody from which cooling water is withdrawn. This chapter discusses CWIS impacts on specific waterbody types, including rivers and streams, lakes and reservoirs (excluding the Great Lakes), the Great Lakes, oceans, and estuaries. Habitats of particular biological sensitivity are highlighted within each type.

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A8-1 CWIS Impingement and Entrainment Impacts in Rivers and Streams

Freshwater rivers and streams are free-flowing bodies of water that do no receive significant inflows of water from oceans or bays (Hynes, 1970; Allan, 1995). Current is typically highest in the center of a river and rapidly drops toward the edges and at depth because of increased friction with river banks and the bottom. Close to and at the bottom, the current can become minimal. The range of flow conditions in undammed rivers helps explain why fish with very different habitat requirements can co-exist within the same stretch of surface water (Matthews, 1998).

In general, the shoreline areas along river banks support a high diversity of aquatic life. These are areas where light penetrates to the bottom and supports the growth of rooted vegetation. Suspended solids tend to settle along shorelines where the current slows, creating shallow, weedy areas that attract aquatic life. Riparian vegetation, if present, also provides cover and shade. Such areas represent important feeding, resting, spawning, and nursery habitats for many aquatic species. In temperate regions, the number of impingeable and entrainable organisms in the littoral zone of rivers increases during the spring and early summer when most riverine fish species reproduce. This concentration of aquatic organisms along river shorelines in turn attracts wading birds and other kinds of wildlife.

Fish species such as common carp (*Cyprinus carpio*), yellow perch (*Perca flavescens*), white bass (*Morone chrysops*), freshwater drum (*Aplodinotus grunniens)*, gizzard shad (*Dorosoma cepedianum*), and alewife (*Alosa pseudoharengus*) are the main fishes harmed by CWIS located in rivers. These species occur in nearshore areas and/or have pelagic early life stages, traits that greatly increase their susceptibility to impingement and entrainment (I&E).

A8-2 CWIS Impingement and Entrainment Impacts in Lakes and Reservoirs

Lakes are inland bodies of open water located in natural depressions (Goldman and Horne, 1983). Lakes are fed by rivers, streams, springs, and/or local precipitation. The residence time of water in lakes can be weeks, months, or even years, depending on the size and volume of the lake. Water currents in lakes are small or negligible compared to rivers, and are most noticeable near lake inlets and outlets.

Larger lakes are divided into three general zones — the littoral zone (shoreline areas where light penetrates to the bottom), the limnetic zone (the surface layer where most photosynthesis takes place), and the profundal zone (relatively deeper and colder offshore area) (Goldman and Horne, 1983). Each zone differs in its biological productivity and species diversity and hence in the potential magnitude of I&E. The importance of these zones in relation to potential I&E impacts of CWIS are discussed below.

The highly productive littoral zone extends farther and deeper in clear lakes than in turbid lakes. In small, shallow lakes, the littoral zone can be quite extensive and even include the entire waterbody. As along river banks, this zone supports high primary productivity and biological diversity. It is used by a host of fish species, benthic invertebrates, and zooplankton for feeding, resting, and reproduction, and as nursery habitat. Many fish species adapted to living in the colder profundal zone also move to shallower in-shore areas to spawn, e.g., lake trout (*Salmo namycush*) and various deep water sculpin species (*Cottus* spp.).

Many fish species spend most of their early development in and around the littoral zone of lakes. These shallow waters warm up rapidly in spring and summer, offer a variety of different habitats (submerged plants, boulders, logs, etc.) in which to hide or feed, and stay well-oxygenated throughout the year. Typically, the littoral zone is a major contributor to the total primary productivity of lakes (Goldman and Horne, 1983).

The limnetic zone is the surface layer of a lake. The vast majority of light that enters the water column is absorbed in this layer. In contrast to the high biological activity observed in the nearshore littoral zone, the offshore limnetic zone supports fewer species of fish and invertebrates. However, during certain times of year, some fish and invertebrate species that spend the daylight hours hiding on the bottom rise to the surface of the limnetic zone at night to feed and reproduce. Adult fish may migrate through the limnetic zone during seasonal spawning migrations. The juvenile stages of numerous aquatic insects — such as caddisflies, stoneflies, mayflies, dragonflies, and damselflies — develop in sediments at the bottom of lakes but move through the limnetic zone to reach the surface and fly away. This activity attracts foraging fish.

The profundal zone is the deeper, colder area of a lake. Rooted plants are absent because insufficient light penetrates at these depths. For the same reason, primary productivity by phytoplankton is minimal. A well-oxygenated profundal zone can support a variety of benthic invertebrates or cold-water fish. With few exceptions, these species seek out shallower areas to spawn, either in littoral areas or in adjacent rivers and streams, where they may become susceptible to I&E at CWIS.

Most of the larger rivers in the United States have one or more dams that create artificial lakes or reservoirs. Reservoirs have some characteristics that mimic those of natural lakes, but large reservoirs differ from most lakes in that they obtain most of their water from a large river instead of from groundwater recharge or from smaller creeks and streams.

The fish species composition in reservoirs may or may not reflect the native assemblages found in the pre-dammed river. Dams create two significant changes to the local aquatic ecosystem that can alter the original species composition:
(1) blockages that prevent anadromous species from migrating upstream, and (2) altered hydrologic regimes that can eliminate species that cannot readily adapt to the resulting changes in flow and habitat.

Reservoirs typically support littoral zones, limnetic zones, and profundal zones, and the same concepts outlined above for lakes apply to these bodies of water. For example, compared to the profundal zone, the littoral zone along the edges of reservoirs supports greater biological diversity and provides prime habitat for spawning, feeding, resting, and protection for numerous fish and zooplankton species. However, there are also several differences. Reservoirs often lack extensive shallow areas along their edges because their banks have been engineered or raised to contain extra water and prevent flooding. In mountainous areas, the banks of reservoirs may be quite steep and drop off precipitously with little or no littoral zone. As with lakes and rivers, however, CWIS located in shallower water have a higher probability of entraining or impinging organisms.

A8-3 CWIS Impingement and Entrainment Impacts in the Great Lakes

The Great Lakes were carved out by glaciers during the last ice age (Bailey and Smith, 1981). They contain nearly 20 percent of the earth's fresh water, or about 23,000 km^3 (5,500 cu. mi.) of water, covering a total area of 244,000 km^2 (94,000 sq. mi.). There are five Great Lakes: Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario. Although part of a single system, each lake has distinct characteristics. Lake Superior is the largest by volume, with a retention time of 191 years, followed by Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario.

Water temperatures in the Great Lakes strongly influence the physiological processes of aquatic organisms, affecting growth, reproduction, survival, and species temporal and spatial distribution. During the spring, many fish species inhabit shallow, warmer waters where temperatures are closer to their thermal optimum. As water temperatures increase, these species migrate to deeper water. For species that are near the northern limit of their range, the availability of shallow, sheltered habitats that warm early in the spring is probably essential for survival (Lane et al., 1996a). For other species, using warmer littoral areas increases the growing season and may significantly increase production.

Some 80 percent of Great Lakes fishes use the littoral zone for at least part of the year (Lane et al., 1996a). Of 139 Great Lakes fish species reviewed by Lane et al. (1996b), all but the deepwater ciscoes (*Coregonus* spp.) and deepwater sculpin (*Myxocephalus thompsoni*) use waters less than 10 m deep as nursery habitat.

A8-4 CWIS Impingement and Entrainment Impacts in Estuaries

Estuaries are semi-enclosed bodies of water that have a an unimpaired natural connection with the open ocean and within which sea water is diluted with fresh water derived from land (Day et al., 1989). The dynamic interactions among freshwater and marine environments in estuaries result in a rich array of habitats used by both terrestrial and aquatic species. Because of the high biological productivity and sensitivity of estuaries, adverse environmental impacts are more likely to occur at CWIS located in estuaries than in other waterbody types.

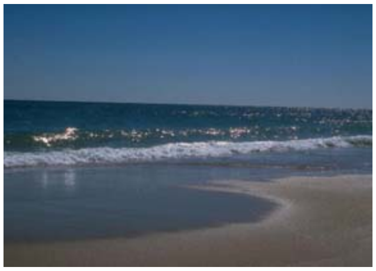
Numerous commercially, recreationally, and ecologically important species of fish and shellfish spend part or all of their life cycle within estuaries. Marine species that spawn offshore take advantage of prevailing inshore currents to transport their eggs, larvae, or juveniles into estuaries where they hatch or mature. Inshore areas along the edges of estuaries support high rates of primary productivity and are used by numerous aquatic species for feeding and as nursery habitats. This high level of biological activity makes these shallow littoral zone habitats highly susceptible to I&E impacts from CWIS.

Estuarine species that show high rates of I&E include bay anchovy (*Anchoa mitchilli*), winter flounder (*Pleuronectes americanus*), and weakfish (*Cynoscion regalis*). During spring, summer and fall, various life stages of these and other estuarine fishes show considerable migratory activity. Adults move in from the ocean to spawn in the marine, brackish, or freshwater portions of estuaries or tributary rivers; the eggs and larvae can be planktonic and move about with prevailing currents or by using selective tidal transport; juveniles actively move upstream or downstream in search of optimal nursery habitat; and young adult anadromous fish move out of freshwater areas and into the ocean to reach sexual maturity. Because of the many complex movements of estuarine-dependent species, a CWIS located in an estuary can harm both resident and migratory species as well as related freshwater, estuarine, and marine food webs.

A8-5 CWIS Impingement and Entrainment Impacts in Oceans

Oceans are marine open coastal waters with salinity greater than or equal to 30 parts per thousand (Ross, 1995). CWIS in oceans are usually located over the continental shelf, a shallow shelf that slopes gently out from the coastline an average of 74 km (46 miles) to where the sea floor reaches a maximum depth of 200 m (660 ft) (Ross, 1995). The deep ocean extends beyond this region. The area over the continental shelf is known as the Neritic Province and the area over the deep ocean is the Oceanic Province (Meadows and Campbell, 1978).

Vertically, the upper, sunlit epipelagic zone over the continental shelf averages about 100 m in depth (Meadows and Campbell, 1978). This zone has pronounced light and temperature gradients that vary seasonally and influence the temporal and spatial distribution of marine organisms.



In oceans, the littoral zone encompasses the photic zone of the area over the continental shelf. As in other waterbody types, the littoral zone is where most marine organisms concentrate. The littoral zone of oceans is of particular concern in the context of section 316(b) because this biologically productive zone is also where most coastal utilities withdraw cooling water.

The morphology of the continental shelf along the U.S. coastline is quite varied (NRC, 1993). Along the Pacific coast of the United States the continental shelf is relatively narrow, ranging from 5 to 20 km (3 to 12 miles), and is cut by several steep-sided submarine canyons. As a result, the littoral zone along this coast tends to be narrow, shallow, and steep. In contrast, along most of the Atlantic coast of the United States, there is a wide, thick, and wedge-shaped shelf that extends as much as 250 km (155 miles) from shore, with the greatest widths generally opposite large rivers. Along the Gulf coast, the shelf ranges from 20 to 50 km (12 to 31 miles).

The potential for I&E at ocean facilities can be quite high if CWIS are located in the productive areas over the continental shelf where many species reproduce, or in nearshore areas that provide nursery habitat. In addition, the early life stages of many species are planktonic, and tides and currents can carry these organisms over large areas. The abundance of plankton in temperate regions is seasonal, with greater numbers in spring and summer and fewer numbers in winter. An additional concern for ocean CWIS is the presence of marine mammals and reptiles, including threatened and endangered species of sea turtles. These species are known to enter submerged offshore CWIS and can drown once inside the intake tunnel.

A8-6 Summary and Conclusions

Fish species with free-floating, early life stages are those most susceptible to CWIS impacts. Such planktonic organisms lack the swimming ability to avoid being drawn into intake flows. Species that spawn in nearshore areas, have planktonic eggs and larvae, and are small as adults experience even greater impacts because both new recruits and the spawning adults are affected (e.g., bay anchovy in estuaries and oceans). Fish species in estuaries and oceans experience the highest rates of I&E because fish spawning and nursery areas are located throughout estuaries and near coastal waters, making it difficult to avoid locating intakes in areas where fish are present.