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Case Study Analysis for the Proposed Section 316(b) Phase II Existing Facilities Rule

Part A - B

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Chapter A1: Ecological Risk Assessment Framework

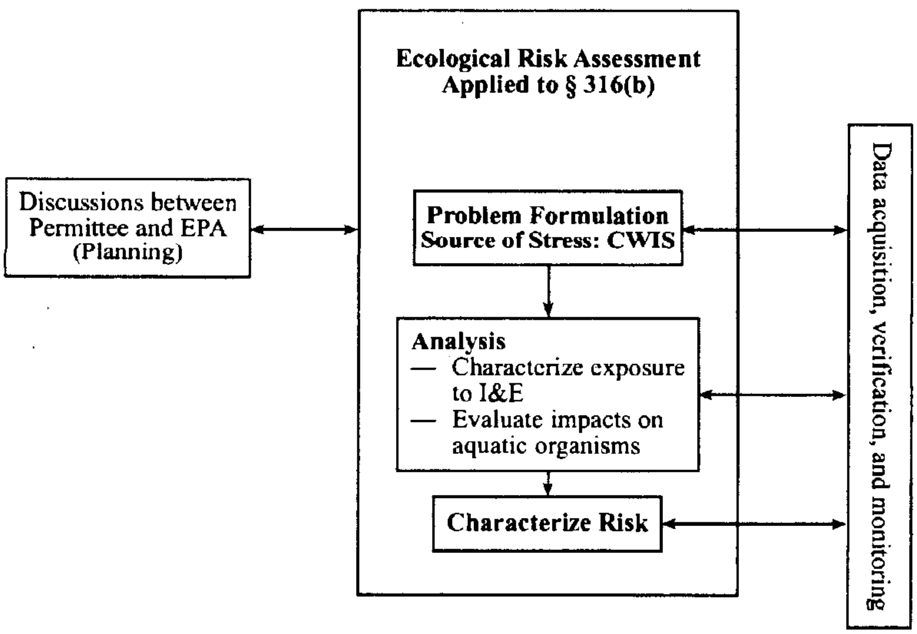
INTRODUCTION

EPA has defined ecological risk assessment as "a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors" (U.S. EPA, 1998b). It is an approach to impact assessment that involves explicit evaluation of the data, assumptions, and uncertainties associated with an impact analysis. Risk assessments range in level of analysis and data requirements, depending on management goals, data availability, and stakeholder concerns.

CHAPTER CONTENTS

In the context of evaluating the impacts of cooling water intake structures (CWIS) under § 316(b), the key stressors of interest for an ecological risk assessment are the impingement and entrainment (I&E) of aquatic organisms. The following sections outline the three phases of ecological risk assessment (problem formulation, analysis, and risk characterization) as they apply to EPA's § 316(b) case studies (see Figure A1-1).

Figure A1-1: EPA's Framework for Ecological Risk Assessment Applied to § 316(b)



Adapted from U.S. EPA, 1998b.

A1-1 Problem Formulation

The problem formulation phase of an ecological risk assessment defines the problem to be evaluated and develops a plan for analyzing available data and characterizing risk (U.S. EPA, 1998b). This involves formulating a conceptual model of the relationships between stressors and receptors, selecting assessment and measurement endpoints, and developing a plan for the analysis of exposure and risk. In the context of § 316(b), the primary stressors associated with CWIS are I&E and the receptors are the aquatic organisms that are exposed to I&E. Figure A1-2 is a conceptual model indicating the primary and secondary ecological effects that result from the exposure of aquatic organisms to I&E.

An assessment endpoint is any ecological entity of concern to stakeholders (U.S. EPA, 1998b). Ecological entities to be assessed may include one or more entities across a range of levels of biological organization, including individuals, subpopulations, populations, species, communities, or ecosystems. Measurement endpoints are the attributes of an assessment endpoint that are evaluated in a risk assessment. Attributes of concern may include individual survival, population recruitment, species abundance, species diversity, or ecosystem structure and function. Ideally, assessment endpoints should include all species directly and indirectly affected by a CWIS. Potentially affected organisms include fish, shellfish, planktonic organisms, sea turtles, and marine mammals. In most cases, assessment endpoints for the § 316(b) case studies include only fish and shellfish species because these species are the focus of most facility studies. Measurement endpoints that should be included in all § 316(b) risk analyses include annual losses of individual organisms, adult equivalent losses, lost fishery yield, and production foregone, as described in detail in Chapter A4.

A1-2 Analysis

The analysis phase of an ecological risk assessment focuses on the characterization of (1) exposure to one or more stressors and (2) the ecological effects that are expected to result from exposure (U.S. EPA, 1998b).

A1-2.1 Characterization of Exposure of Aquatic Organisms to CWIS

Exposure characterization describes the potential or actual co-occurrence of stressors and receptors (U.S. EPA, 1998b). In the case of CWIS, characterization of exposure involves description of facility characteristics that influence rates of I&E, and the physical, chemical, and biological characteristics of the surrounding ecosystem that influence the intensity, time, and spatial extent of contact of aquatic organisms with a facility's CWIS.

Exposure of aquatic organisms to I&E depends on factors related to the location, design, construction, capacity, and operation of the facility's CWIS (U.S. EPA, 1976; SAIC, 1994; SAIC, 1995; SAIC, 1996a and b). Table A1-1 lists facility characteristics as well as characteristics of species and the surrounding environment that influence when, how, and why aquatic organisms may become exposed to and experience adverse effects of CWIS. These characteristics are described in the following sections based on information provided in EPA's 1976 § 316(b) development document (U.S. EPA, 1976) and background papers developed for EPA's § 316(b) rulemaking activities by Science Applications International Corporation (SAIC) (SAIC, 1994; SAIC, 1995; SAIC, 1996a and b).

a. Intake location

Two major components of a CWIS's location that influence the relative magnitude of I&E are (1) the type of waterbody from which a CWIS is withdrawing water, and (2) the placement of the CWIS relative to sensitive biological areas within the waterbody. Considerations in siting include intake depth and distance from the shoreline in relation to the physical, chemical, and biological characteristics of the source waterbody. In general, intakes located in nearshore areas (riparian or littoral zones) will have greater ecological impacts than intakes located offshore, since nearshore areas are usually more biologically productive and have higher concentrations of aquatic organisms.

Figure A1-2: Conceptual Model Indicating Some Primary and Secondary Effects of Impingement and Entrainment by CWIS

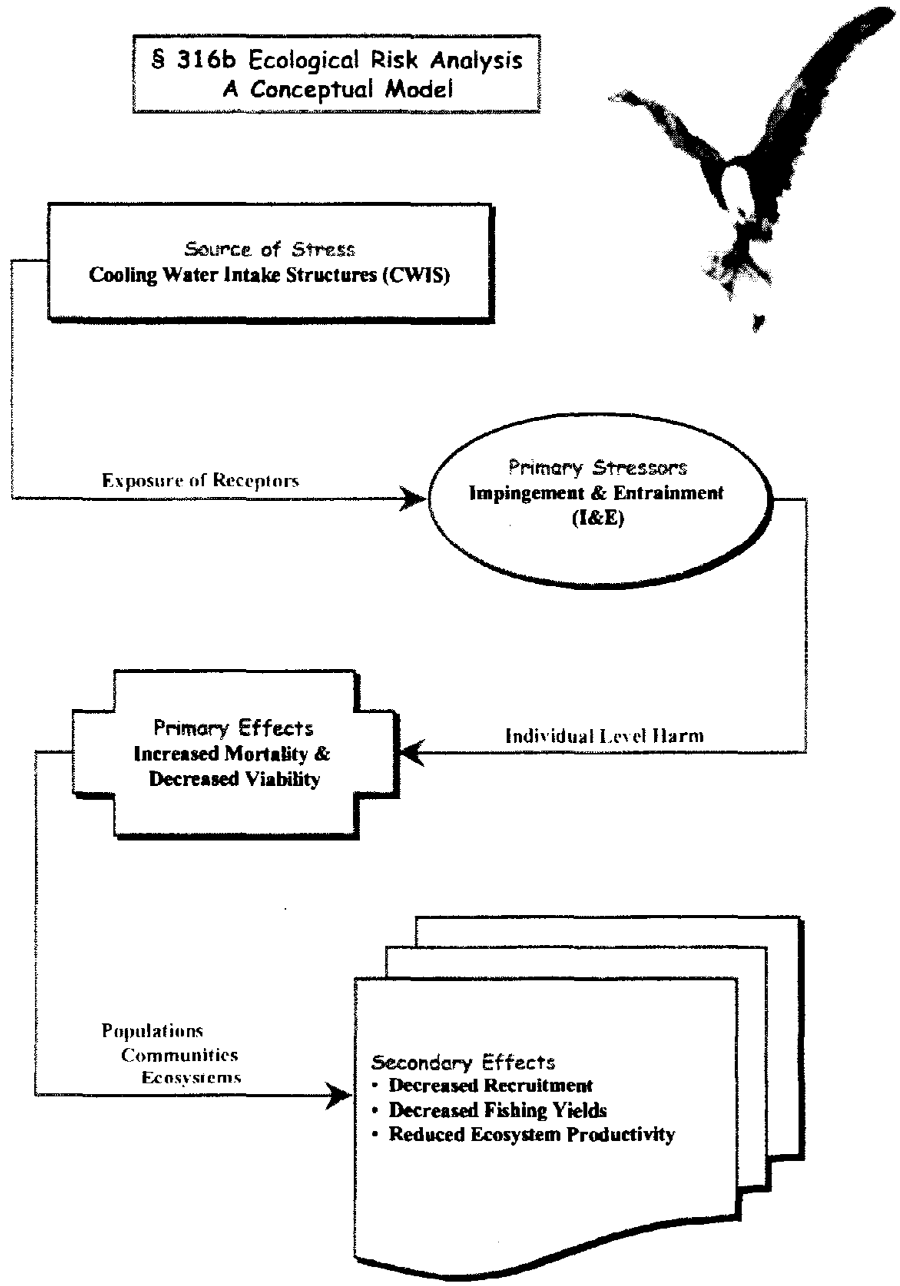


Table A1-1: Partial List of CWIS Characteristics and Ecosystem and Species Characteristics Influencing Exposure to I&E

CWIS Characteristics	Ecosystem and Species Characteristics
▸ Depth of intake	**Ecosystem Characteristics (abiotic environment)**:
▸ Distance from shoreline	▸ Source waterbody type (marine, estuarine, riverine, lacustrine)
▸ Proximity of intake withdrawal and discharge	▸ Water temperatures
▸ Proximity to other industrial discharges or water withdrawals	▸ Ambient light conditions
▸ Proximity to an area of biological concern	▸ Salinity levels
▸ Type of intake structure (size, shape, configuration, orientation)	▸ Dissolved oxygen levels
▸ Approach velocity	▸ Tides/currents
▸ Presence/absence of intake control and fish protection technologies	▸ Direction and rate of ambient flows
a. Intake screen systems	**Species Characteristics (physiology, behavior, life history)**:
b. Passive intake systems	▸ Density in zone of influence of CWIS
c. Fish diversion/avoidance systems	▸ Spatial and temporal distributions (e.g., daily, seasonal, annual migrations)
▸ Water temperature in cooling system	▸ Habitat preferences (e.g., depth, substrate)
▸ Temperature change during entrainment	▸ Ability to detect and avoid intake currents
▸ Duration of entrainment	▸ Swimming speeds
▸ Use of intake biocides and ice removal technologies	▸ Body size
▸ Scheduling of timing, duration, frequency, and quantity of water withdrawal	▸ Age/developmental stage
▸ Mortality of aquatic organisms	▸ Physiological tolerances (e.g., temperature, salinity, dissolved oxygen)
▸ Displacement of aquatic organisms	▸ Feeding habits
▸ Destruction of habitat (e.g., burial of eggs deposited in stream beds, increased turbidity of water column)	▸ Reproductive strategy
▸ Type of withdrawal - once through vs. recycled (cooling water volume and volume per unit time)	▸ Mode of egg and larval dispersal
▸ Ratio of cooling water intake flow to source water flow	▸ Generation time

Critical physical and chemical factors related to siting of an intake include the direction and rate of waterbody flow, tidal influences, currents, salinity, dissolved oxygen levels, thermal stratification, and the presence of pollutants. The withdrawal of water by an intake can change ambient flows, velocities, and currents within the source waterbody, which may cause organisms to concentrate in the vicinity of an intake or reduce their ability to escape a current. Effects vary according to the type of waterbody and species present.

In large rivers, withdrawal of water may have little effect on flows because of the strong, unidirectional nature of ambient currents. In contrast, lakes and reservoirs have small ambient flows and currents, and therefore a large intake flow can significantly alter current patterns. Tidal currents in estuaries or tidally influenced sections of rivers can carry small, passive organisms past intakes multiple times, thereby increasing their probability of entrainment. If intake withdrawal and discharge are in close proximity, entrained organisms released in the discharge can become re-entrained.

The magnitude of I&E in relation to intake location also depends on biological factors such as species' distributions and the presence of critical habitats within an intake's zone of influence. Species with planktonic (free-floating) early life stages have higher rates of entrainment because they are unable to actively avoid being drawn into the intake flow.

b. Intake design

Intake design refers to the design and configuration of various components of the intake structure, including screening systems (trash racks, pumps, pressure washes); passive intake systems; and fish diversion and avoidance technologies (U.S. EPA, 1976). After entering the CWIS, water must pass through a screening device before entering the power plant. The screen is designed, at a minimum, to prevent debris from entering and clogging the condenser tubes. Screen mesh size and velocity characteristics are two important design features of the screening system that influence the potential for impingement and entrainment of aquatic organisms that are withdrawn from the water body with the cooling water (U.S. EPA, 1976).

Approach velocity has a significant influence on the potential for impingement (Boreman, 1977). Approach velocity is the velocity of the current in the area approaching the screen and is measured at the screen upstream of the screen face in feet per second (fps). Approach velocity is directly related to the area of the screen and the size of the intake structure (U.S. EPA, 1976). The biological significance of approach velocity depends on species-specific characteristics such as fish swimming ability and endurance. These characteristics are a function of the size of the organism and the temperature and oxygen levels of water in the area of the intake (U.S. EPA, 1976). The maximum velocity protecting most small fish is 0.5 fps, but lower velocities will still impinge some fish and entrain eggs and larvae and other small organisms (Boreman, 1977).

Conventional traveling screens have been modified to improve fish survival of screen impingement and spray wash removal (Taft, 1999). However, a review by SAIC of steam electric utilities indicated that alternative screen technologies are usually not much more effective at reducing impingement than the conventional vertical traveling screens used by most steam electric facilities (SAIC, 1994). An exception may be traveling screens modified with fish collection systems (e.g., Ristroph screens). Studies of improved fish collection baskets at the Salem Generating Station showed increased survival of impinged fish (Ronafalvy et al., 2000).

Passive intake systems (physical exclusion devices) screen out debris and aquatic organisms with minimal mechanical activity and low withdrawal velocities (Taft, 1999). The most effective passive intake systems are wedge-wire screens and radial wells (SAIC, 1994). A new technology, the filter fabric barrier system (known commercially as the Gunderboom) consists of polyester fiber strands pressed into a water-permeable fabric mat, has shown promise in reducing entrainment of ichthyoplankton (free-floating fish eggs and larvae) at the Lovett Generating Station on the Hudson River (Taft, 1999).

Fish diversion/avoidance systems (behavioral barriers) take advantage of natural behavioral characteristics of fish to guide them away from an intake structure or into a bypass system (SAIC, 1994; Taft, 1999). The most effective of these technologies are velocity caps, which divert fish away from intakes, and underwater strobe lights, which repel some species (Taft, 1999). Velocity caps are used mostly at offshore facilities and have proven effective in reducing impingement (e.g., California's San Onofre Nuclear Generating Station, SONGS).

Another important design consideration is the orientation of the intake in relation to the source waterbody (U.S. EPA, 1976). Conventional intake designs include shoreline, offshore, and approach channel intakes. In addition, intake operation can be modified to reduce the quantity of source water withdrawn or the timing, duration, and frequency of water withdrawal. This is an important way to reduce entrainment. For example, larval entrainment at the San Onofre facility was reduced by 50% by rescheduling the timing of high volume water withdrawals (SAIC, 1996a).

c. Intake capacity

Intake capacity is a measure of the volume of water withdrawn per unit time. Intake capacity can be expressed as millions of gallons per day (MGD), or as cubic feet per second (cfs). Capacity can be measured for the facility as a whole, for all of the intakes used by a single unit, or for the intake structure alone. In defining an intake's capacity it is important to distinguish between the design intake flow (the maximum possible) and the actual operational intake flow.

The quantity of cooling water needed and the type of cooling system are the most important factors determining the quantity of intake flow (U.S. EPA, 1976). Once-through cooling systems withdraw water from a natural waterbody, circulate the water through condensers, and then discharge it back to the source waterbody. Closed-cycle cooling systems withdraw water from a natural waterbody, circulate the water through the condensers, and then send it to a cooling tower or cooling pond before recirculating it back through the condensers. Because cooling water is recirculated, closed-cycle systems reduce intake water flow substantially. It is generally assumed that this will result in a comparable reduction in I&E (Goodyear, 1977b). Systems with helper towers reduce water usage much less. Plants with helper towers can operate in once-through or closed-cycle modes.

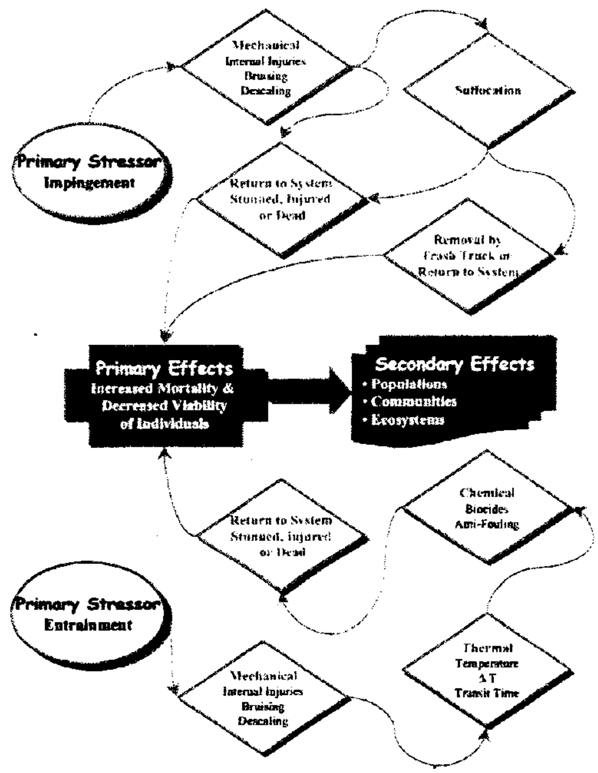
Circulating water intakes are used by once-through cooling systems to continuously withdraw water from the cooling water source. The typical circulating water intake is designed to use 1.06-3.53 cfs (500-1500 gallons per minute, gpm) per megawatt (MW) of electricity generated (U.S. EPA, 1976). Closed cycle systems use makeup water intakes to provide water lost by evaporation, blowdown, and drift. Although makeup quantities are only a fraction of the intake flows of once-through systems, quantities of water withdrawn can still be significant, especially by large facilities (U.S. EPA, 1976).

If the quantity of water withdrawn is large relative to the flow of the source waterbody, a larger number of organisms is more likely to be affected by a facility's CWIS. Thus, the proportion of the source water flow supplied to a CWIS is often used to derive a conservative estimate of the potential for adverse impact (e.g., Goodyear, 1977b). For example, withdrawal of 5% of the source water flow may be expected to result in a loss of 5% of planktonic organisms based on the assumption that organisms are uniformly distributed in the vicinity of an intake. Although the assumption of uniform distribution may not always be met, when data on actual distributions are unavailable, simple mathematical models based on this assumption provide a conservative and easily applied method for predicting potential losses (Goodyear, 1977b).

A1-2.2 Characterization of Ecological Effects

The characterization of ecological effects involves describing the effects resulting from the stressor(s) of interest, linking effects to assessment endpoints, and measuring endpoints to evaluate how effects change as a function of changes in stressor levels (U.S. EPA, 1998b). For EPA's § 316(b) case studies, measures of ecological effects included measures of both primary and secondary effects (Figure A1-3). Losses of impinged and entrained organisms are measures of primary effects and are the most direct measure of the effects of CWIS on aquatic organisms. It is necessary to fully evaluate primary effects in order to evaluate the consequences of these losses for fishery yields, ecosystem production, or other measures of indirect or secondary effects. The measurement endpoints evaluated for the § 316(b) case studies are discussed in detail in Chapter A4.

Figure A1-3: Stressor-Effects Pathway

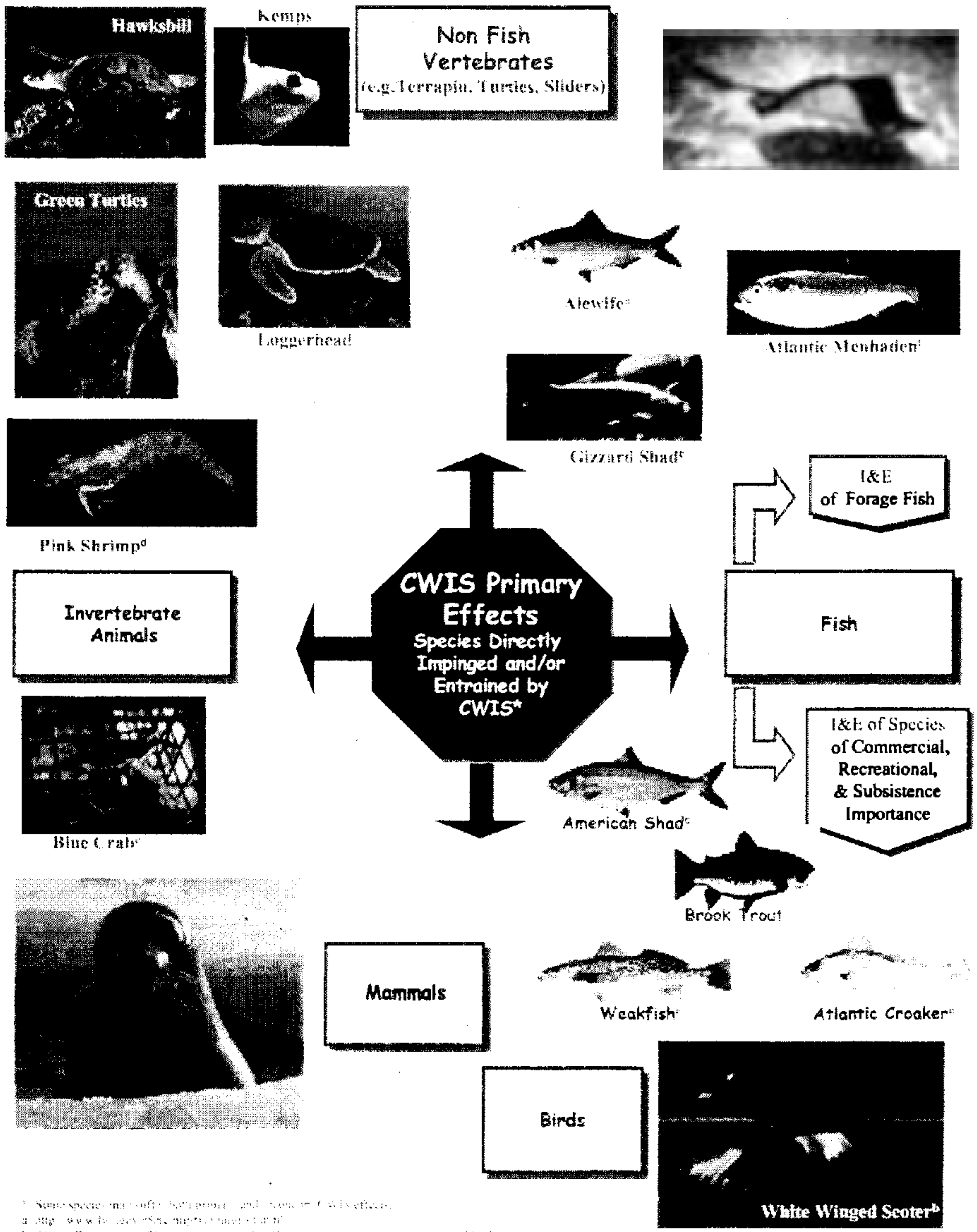


A1-3 RISK CHARACTERIZATION

The final step of an ecological risk assessment is the characterization of risk (U.S. EPA, 1998b). Risk refers to the likelihood of an undesirable ecological effect resulting from the stressor of concern. Because of the intrinsic variability and inevitable uncertainty associated with the evaluation of ecological phenomena, ecological impacts cannot be determined exactly, and thus only the probability (or risk) of an effect can be assessed (Hilborn, 1987; Burgman et al., 1993).

Risk can be defined qualitatively or quantitatively, depending on factors such as the goals of a risk manager and data availability (U.S. EPA, 1998b). Qualitative assessments usually involve best professional judgment. Quantitative assessments involve calculation of the change in risk (Ginzburg et al., 1982; Akçakaya and Ginzburg, 1991). The ecological risk assessments for EPA's § 316(b) case studies used available facility data to quantitatively evaluate impingement and entrainment risks to aquatic organisms.

Figure A1-4: Examples of Species Directly Affected by CWIS



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Chapter A2: Everything You Ever Wanted to Know about Fish

A2-1 INTRODUCTION

Fish are the most numerous and diverse of all vertebrate groups. They go back more than 400 million years and make up over half of all vertebrate species. About 24,600 species in 482 families live in the world today. Experts think that thousands more species are yet to be found.

Fifty-eight percent of the world's fish species live in the sea and 41 percent live in freshwater. This number is striking, since the volume of freshwater is only 1/7,500th that of the oceans. One percent, just over 200 species, move between freshwater and the sea. Most of these 200 species are *anadromous*, i.e., they reproduce in freshwater but mature at sea. A few species are *catadromous*, spawning in the sea but maturing in freshwater.

More than three quarters of marine species live on or along the shallow continental shelves. The deep waters beyond, which comprise most of the oceans, have only about 2,900 fish species.

This chapter provides general information on the distribution, anatomy, physiology, and ecology of fish based on information in Wetzel (1983), Nelson (1994), Ross (1995), Moyle and Cech (1996), and Helfman et al. (1997).

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A2-2 FISH DIVERSITY AND ABUNDANCE

A2-2.1 Biological Diversity

The behavior, physiology, and morphology of fish are very diverse. Fish eat all conceivable plant or animal food items. Some species form large schools; others have territorial or solitary lifestyles. Fish migrate over short or long distances looking for food or areas to mate. Extreme examples are some species of Pacific salmon, which swim more than 1,880 miles (3,000 km) up the Yukon River to reproduce; or the giant blue tuna, which swims throughout the world's oceans seeking food. Some species can also walk on land or glide in the air.

Most fish are cold-blooded, but some are partially warm-blooded. Most species use gills to get oxygen, but some supplement gill breathing by gulping air. A few will drown if they cannot breathe air. Some fish make venom, electricity, sound, or light. Most fish release sperm and eggs into the water or the bottom with little parental care; others build nests, are live bearers, or mouth brooders. Most fish have fixed sexual patterns, i.e., they are either male or female for their entire lives. A surprising number switch sex at some point in their lives. The majority of species reproduce many times over a lifetime; some die after the first mating.

Fish live from one year to over a century. Adult fish range from a 0.4 inch (10 mm) marine goby to the giant 39.4 ft (12 m) whale shark. Fish shapes range from snake-like to ball-like, saucer-like, or torpedo-like, with many forms in-between. Some species are sleek and graceful; others are ungainly or grotesque. Fins may be missing or are changed for use as sexual organs, suction cups, pincers, claspers, lures, or to serve other functions. Fish can be highly-colored to drab grey. Finally, approximately 50 species lack eyes.

A2-2.2 Distribution and Zoogeography

Fish live in all possible aquatic habitats on the planet. Most are found in "normal" habitats, such as lakes, rivers, tidal rivers, estuaries, and oceans. Within those habitats, fish are found at elevations of up to 17,000 ft (5,200 m) in Tibet, and depths of over 3,300 ft (1,000 m) in Lake Baikal and 23,000 ft (7,000 m) below the ocean surface. Fish live in water ranging from essentially pure freshwater with salt levels close to that of distilled water, to hyper-saline lakes with salt levels over three times that found in the sea. Their habitats extend from caves or springs to the entire ocean, from hot soda lakes in Africa with water temperatures up to 44 °C (111 °F) to deep-sea hydrothermal vents in the eastern Pacific, and the Antarctic ocean where water temperatures drop to -2 °C (28 °F).

a. Freshwater

Freshwaters support most of the world's fish species, when one considers the volume of available water. This disparity arises from greater productivity, and isolation.

- Freshwaters are quite shallow on average. Sunlight, which stimulates photosynthesis and increases algal growth, can reach a relatively large part of their volume. In contrast, the oceans have a mean depth of 12,100 ft (3,700 m). Much of the water column is too deep and dark for photosynthesis and stays unproductive. The shallower continental margins, which support most marine species, are an exception.

- Freshwater habitats easily break up into isolated water bodies, creating many distinct "islands" of water over the terrestrial landscape. This isolation promotes the formation of new species over time. Droughts, volcanos, earthquakes, landslides, glaciation, and river course adjustments break up habitats. In contrast, marine habitats are unbroken over great distances and volumes. They are less likely to form barriers, except on a trans-oceanic scale.

In North America, from the Arctic to the Mexican Plateau, freshwaters belong to a zoogeographic region called the *Nearctic*. This area has approximately 950 known fish species, classified into 14 families. The most species-rich families are the Cyprinids (minnows and related species), Catostomids (suckers and related species), Ictalurids (catfish and related species), Percids (darters and related species), and Centrarchids (sunfish and related species).

The Nearctic region in North America is divided into two subregions, each with many "provinces":

- The *Arctic-Atlantic subregion* includes the Mississippi-Missouri drainage basins, the Great Lakes-Saint Lawrence drainage basin, the rivers that drain the Atlantic seaboard, the Hudson Bay drainage basin, the rivers that drain into the Arctic Ocean, and the Rio Grande drainage basin.

- The *Pacific subregion* contains the Pacific drainages from the Yukon river to Mexico, and the interior drainages west of the Rocky Mountains.

b. Oceans

The distribution of marine fish in the world's oceans suggests four major marine regions, two of which are associated with North America:

- The *Western Atlantic Region* includes the *temperate* shores of the Atlantic seaboard, the Gulf of Mexico, the *tropical* shores of the Caribbean Sea, and the tropical and temperate shores of the Atlantic ocean along South America. Most of the 1,200 fish species in this region live in the West Indian coral reefs.

- The *Eastern Pacific Region* is split from the rest of the Pacific Ocean by the expanse of water between the continent and the Pacific islands. The fish diversity is less than that of the Western Atlantic, mainly because this region has fewer coral reefs. Several species in the Eastern Pacific Region are closely related to species in the Western Atlantic

Region, since these two regions were once connected until the Isthmus of Panama formed a barrier around 3 million years ago.

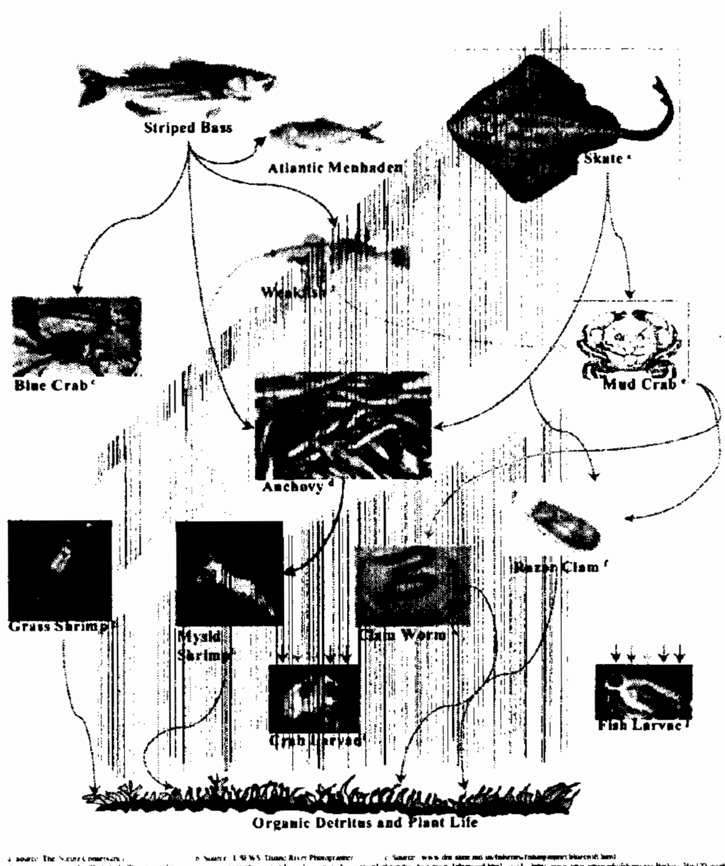
Most fish species live in coral reefs. *Speciation* drops in temperate or polar regions, even though the number of individual fish within a species may be quite high. Many species also have relatively small ranges, resulting in a high degree of *endemism* (i.e., confinement to relatively small geographic areas). Global distribution of marine fish is hampered by physical barriers (e.g., land and mid-ocean barriers). Distribution of freshwater fish is limited by land and salt water barriers.

A2-2.3 Habitat Diversity

Different variables determine where fish can live and reproduce. These variables include dissolved oxygen levels, water temperature, turbidity, salinity, currents, *substrate* type, competition, and predation. Lake-dwelling species may prefer deep, cold, nutrient-poor lakes versus shallow, warmer, nutrient-rich lakes. Species within lakes may seek out open water areas, the shallow or deep *benthic zone*, or in-shore areas. A similar pattern exists in streams and rivers: some fish prefer swifter waters, whereas others seek pools or quiet backwaters. Regional species assemblages differ between the cooler, swifter, and clear headwaters and warmer, slower, more turbid low-land stretches.

Habitat use changes seasonally or throughout the life of a fish: a species may have eggs and larvae that are *pelagic*, juveniles that seek inshore nursery habitat, and adults that live in deep, cool, open water. Some fish are flexible enough to thrive in different habitats: trout, sunfish, minnows, or smallmouth bass are equally successful in lakes and streams, as long as conditions are acceptable. Others, such as sculpins, are more selective, and only tolerate a relatively narrow range of conditions.

Figure A2-1: Simplified Food Web Associated with the Bay Anchovy



A2-3 Influence of Fish on Aquatic Systems

Fish are an intrinsic part of aquatic food webs due to their numbers and functional diversity, and their effects as competitors, predators, and prey. Studies show that fish have direct effects on the structure and function of aquatic ecosystems: their presence causes changes in habitat use, prey population structure, population dynamics, and nutrient flows. Large shifts can occur when fish are removed or eliminated.

A fish's lifecycle starts as a fertilized egg. The egg hatches in days, weeks, or even months, based on the species and on water temperature. Larvae are called sac fry for the first several days or weeks of their life until they consume all their yolk. In their first year, they are called yearlings or age 0+ fish. The term juvenile is more generic and refers to sexually immature fish. The age of first reproduction is species-specific: small, shorter-lived species such as minnows mature in one or two years. Larger or longer-lived species such as sharks, sturgeons, or tarpon can take ten or more years to reproduce.

Each fish plays a role in aquatic food webs based on its size, feeding habits, or habitat needs. The term "*game fish*" refers to species wanted by recreational fishers; these fish have high value in a benefits analysis because they are highly valued by mankind. The term, even though not based on biology, normally refers to fish that are predators near or at the top of aquatic food chains. Examples of game fish include pike, largemouth bass, salmon, bluefish, snook, or tarpon.

The term "*forage fish*" or "prey fish" is vague because all fish in their younger life stages are eaten by bigger fish and other organisms. Forage fish often refers mainly to smaller species that feed on plant material or small animals (*zooplankton*, fish eggs or *sac fry*, small crustaceans, etc.) and are themselves eaten, even as adults. Examples of forage fish include anchovies, rainbow smelt, bluegill sunfish, and numerous minnow species. Their value to humankind in a benefits analysis is less than that of game fish, but their biological value to the ecosystem is even more important, because without them, there wouldn't be any game fish.

Many predators eat fish. Invertebrate predators include diving beetles, dragonfly larvae, jellyfish, sea anemones, squids, cone shells, crabs, and others. Amphibian predators include bullfrogs and other large frog species. Reptilian predators include water snakes, aquatic lizards, turtles, and crocodiles or alligators. Bird predators include albatrosses, auks, cormorants, eagles, egrets, gannets, goldeneye ducks, herons, kingfishers, loons, mergansers, murres, ospreys, pelicans, petrels, penguins, seagulls, skimmers, spoonbills, storks, terns, and many others. Finally, mammal predators include dolphins, seals, sea lions, bears, otters, mink, and raccoons, among others.

This great predatory pressure affects fish distribution. Wading birds, for instance, feed in shallows along weedy edges or quiet backwaters. Small fish measuring less than 1.6 inches (<4cm) are safe there, because they can hide among stems, leaves, rocks, debris, or other structures. In contrast, larger prey fish avoid shallows and seek deeper water out of the reach of wading birds. The deeper water is a relatively safe alternative, because the piscivorous fish that live there are usually *gape limited* (i.e., limited by the size of prey fish they can swallow because their mouths can open only so wide).

A2-3.1 Responses by Different Aquatic Receptors to Fish

❖ *Aquatic plants*

Grazing by fish (and other organisms) affects plants, by altering plant biomass and productivity, changing the species composition of the vegetation, and causing plants to invest energy in growth instead of reproduction to replace parts lost to grazing. Less than 25 percent of fish species in temperate streams are true herbivores, compared with 25 percent to 100 percent in tropical streams. In temperate seas, only 5 to 15 percent of species are herbivores, compared with 30 percent to 50 percent in coral reefs.

❖ *Zooplankton*

Fish predation in lakes, ponds, and reservoirs can affect zooplankton by forcing changes in their daily vertical migrations. During the day, zooplankters hide at depth, on the bottom, or in dense vegetation, to avoid being eaten by fish. The zooplankters rise to the surface at night to feed. These migration patterns become less pronounced when the number of planktivorous fish drops.

❖ *Benthic invertebrates*

Benthic invertebrates live on or in the substrate. The population dynamics and behaviors of the benthos can change in response to fish predators. Studies have shown that these changes are subtler than for the more exposed zooplankton. Aggressive benthic feeders, such as bluegill sunfish in lakes or creek chubs in streams, can depress local populations of benthic invertebrates. More often, the presence of benthic feeders causes behavioral changes in prey to reduce predation. For example:

- insect larvae move from the surface of rocks to less desirable (but more protective) spots underneath the same rocks;
- crayfish — a favorite bass prey — move less and hide over bottom types that match their colors and make them less visible when bass are present;

- the amount of benthic *invertebrate drift* drops when fish predators are present.

A2-3.2 Ecosystems are Complex — Fish Predation and Trophic Cascades

The effects described above show that predators and prey are linked. The next sections show that fish do not live in a biological vacuum, but interact at different levels with other organisms.

a. Trophic cascades and their effects on biological responses

- A *trophic cascade* is a kind of "ripple effect" that occurs when the numbers of organisms at different levels within a food web change as a result of the addition or deletion of predators or prey. For example, fewer zooplanktivores are consumed when top predators are removed, and therefore the number of zooplanktivores rises. In turn, the increased numbers of zooplanktivores deplete populations of zooplankton, reducing predation on phytoplankton and increasing algal blooms. The opposite response can occur if top predators are added (for example, by stocking) or zooplanktivores are removed (for example, by commercial fishing, disease, or I&E).

Such responses have been seen in freshwater systems, as shown by the following experiments:

- A lake contained the trophic cascade of redear sunfish — snails — epiphytes (i.e., algae that grow on submerged plants) - submerged plants. When the sunfish were removed from test plots in the lake, the snail population grew and ate more epiphytes. The absence of epiphytes afforded more light for the plants, which grew better than in areas of the lake where sunfish were present.

- A similar situation occurred in rivers. This trophic cascade included piscivorous fish (large roach and steel head trout) - predators of benthic invertebrates (damselfly nymphs and fish fry) — herbivorous benthos (midges) — filamentous algae. The number of nymphs and fish fry increased when roaches and steel head trout were removed from test plots. The predation rate on midges went up and reduced their population levels. The resulting growth of the filamentous algae was better than that seen in areas where the roaches and trout remained.

b. Trophic Cascades and their effects on physical parameters

Big changes in physical variables can result from the presence or absence of fish predators. Lakes or reservoirs with hard waters and high pH levels can have "whiting events" in the summer. Lake Michigan is such a lake. These events occur when photosynthesis by phytoplankton is very high in the warm surface layers. This activity removes dissolved CO_2, raises the pH of the water even further and causes calcium carbonate ($CaCO_3$) to precipitate (the solubility of $CaCO_3$ goes down as pH goes up) and turns water into a milky, white color. Whiting affects zooplankton feeding, decreases primary productivity, and causes nutrients to sink to the bottom.

In the 1970s, salmonids were stocked in Lake Michigan. By 1983, these fish ate so many zooplanktivorous alewives that predation pressures on zooplankton fell. The lower pressure increased the number of phytoplankton-eating cladocerans and led to more grazing on the phytoplankton. As a result, photosynthetic activity dropped, the rise in pH during the summer was lower than normal, little or no $CaCO_3$ precipitated out of solution, and no whiting event took place in 1983.

The absence of zooplankton-eating fish can affect temperature regimes in small lakes (<20 km^2). Compared to similar lakes with piscivorous fish, such lakes have many zooplankton, which keep the phytoplankton in check. The clarity of the water column increases, light goes deeper, and water temperatures are higher at greater depth. Trophic cascades have been used to control eutrophication in lakes because they can generate strong biological and physical responses. Piscivorous fish are stocked to lower the number of zooplanktivores, enhancing the populations of herbaceous zooplankters who control the algal blooms.

A2-3.3 Effects of Fish on the Cycling and Transport of Nutrients

Fish can affect nutrient cycling. Phosphorus (P) is generally the limiting nutrient for plants in lakes and reservoirs. Fish excrete P as soluble reactive phosphorus (SRP) through their gills or feces. SRP is easily taken up by algae. Studies show that fish excretion is an important source of SRP to lakes and reservoirs and may have direct impacts on primary productivity in those systems.

Fish are found in different trophic levels and feeding groups. They are highly mobile organisms that move nutrients among compartments. In lakes, bottom feeders such as suckers, carp, or catfish stir up sediments while looking for food. Nutrients are resuspended in the water and support algal growth. Some fish species that live in lakes make daily vertical migrations; they transport N and P from the deeper, colder layers to the surface, and release these nutrients through excretion and defecation in areas where most algal growth occurs.

Fish are also major nutrient reservoirs. In certain lakes, up to 90 percent of the P is tied up in bluegill sunfish. This value shows the importance of fish to primary productivity, at least in nutrient-deficient waters: nutrients in fish are released to the water by the gills or feces, or during fish decomposition after death. Studies in a clear, deep lake showed that P released by roaches represented around 30 percent of the P budget of the epilimnion during summer stratification. Fish removal experiments in lakes can also lead to drops in N and P in the water, presumably because the fish increase nutrient levels. Fish biomass loss from emigration, fishing, or other ways (including I&E) can affect nutrient balances, hence primary productivity.

Fish tie different ecosystems together, particularly species that spend part of their lives in freshwater and part at sea. Such fish move large amounts of nutrients when they migrate between habitats. Prolific species, such as menhaden or herring, are prey for larger piscivorous fish in coastal areas and are major sources of nutrients. The gulf menhaden , an abundant species in Gulf estuaries, is a case in point. The fish spawn off-shore in late winter. Their larvae enter estuaries to feed. Juveniles grow by a factor of 80 over a nine-month period; they return to the Gulf in late fall to mature. Each year, an estimated 5 to 10 percent of the primary productivity in the salt marshes and estuaries is exported into the Gulf in the form of menhaden. Up to 50 percent of the total N and P lost annually from these habitats does so in the form of migrating menhaden. The loss in one habitat is a gain for another, because menhaden are a major source of prey. The carbon in these fish represents 25 to 50 percent of off-shore production in the Gulf. Other fish species with similar lifecycles all along our coastal habitats help move energy, nutrients, and carbon across aquatic ecosystems.

In conclusion, the links and feedback loops in aquatic food webs make it difficult to predict what effects could result from the loss of fish from such systems. The examples above remind us that every action leads to a reaction, some of which are unpredictable but can have large effects. Thus, losses of impinged and entrained organisms from the local population can have cascading effects throughout the food web.

A2-4 Exterior Fish Anatomy

Most people can recognize a fish. Its external shape, the structure and position of its mouth, the location of fins, or the presence of spines are a few of the characteristics that vary among species. The long evolutionary history of fish has led to many changes that help fish use all aquatic environment habitats. Some basic patterns are present in the exterior anatomy of most fish species. These are discussed below.

The external shape of a fish reflects its lifestyle and habitat use. For example, the lifestyles of tuna and flounders have changed the "typical" fish body shape. Tuna migrate and hunt throughout the world's oceans. They have streamlined bodies with strong muscles and a specially-shaped tail to swim fast and catch prey. The largest members of this group, such as the bluefin tuna, are even partially warm-blooded to raise their endurance and speed. Flounders, on the other hand, are flat and move less: they spend much time on the ocean floor buried in the sand. They catch molluscs, worms, or fish that swim by.

Figure A2-2: Exterior Fish Anatomy

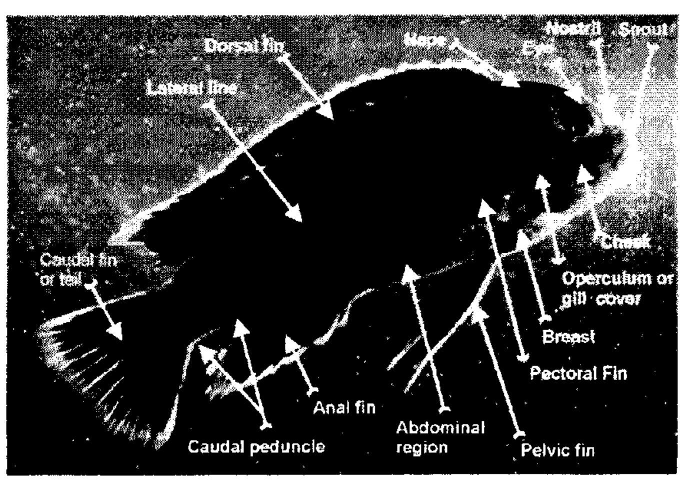


Figure A2-2 details a fish's exterior anatomy and the rest of Section A2-4 describes the major elements of exterior fish anatomy. Green underlined words refer back to the corresponding figure. The section focuses on those elements that may be important to impingement or entrainment. A basic knowledge of scales, for example, may help in understanding survival in fish that have lost their scales from I&E.

A2-4.1 Fish Shapes

The "typical" fish is long and cigar-like. Six general body shapes have developed around this basic design depending on the species' lifestyle and habitat preferences:

- **Rover-predators** are streamlined, with well-spaced fins along the body to provide stability and maneuverability. These fish are always mobile looking for prey. Examples include bluefin tuna and *pelagic* sharks.
- **Lie-in-wait predators** have long bodies, flattened heads, and large mouths. Their *dorsal fins* and *anal fins* are located far back on the body and their *caudal fin* is large. The size and place of most of their fins provide quick, forward thrust needed to catch prey. Their colors and secretive behavior make them blend into their surroundings. These fish lie in ambush and capture prey by quick-burst swimming. A typical example of a lie-in-wait predator is the pike.
- **Surface-oriented fish** are smaller, with an upward-pointing mouth, a flattened head, large eyes, and a dorsal fin located toward the tail. Their shape lets them capture small prey living below the water surface. Examples of surface-oriented fish include mosquito fish and brook silversides.
- **Bottom-dwelling fish** generally have a small or nonexistent *air (e.g. swim) bladder*. They spend much time foraging or resting on the bottom. Examples are rays and skates, which are flattened dorso-ventrally; and flounders, which lie on their sides.
- **Deep-bodied fish** are usually flattened sideways, with a body depth measuring at least one-third of their length. Their dorsal and anal fins are long and the *pectoral fins* are placed high on the body, directly above the *pelvic fins*. Deep-bodied fish tend to have a *protrusible* mouth, large eyes, and a short snout. Many have spines that increase their ability to escape predators, but at the expense of speed. Sunfish are examples of deep-bodied fish.
- **Eel-like fish** have long bodies, blunt or wedge-shaped heads, and tapered or rounded tails. Their pelvic fins are small or missing. Such fish are well adapted to entering small crevices and holes in reefs or rock formations. Examples include the American eel and the murray eel.

A2-4.2 Skin and Scales

Skin covers the entire body of a fish. It protects against micro-organisms and helps regulate water and salt balances. It also has the pigment cells that give fish their colors. The outer skin layer is the *epidermis*: it is thin and lacks blood vessels but is replaced as it wears off. The *dermis* is the inner, thicker layer, from which the scales grow. Much mucus is released by mucus glands in the dermis. Mucus covers the fish with a protective layer: it cleans body surfaces, prevents the entry of pathogens, helps regulate salt balances, and reduces friction.

Most fish are covered with scales. Some fish are scaleless, others are partially covered. Differences may be big even in closely-related species: the leather carp is scale-less, the mirror carp is partly covered with scales, and the common carp is fully covered with scales. Scale-less species generally have a tough, leathery skin to compensate.

Scales are thin, calcified plates that grow out of the dermis and protect the skin. They usually overlap like roof shingles and are known as *imbricate scales*. Another type of scale, *mosaic scales*, fit closely together like a mosaic but do not overlap; adjacent scales may touch, or they may be separated by a small space. The scale structure also varies by fish group: sharks, skates, and rays are covered with *placoid scales* (or *dermal denticles*), which give these fish the rough feel of sandpaper. Higher, bony fish, such as sunfish or minnows, are covered by smoother *leptoid scales*. Scale and mucus loss make fish more vulnerable to infections.

Scales are colorless; color comes from cells called *chromatophores* found in the dermis. Some of these cells contain pigments that produce the bright colors seen in fish. Others create various color hues (such as the typical "metallic" coloration in some fish species) by scattering or reflecting light.

Mechanical injuries from impingement and entrainment can abrade the epidermis, dermis and scales, removing them. This causes increased susceptibility to infection and osmotic stress. Freshwater fish will suffer from excessive water uptake, while saltwater fish will lose water (Rottmann et al., 1992). Abrasion can also cause a reduction in the lethal shear threshold of a fish, creating a greater susceptibility to injury or mortality from the shear forces created by spatial differences in the velocity of moving water ([22024]).

A2-4.3 Fins

Swimming is a challenge because water is not a solid material, but flows upon impact. Deep-bodied fish tend to fall over on their side, because the water provides no support. The body of a fish also shifts sideways as it swims. Fish have developed several strategies, including fins, to lend stability and maneuverability for swimming more efficiently through the water. Fins are bony or *cartilaginous rays* projecting from the fish's body, and which are connected by a thin membrane. Some of those rays are articulated and are called *soft rays*. Others are stiff and are known as *spines*. Many fish incorporate soft rays and spines in their fins to provide flexibility and protection. Some species also have poison glands attached to the base of hollow spines to protect against predators.

Fins have many roles: they are used to swim and maneuver but also serve as rudders, balancers, defensive weapons, feelers, sexual structures, sucking disks, and prey or mate attractors. They have many shapes, colors, and lengths, and are found in different locations on the body. Fins come in two varieties: *paired fins* and *vertical* (or *median*) *fins*.

a. Paired fins

Paired fins include the *pectoral fins* and *pelvic fins*, which are *ventral fins* found at the bottom of the body (compared to dorsal fins, found on top of the body). Pectoral and pelvic fins resemble the four limbs of the higher vertebrates: the pectoral fins are the forelimbs and are attached to the shoulders; the pelvic fins represent the hind limbs. Neither fin type plays a major role in locomotion; they prevent the body from pitching and rolling and to help to brake forward motion.

❖ *Pectoral fins*

Pectoral fins are located behind the gill openings. They provide maneuverability, but also balance the body at low swimming speeds. Pectorals can have different shapes and functions: flying fish have large pectoral fins to help them soar in the air; mudskippers have modified pectoral fins for crawling on land; and sea robins use the three front rays of their pectoral fins as feelers.

❖ *Pelvic fins*

Pelvic fins are located on the underside of the body but vary in their placement: they may be found in front of the pectorals (e.g., in cods, pollock, or winter flounder), below the pectorals (e.g., in largemouth bass, Atlantic croakers, or darter goby), or in the middle of the body (e.g., in salmon, American shad, herring, or striped mullet). The pelvic fin is used to stop, hover, maneuver, and balance. Pelvic fins can become specialized. Some species have fused pelvic fins, which form a suction disk for clinging to rocks and coral. In male sharks, the pelvic fins form claspers, which serve as sperm cell conduits.

Either one of these fin types may be absent in fish. Eels lack pelvic fins but have fused dorsal, caudal, and anal fins (see discussion below). Lampreys lack pectoral fins. Generally, however, pelvic fins are much more likely than pectoral fins to be absent.

b. Vertical fins

Vertical fins are found along the centerline of the body, at the top, bottom, and back of a fish. *Dorsal fins*, *anal fins*, and *caudal fins* are vertical fins found on most fish. Their roles include locomotion, protection, and balance.

❖ *Dorsal fins*

Dorsal fins are found on top of the body and consist of one or two (and rarely three) separate fins. They help prevent the fish from turning over in the water. Many species incorporate stiff spines in their dorsals to protect against predators. The dorsal fin may be followed by the adipose fin, a fleshy outgrowth with no rays, typically found in salmonids and catfish. Mackerel-like fish have small, detached finlets consisting of a single ray behind their dorsal (and anal) fins. Other species have highly modified dorsal fins: remoras have a sucker disk used for attaching to sharks, sea turtles, and other large marine animals. Angler fish have a modified dorsal fin ray that bears a fleshy, moving lure used for attracting prey.

- *Anal fin*

The anal fin is found on the belly of the fish behind the vent, or anus. It is usually a single fin (rarely two) used in balance. Many species include stiff, sharp spines to protect against predators. The anal fin is absent in rays and skates, which move about and feed close to the bottom. (Contrary to rays and skates, which have a depressed body shape, flatfish actually lie on their sides and have normal anal fins.) Anal fins also serve other purposes; in male mosquitofish, the anterior rays of the anal fin have joined into a single structure used to transfer sperm to the female.

- *Caudal fin*

The caudal fin is at the back of the fish and serves mainly to aid in locomotion. Swimming behavior shapes the caudal fin. Some rover-predators, such as tuna and marlin, have a stiff, quartermoon-shaped forked tail attached to a narrow *caudal peduncle*. The deeper the fork, the more active the fish. Deep-bodied fish and most surface- and bottom-oriented fish have rounded, square, or only slightly-forked tails. A few fish, such as sea horses, lack a caudal fin.

A2-4.4 Mouth and Dentition

The shape, size, and position of the mouth and teeth reflect the fish's habitat and diet. The mouths of bottom-feeding fish, such as carps, suckers, or catfish, generally point downward. In extreme cases, the mouth is tucked underneath the fish, as in rays, skates, and sturgeons. The mouth of surface-oriented fish, such as killifish, mosquitofish, and Atlantic silversides, points upwards. Most fish, however, have a *terminal mouth*. Mouths can become highly specialized, with shapes ranging from long, tube-like, probing structures to large, parrot-like beaks.

Fish do not chew their food; their teeth grab and hold prey until it can be crushed, torn apart, or positioned to be swallowed. Predators, such as sharks, barracudas, and piranhas, have rows of highly-developed teeth. Most species have teeth that look alike and are packed along the inner rim of the lower and upper jaw. Teeth typically point inward to prevent prey from fleeing after capture. Some predators, including pikes and pickerels, also have teeth on their tongues, gill arches, throats, and the roofs of their mouths. Fish that strain the water for plankton or eat plants have few well-developed teeth. Species that crush coral or clams have fused teeth in the form of a cutting edge, crushing plates, or broad, blunt teeth arranged like cobblestones. These species include parrot fish or skates and rays. The number of teeth in fish varies greatly and ranges from 0 to more than 10,000.

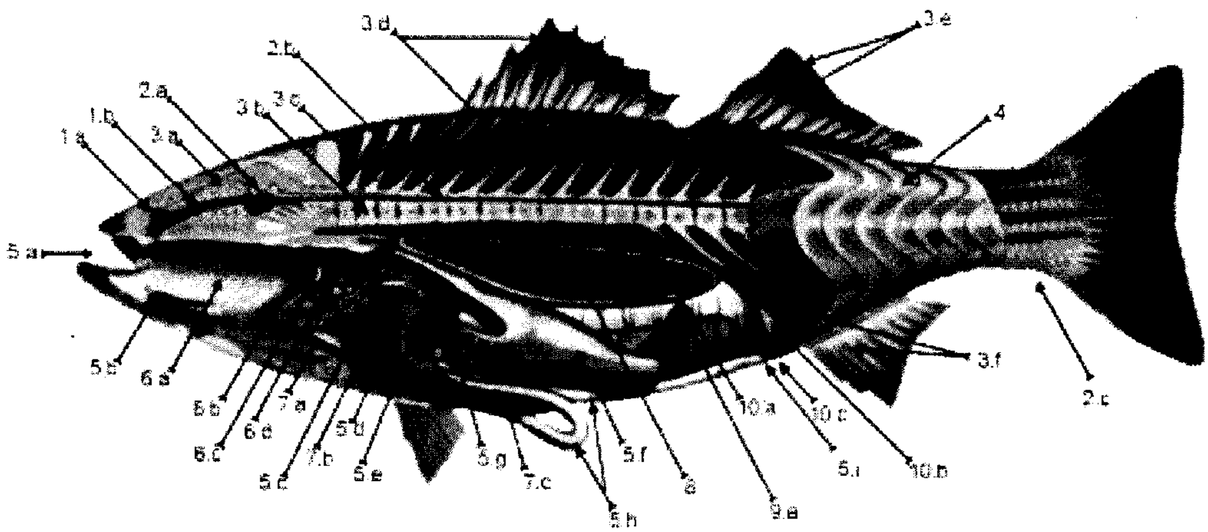
A2-5 Interior Anatomy

Section A2-5 discusses various components of the interior anatomy of a fish. Terms in this section that are green and underlined are glossary terms that also refer to Figure A2-3 which diagrams many of the internal organs of the striped bass.

The internal anatomy of fish varies less than their external anatomy. All vertebrates share many structures, such as a central nervous system or an internal skeleton. Other structures are unique to fish (e.g., *air or swim bladders* (Figure A2-3) for *buoyancy* control and internal gills for gas exchange and salt regulation). This section outlines basic features of the internal anatomy of fish. Rather than in-depth review , this section provides a basic understanding of the structure and function of the major organ systems in fish.

This knowledge is important because the systems discussed here may play a role during impingement or entrainment. For example, (1) impinged fish may suffocate if they cannot pass water over their gills due to high water pressures; (2) anadromous fish adjusting to different salt levels in the water during migrations may be more vulnerable than resident species to the stresses of impingement; and (3) the air or swim bladder of larval fish may be damaged when they undergo rapid pressure changes within the cooling system.

Figure A2-3: Interior Fish Anatomy



Source: EPA, based on a drawing by Jack J. Kunz, National Geographic Society, 1969

1. Olfactory System
   - 1.a Nasal Capsule
   - 1.b Olfactory Nerve
2. Nervous System
   - 2.a Brain
   - 2.b Spinal Column
   - 2.c Lateral Line
3. Skeletal System
   - 3.a Cranium/Skull
   - 3.b Vertebra/Backbone
   - 3.c Neural Spines
   - 3.d 1st Dorsal Fin Spines & Pterygiophore
   - 3.e 2nd Dorsal Fin Spines & Pterygiophore
   - 3.f Anal Fin Spines and Support
4. Muscle Segment (myomere)
5. Digestive System
   - 5.a Mouth
   - 5.b Tongue
   - 5.c Esophagus
   - 5.d Liver
   - 5.e Gall Bladder
   - 5.f Stomach
   - 5.g Pyloric Caeca
   - 5.h Intestines
   - 5.i Anus
6. Respiratory System
   - 6.a Buccal Cavity
   - 6.b Gill Rakers
   - 6.c Gill Arches
   - 6.d Branchial Cavity
7. Circulatory / Cardiovascular System
   - 7.a Ventral Aorta
   - 7.b Heart
   - 7.c Spleen
8. Air Bladder
9. Reproductive System
   - 9.a Ovary
10. Excretory System
    - 10.a Kidney
    - 10.b Bladder
    - 10.c Urinary Duct/Urogenital Opening

A2-5.1 Skeletal System

The internal skeleton holds together and protects the soft, internal organs, helps maintain the proper body shape, and serves as an attachment or leverage point for *striated* (i.e., skeletal) *muscles*.

a. Types of skeletons

Fish belong to three broad groups, based on skeletal differences:

❖ *Agnathans*

Agnathans, the jawless fish, are the most primitive of all fish. Most species became extinct 350 million years ago, except for the eel-like hagfish and lampreys. Hagfish live in the ocean and scavenge dead fish or other vertebrates. Lampreys live both in marine and freshwater environments; some species parasitize other fish. Agnathans lack jaws; they also lack a true vertebral column, ribs, scales, paired appendages, and other skeletal features typically found in more modern fish. Instead of true hollow *vertebrae* (Figure A2-3), hagfish and lampreys have a flexible *notochord*, a long, cartilaginous rod that acts like a primitive backbone.

❖ *Chondrichthyes*

Chondrichthyes, the *cartilaginous* fish, include sharks, rays, skates, and the less familiar but striking Chimaeras. These fish do not have true bone; instead, their skeletons are made of cartilage combining hardness and elasticity. Unlike bone, cartilage usually does not mineralize (there are exceptions), but instead consists of a flexible matrix made of fibers meshed in a protein-like material. Typical Chondrichthyes are also distinct from bony fish for other reasons, including: (1) lack of a air/swim bladder; (2) presence of a solid braincase instead of one with many pieces of bone; (3) individual external gill openings instead of a single combined opening; (4) primitive fin structure; and (5) tooth-like scales.

❖ *Osteichthyes*

Osteichthyes, the bony fish, include all other living fish species. The Osteichthyes have a bony skeleton; notable exceptions include primitive bony fish, such as sturgeons or paddlefish, which have only partly *ossified* skeletons. Bony fish have gills in a common chamber covered by a movable bony *operculum* (see Figure A2-2), and fins supported by bony rays radiating from the fin base. They usually have a gas bladder to provide buoyancy. The *teleosts* are the most successful bony fish; most aquarium, commercial, and recreational species belong to this group. Teleosts comprise more than 30,000 species and subspecies.

b. Major components

The major components of the internal skeleton in modern fish include the following:

- The **backbone** replaces the notochord of the jawless fish and consists of interlocking hollow vertebrae that run from the back of the *skull* (Figure A2-3) to the tail. The *spinal cord* (Figure A2-3), which starts in the brain and runs through the backbone, is also protected by it. The number of vertebrae range from 16 to more than 400, depending on the fish species. Each vertebra has an upward-projecting spine called the *neural spine* (Figure A2-3). The vertebrae found behind the abdominal cavity may also have one or more downward-pointing spines (the *haemal spines*).

- The **skull** is a complex structure in the head region. Its major part is the *cranium* (Figure A2-3), or braincase, which protects the brain and several sense organs. The skull is also an attachment point for the lower jaw, the backbone, and the shoulder and *pelvic girdles*. In sharks and related fish, the skull does not have sutures. The skull of bony fish consists of many fused bones.

- The **ribs** or *spines* (Figure A2-3) are loosely attached to the vertebrae and surround the fish's abdominal cavity. They are small projections in cartilaginous fish, but are fairly well-developed in bony fish. Unlike in terrestrial vertebrates, fish ribs play no part in breathing. They instead transmit muscle contractions during swimming and frame the body. Fish also lack a breastbone to create a rigid rib cage.

- The *fin spines* (Figure A2-3) are spine-like bones not directly connected to the rest of the skeleton. They anchor both dorsal and ventral fins into the muscles through connecting structure called *pterygiophores* that reach toward or may intertwine with both the neural and haemal spines of the vertebrae.

A2-5.2 Muscle System

Muscles comprise one-third to one-half of the mass of an average fish. The activity of the nervous system has little consequence except through its action on muscles, which are used both to swim and to aid digestion, nutrition, secretion, and circulation. Muscles exert their force by contracting. If a muscle is attached to different places on the skeleton, the contraction creates a pull, resulting in movement. Two major types of vertebrate muscle tissue exist:

- **Smooth muscle**, the simpler of the two, is under involuntary control. It is found in the lining of the digestive tract, where it provides the slow contractions needed to advance food. It is also found in the ducts of glands connected to the gut and the bladder, as well as in blood vessels, genital organs, and other locations (the heart consists of highly modified smooth muscle). Although it plays a major role in the well-being of fish, smooth muscle is not involved in swimming.

- *Striated muscle* (Figure A2-3), forming the "flesh" of the fish, is under rapid, voluntary control. These muscles are large, well-formed structures; their main role is in swimming. Striated muscles are also used to move eyes, jaws, fins, and gill covers.

The biggest muscle mass in fish is the *axial musculature*, which runs from head to tail on both sides of the body. It is arranged in repeating, W-shaped, overlapping segments called *myomeres*. A tough membrane connects each myomere to its neighbor. An additional membrane, called the *horizontal septum*, divides the myomeres into a dorsal and ventral half.

The fish creates a wave along its flanks by contracting opposite *muscle segments* (Figure A2-3). The wave gains speed as it travels backwards and causes the tail to thrust against the resistance of the water, thereby moving the fish forward. There is little specialization in the axial musculature. One exception are the muscles used for moving the pectoral and pelvic fins. Each fin has two opposing muscles: one extends the fin, the other depresses it.

A2-5.3 Major Sense Organs

The sense organs in fish have many uses, including orienting the animals and detecting electrical, mechanical, chemical, thermal, and electromagnetic signals from their surroundings. The nervous system is split into two main parts: the *central nervous system* (CNS) and the *peripheral nervous system* (PNS). The CNS includes the brain and spinal cord. The PNS consists of paired nerves that run outward from the CNS and connect to other areas in the body. One function of the nervous system is to tie *receptor cells*, such as the eyes or lateral line, to *effector cells*, such as the skeletal muscles. Receptor cells detect outside signals; effector cells create a response. Another part, the *visceral nervous system*, serves the gut, circulatory system, glands, and other internal organs.

This section discusses the structure and function of the organs tied to olfaction, taste, equilibrium/hearing, vision, and the lateral line.

a. Olfaction

Many fish have a keen sense of smell. Certain shark species can detect the odor of blood over great distances in the ocean. The *olfactory epithelium* is found at the bottom of specialized holes called *nasal pits* located in the snout. Unlike the noses of terrestrial vertebrates, the pits do not open into the *buccal cavity* (Figure A2-3). Each *olfactory cell* connects to the *olfactory bulb* of the brain via nerves. The olfactory cells project rod-like extensions into the nasal pit. These extensions detect the odor molecules. Little is known about the exact processes that generate the sense of smell in fish.

b. Taste

The taste cells are grouped in clusters called *taste buds*. Each cluster has 30 to 40 taste cells connected to nerve fibers. Taste buds are usually found in small depressions. Each sensory cell has a hair-like projection, which may extend to the surface of the epithelium via the *taste pore* and detect taste. Fish can detect sourness, saltiness, bitterness, and/or sweetness.

All fish do not experience taste in the same way. Most have taste buds in their *mouth* and *pharynx*, and can therefore taste to one degree or another. Some, like the bullhead catfish, also have tastebuds over their entire body surface. Others, such as sturgeons and carp, have taste buds on oral feelers to facilitate finding food in mud or murky waters. Still others have taste buds covering their heads.

c. Equilibrium and hearing

Fish do not have the features of hearing found in terrestrial vertebrates (i.e., ear lobes, ear canals, ear drums, ear ossicles). The basic ear structure in fish and all higher vertebrates is the *inner ear*, a paired sensory organ found in the skull. This structure originally evolved as an organ of equilibrium and is still used as such by all terrestrial and aquatic vertebrates. The ability to hear evolved later.

The inner ear in fish consists of sacs and canals that form a closed system containing a liquid called an *endolymph*. Some of the internal surfaces of the sacs and canals are lined by a tissue called the *macula*. The sensory cells that make up the macula resemble the neuromasts found in the lateral line system discussed below. These cells connect to auditory nerves in the brain. Calcium carbonate crystals are deposited on top of the macula and combine to form ear stones called *otoliths*. Depending on the tilt of the head, the acceleration, or the rate of turning, the otoliths contact the sensory cells in different ways, causing specific patterns of nerve firings. The CNS interprets these signals and provides data to the fish on its orientation and movement through space.

The inner ear also captures sound waves. Sound waves carry farther in water than in air and are therefore a source of information to fish. Whereas cartilaginous fish (e.g., sharks, ray, skates) respond only to very low vibrations, most bony fish hear a range of sounds. Fish do not have external hearing structures; sound is believed to pass through the skull into the inner ear. The vibrations cause the otoliths to shake, generating the effect of hearing.

Sound must generate head vibrations for fish to hear. Some fish have "hearing aids" to better capture sounds. These aids rely on the gas in air/swim bladders to amplify the vibrations of sound in water. The swim bladder in herrings has an extension that reaches forward and carries vibrations directly to the inner ear. Catfish and carp use a different method: bony processes of the anterior vertebrae form a chain called the *Weberian ossicles*, which connect the swim bladder to the head region. These modifications show the importance of sound to fish.

d. Vision

The basic anatomy of fish eyes resembles that of other vertebrates. The *cornea* is the outermost layer, through which light enters the eyeball. The cornea is followed by a *lens*, which serves to bend and focus the light rays on the *retina* in the back of the eye. Muscles attached to the lens allow fish to focus on nearby or far away objects. *Ocular fluid* fills the interior of the eye and the space between the cornea and lens. Fish have evolved a *tapetum* to let the eye catch more light. This is a highly reflective tissue that mirrors the light back onto the eye. Unlike terrestrial vertebrates, fish lack a pupil to control the intensity of the incoming light.

The retina in fish is composed of *rods* and *cones*, which are light-gathering cells containing *visual pigments*. Rods have more pigments than cones and are more sensitive to dim light. Cones work only at higher light levels and are usually missing in fish that live in low-light habitats, such as the deep sea. Different pigments have distinct molecular structures and are sensitive to specific wavelengths. When light hits visual pigments, a chemical reaction is started that results in nerve impulses. These are carried by the *optic nerve* to the brain for processing.

Fish have adapted to deal with the unique optics of water and the different light conditions that exist in aquatic environments.

❖ *Refraction*

Refraction refers to the bending of light as it passes from one medium to another, such as from air to water or from water to tissue. The cornea and ocular fluids of fish do not refract light. Fish lenses are good at bending light, and make images free of aberrations or distortions by changing the refractive properties of the tissues within the lens. Light passing through the lens follows curved paths to form sharp images on the retina.

This arrangement is a problem when fish need to focus on nearby or far away objects. Mammals focus by changing the curvature of the lens. Fish cannot do that. Most fish move the lens toward or away from the retina along the optical axis. As a general rule, freshwater species accommodate less than do marine species; useful vision is more limited in the more turbid waters of lakes and rivers, compared to ocean water.

❖ *Light absorption*

Water's light absorption properties change with depth. Longer wavelengths (reds and greens) are quickly removed at the surface; only shorter wavelengths (blues) go farther down. Deep water fish have visual pigments sensitive to blue light. A change in spectral quality with depth affects fish that move between the seas and inland waters. Adult salmon in the ocean, for example, have rod pigments that best absorb in blue end of the spectrum. As the fish migrate into shallower freshwater, their pigments are gradually replaced by new ones that are more sensitive to the redder end of the spectrum.

❖ *Color vision*

Fish can see colors if they live in relatively shallow or clear water. Consequently, numerous tropical fish species display brilliant colors.

e. Lateral line

Most fish have a "*lateral line*"(Figure A2-3) running along their flanks from head to tail. The lateral line provides spatial and temporal information. It is so sensitive that blinded fish can locate fish or other nearby objects. A fish can also feel the motion of its own body relative to the surrounding water: as it approaches an object, the pressure waves around the fish's body are slightly distorted. The lateral line detects these changes and enables the fish to swerve. Low frequency sound waves generate pressure waves in the water column, which are also detected by the lateral line.

The lateral line can be single, double, or forked, consisting of thousands of tiny sensory organs that lie on the skin surface within small pits. These sensory organs connect to the brain. At the bottom of each pit is a *neuromast*, a small structure that detects vibrations and water movement around the fish. The neuromast consists of sensory hairs enclosed in a gel-filled capsule that protrudes into the water. The neuromasts send out electrical impulses to the brain. The enclosed sensory hairs bend when a pressure wave distorts the gelatinous caps. This movement either increases or decreases the frequency of nerve impulses depending on the bending. It is this change in frequency which is sensed by the fish.

A2-5.4 Circulatory System

The circulatory system transports and distributes various substances including oxygen, nutrients, salts, hormones, or vitamins to cells throughout the body; and removes waste products such as carbon dioxide, nitrogenous wastes, excess salt, or metabolic water. The circulatory system also maintains proper physiological conditions within the body, fights diseases, heals wounds, and serves as an accessory to the nervous system through the *endocrine* (i.e., hormone) *system*.

The major parts of the circulatory system are the *blood* and the *circulatory vessels*.

a. Blood

Blood fills the circulatory system vessels. Blood's liquid "matrix," called *blood plasma*, contains several cell types:

- *Red blood cells* are packed with *hemoglobin*, which contains iron atoms to carry oxygen to the cells and carbon dioxide away from the cells.

- *White blood cells* fight infections and other diseases.

- *Thrombocytes* help the blood to clot.

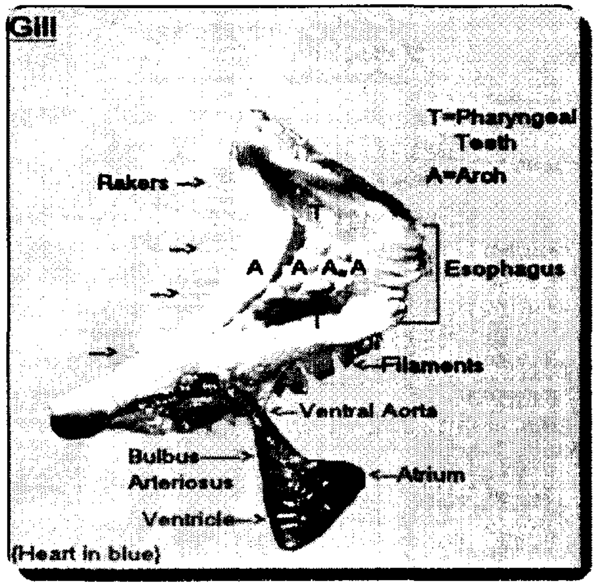
The life span of blood cells ranges from hours to months, depending on cell type. The body must therefore make new cells to replace old ones. Blood-forming tissue in fish is found in one or more of the: *spleen* (Figure A2-2), *kidneys* (Figure A2-3), *gonads* (sex organs), *liver* (Figure A2-3), and *heart* (Figure A2-3 and Figure A2-4). Bone marrow does not form blood cells in fish.

b. Circulatory vessels

The circulatory system includes the heart, *arteries* and *veins*, *capillaries*, and the *lymphatics*.

The heart of a typical fish, a modified tube with four sequential chambers, is found close to the gills. Oxygen-poor blood enters the *sinus venosus*, and is pumped through the *atrium* and *ventricle* into the *bulbus* (Figure A2-3) or *conus* arteriosus. From there, it is pumped out of the heart, into the *ventral aorta*. The ventricle does most of the pumping. One-way valves prevent blood from flowing backward. The ventral aorta runs toward the gills and branches into parallel *aortic arches* that run through each gill. After the blood is re-oxygenated, the blood vessels rejoin into one large *dorsal aorta*, which carries the blood to the organs.

Figure A2-4: Gill and Heart Anatomy



Arteries carry higher-pressure, oxygen-rich blood. When they reach their target organs, the arteries split into smaller branches called *arterioles*. These enter the organ and continue to divide until they become so narrow that red blood cells can pass through them only single-file. At this point, the blood vessels are called *capillaries*. The microscopic capillaries are the most important part of the circulatory system. Whereas blood is simply carried through the arteries and veins, blood in the capillaries releases oxygen and nourishment to the cells and picks up carbon dioxide and other wastes. The capillaries rejoin and form larger *venules*. The venules merge into *veins*, which carry the oxygen-poor blood out of the organs and back to the heart. The venous system is at a lower pressure than the arterial system because pressure is lost as blood passes through the capillaries.

Bony fish also have a lymphatic system, a network of vessels running parallel to the venous system, returning excess fluids from the tissues to the heart. The lymphatics are not connected to the arterial blood supply, but instead arise from their own dead-end capillaries within the tissues. The excess fluid is captured as *lymph* and returned to the venous system.

A2-5.5 Respiratory System

Fish are *aerobic*, i.e., they must breathe oxygen. Most fish obtain their oxygen from the water. Extracting oxygen from water is difficult because (1) water is a thousand times denser and 50 times more viscous (at 68 °F [20 °C]) than air; (2) when saturated, water contains only 3 percent of the oxygen found in an equal volume of air; and (3) oxygen solubility in water decreases with increasing temperature. Fish expend much energy moving water over their gills; they have evolved efficient gills to maximize oxygen uptake while minimizing the cost of breathing.

a. Basic gill anatomy

Gills are similar among groups of fish. The paired gills are internal and located in the *pharyngeal region*, specifically the *branchial cavity*. They are supported by flexible rods called *gill bars*. The number of gill bars ranges from four to six. On the side facing the pharynx, the gill bars carry stiff strainers called *gill rakers* (Figure A2-3 and Figure A2-4). Though not used in breathing, some species use gill rakers to strain out food particles. A typical gill bar has two large *gill filaments* (Figure A2-3 and Figure A2-4), which point outward (i.e., away from the pharynx and into the branchial cavity). Each gill filament supports many *gill lamellae*, where the gases are exchanged.

An average of 20 lamellae are found on each mm of gill filament. Lamellae are covered by tissue one cell layer thick to optimize gas exchange. Those of adjacent gill filaments usually touch or mesh together, which favors contact between the gills and water. The gill surface area varies by a factor of 10 (on a per weight basis) and depends on the animal's activity. Active swimmers like white shark or tuna have larger gill surface areas than do sedentary fish like sunfish or carp. A fish such as a 44-pound sea bass has a respiratory surface of about 60 ft^2.

b. Gas exchange

When the fish opens its mouth to breathe, the branchial cavity is closed by a stiff *operculum* (in bony fish) or a series of flap-like *gill septa* (in cartilaginous fish) to prevent oxygen-depleted water from re-entering the branchial cavity. The operculum and septa also help keep a negative pressure in the buccal cavity when the mouth opens, forcing water to rush in. As the fish closes its mouth, the buccal cavity becomes smaller and water is forced backward over the gills.

Breathing water has drawbacks, partly due to its low oxygen content. Gills increase oxygen uptake using a *countercurrent exchange* mechanism. The gill lamellae face the incoming water, which always moves from the buccal cavity to the branchial cavity. Blood flows through the lamellae in the opposite direction. When blood first enters the lamellae, it encounters water low in oxygen (the "upstream" gill lamellae have already removed some oxygen). The blood entering the lamellae contains even less oxygen. This difference lets the small amount of oxygen still present in the water move into the blood. The oxygen content of blood flowing into the incoming water goes up, but so does that of the ever "fresher" water. A nonstop oxygen flow in favor of the blood all along the lamellae results. Oxygen keeps moving into the bloodstream until the blood leaves the lamella. Through this process, fish remove up to 80 percent of the oxygen from the water. Carbon dioxide moves in the opposite direction based on the same principle.

c. Other gill functions

The central role of gills is to take up oxygen and release carbon dioxide. Gills also have other functions due to their large surface area and close contact with water.

❖ *Osmoregulation*

Gills, together with kidneys, are used in *osmoregulation*: the control of salt and water balances. The internal fluids of freshwater fish are "saltier" than the surrounding water. When blood moves through the gills, salt diffuses from the blood into the water, whereas water tends to move into the body. The kidneys release the extra water as dilute urine to keep a proper internal water balance. Freshwater fish also drink little or no water. Any salt loss is made up by *chloride cells* located in gill filaments and lamellae. These cells move salts from the water into the blood to make up for the loss. Mucus covers the gills, which protects them from injuries but helps in osmoregulation.

This situation reverses in marine bony fish: their internal fluids are less "salty" than their surroundings: water in the blood moves out of the body, but salts move in. These fish drink freely to make up for water loss. Drinking sea water brings salts into the body; these salts are excreted by both the gill chloride cells and the kidneys.

✣ Osmoregulation is a vital physiological need for fish and other aquatic organisms. This is particularly true for anadromous fish, which move from the ocean into freshwater habitats to spawn, and whose offspring migrate back into the ocean to mature. These species undergo profound physiological changes over relatively short periods of time to adapt to and survive in drastically different osmotic environments. Some species may be less able to survive physical shock or extreme stress during this transitional period, and could therefore be more susceptible to mortality from impingement.

Cartilaginous fish (and some primitive bony fish) also live in salt water but maintain their water balance differently. These fish keep high levels of urea in their blood, which causes their internal fluids to be saltier than seawater. Some water enters the gills, and the kidneys produce moderate amounts of urine. These fish need little or no additional water and drink infrequently.

❖ *Heat exchange*

Most fish are cold-blooded: their body temperature equals that of the water. Internal heat created by muscle activity is lost to the environment when the fish's blood passes through the gills to extract oxygen-from water. Pelagic fish, such as certain tuna and sharks, are exceptions. These fish have countercurrent heat exchangers in their muscles to keep much of the heat inside and prevent it from being lost through the gills. Their body temperatures can be up to 20-25 °F (-6.7 to -3.9°C) higher than that of the surrounding water.

❖ *Excretion*
Freshwater and marine bony fish release their nitrogenous wastes through their gills. Blood moves the waste, in the form of *urea*, to the gills. There, urea changes into toxic ammonia, which quickly diffuses into the water. Cartilaginous fish (i.e., Chondrichthyes) keep high levels of urea in their blood and lose very little of it through their gills to help in osmoregulation.

❖ *Predation*
Gills have evolved to catch prey in plankton feeders, which swim with their mouths open. These fish have numerous, fine, and long gill rakers that strain plankton. Examples include the paddlefish (*Polyodon spathula*), the gizzard shad, and the Atlantic herring (*Clupea harengus*).

A2-5.6 Air/Swim Bladder

Buoyancy is the tendency of an object to float or rise in water, and depends on the object's density versus that of water. An aquatic organism with a density like water is weightless, neither rising or sinking. Less effort is needed to keep it from sinking or to move about. Most fish regulate their density to reach neutral buoyancy.

a. Strategies to increase buoyancy

Fat is less dense than water. One way to reduce body density, and increase buoyancy, is to increase body fat. About one-third of a fish's body weight needs to be fat to make the fish weightless in seawater. Several shark species increase buoyancy in this manner: they have huge livers full of *squalene*, a fatty substance that provides buoyancy, being much less dense than seawater. Buoyancy is also attained by storing gases within the body. Many bony fish have an air/swim bladder for this purpose.

The amount of body volume that must be in the form of gas to achieve "weightlessness" depends on the saltiness of the water. Freshwater contains less salt than seawater; it is therefore less dense and provides less buoyancy. Swim bladders in freshwater fish range from 7 to 11 percent of body volume, while those of marine fish range from 4 to 6 percent of body volume.

b. Structure and function

Fish would be neutrally buoyant at only one depth, if air/swim bladders had a fixed amount of gas. Water pressure increases as water depth increases. When a fish swims to a lower depth, the increased pressure compresses the gas in the swim bladder, lowering its volume and increasing the density of the fish. The fish must swim more actively to compensate for this to prevent its denser body from sinking further. Water pressure decreases expanding the volume of gas in the swim bladder, when a fish swims toward the surface. Without the ability to change the amount of air in the swim bladder, a fish becomes less dense and rises to the surface like a cork.

The volume of gas in an air/swim bladder, and hence its pressure, needs adjusting as a fish changes depths. Most fish have an air/swim bladder that is isolated from the outside of the body and air pressure within the bladder varies when gas moves from the bladder to nearby blood vessels and back again. In some species, such as carp, a *pneumatic duct* joins the air/swim bladder with the *esophagus*. This connection acts as a " valve" to release extra gas as the fish swims toward the surface, or to take up gas by gulping air at the surface before swimming toward the bottom.

It is simple to remove gas from an expanding air/swim bladder: the pressure forces the gas into the surrounding blood capillaries, which carry it away. Filling up a bladder is more difficult because it is done against the high pressures already in the bladder.

In most bony fish (i.e., Osteichthyes), gas enter the air/swim bladder through the *red body*. The name comes from a structure known as the *rete mirabile* (the "marvelous net"), a dense bundle of capillaries arranged side by side in countercurrent fashion. Blood leaving the area carries gases at the same pressure found in the air/swim bladder. The gas pressure of blood coming into the area is much lower, similar to that in the surrounding water. Gases move from the outgoing blood to the incoming blood, not unlike the gas exchange process in the gills. The red body boosts the process by releasing compounds that raise the incoming blood's oxygen level. When the gas pressure in the red body exceeds that within the swim bladder, gas moves into the latter. Gas uptake and release is not immediate; swim bladders can burst when fish caught at great depth come to the surface too fast.

c. Effect of entrainment on the swim bladder

Changes in pressure can have a dramatic and often lethal effect on fish with swim bladders. Cooling water systems contain both positive and negative pressure differentials. A large positive pressure change will cause the swim bladder to implode. The effects of negative pressure changes appear to be more damaging. Negative pressure changes can cause the swim bladder to explode if the pressure across the membrane cannot be equalized fast enough. Pressure effects may be the leading cause of mortality in larvae of bluegill, carp, and gizzard shad. Gas disease may also result from a negative pressure change. Gas becomes more soluble in a negative pressure system, and following the release of pressure, hemorrhaging of blood vessel walls may occur around the eyes, gills, fins, and kidneys.

A2-5.7 Digestive System

The digestive system processes ingested food to meet the energy needs of fish.

The digestive system of fish has four major functions:

- **Transportation:** Swallowed food moves through the various gut sections for handling. Solid wastes must be removed at the end.
- **Physical treatment:** Food must be reduced in size by muscular action before it can broken down by digestive chemicals. Fluids are added to turn the food into a soft, pasty pulp.
- **Chemical treatment:** Food is turned into simpler compounds in the "digestive" phase.
- **Absorption:** The products of digestion are absorbed through the intestinal wall and either distributed as fuel or stored for later use.

The digestive system starts at the *mouth* (Figure A2-3), which captures prey. Food is passed through the *buccal cavity* into the muscular *pharynx*, where it is swallowed into the tube-like *esophagus* (Figure A2-3). The esophagus uses smooth muscle to transport food to the *stomach* (Figure A2-3) (note that some fish such as chimaera, lungfish, and certain teleosts do not have a stomach; the esophagus connects directly to the *intestine* (Figure A2-3)). In many fish, a muscular *sphincter* exists where the esophagus meets the stomach. The stomach, when present, can be either a "U"- or "V"-shaped tube or a straight, cigar-shaped organ. Its internal wall is deeply folded and rich with mucus-secreting glands. Other glands release digestive acids, and enzymes such as pepsin and lipases, to break down protein and fats. At the end of the stomach, many bony fish have extensions called *pyloric caeca* (Figure A2-3), which may help digest and absorb food.

The *pancreas* is a major source of digestive enzymes, that form an "intestinal juice" to break down fats, proteins, and carbohydrates into simpler molecules. The intestine has glands which produce more digestive enzymes, or mucus to lubricate food passage. Intestinal contractions move the food along. The inner lining of the intestine is deeply folded to increase the surface area for absorption. All Chondrichthyes and some primitive bony fish have an intestinal *spiral valve*, which looks like an auger enclosed in a tube. This valve increases the surface area of the gut because the food must twist through the intestine instead of moving straight through. The length of the intestine in bony fish varies: herbivores have long, coiled intestines, but carnivores have short, straight intestines. After digestion is complete, the wastes pass through the *rectum* and are excreted via the *anus* (Figure A2-3).

The *liver* (Figure A2-3) is not directly tied to digestion but is associated with it. This organ produces *bile* and bile salts, which help pancreatic enzymes split and absorb fats. Bile collects in the *gall bladder* (Figure A2-3) before it enters the intestine. The liver is a major storage organ. Blood leaving the intestines passes through the liver; fats, amino acids (building blocks for protein), and carbohydrates (simple sugars) are removed and stored there. The simple sugars are stored as *glycogen* and released to the blood when a burst of energy is needed.

Chapter A3: Aquatic Organisms Other than Fish that are Vulnerable to CWIS

INTRODUCTION

Chapter A2 focused specifically on fish species. Fish are of particular concern in the context of § 316(b) because of their importance in aquatic food webs and their commercial and recreational value. However, numerous others kinds of aquatic organisms are vulnerable to cooling water intake structures (CWISs), including diverse planktonic organisms, macroinvertebrates such as crabs and shrimp, and aquatic vertebrates such as sea turtles. These other organisms are discussed briefly in this chapter based on information compiled for EPA's § 316(b) rulemaking activities (SAIC, 1995).

CHAPTER CONTENTS

A3-1 PLANKTON

Plankton includes microscopic organisms, plant or animal, that are suspended in the water column and are neutrally buoyant. Because of their physical characteristics, most planktonic organisms are incapable of sustained mobility against the flow of water. Consequently, plankton drift passively in prevailing currents and have limited ability to avoid CWIS.

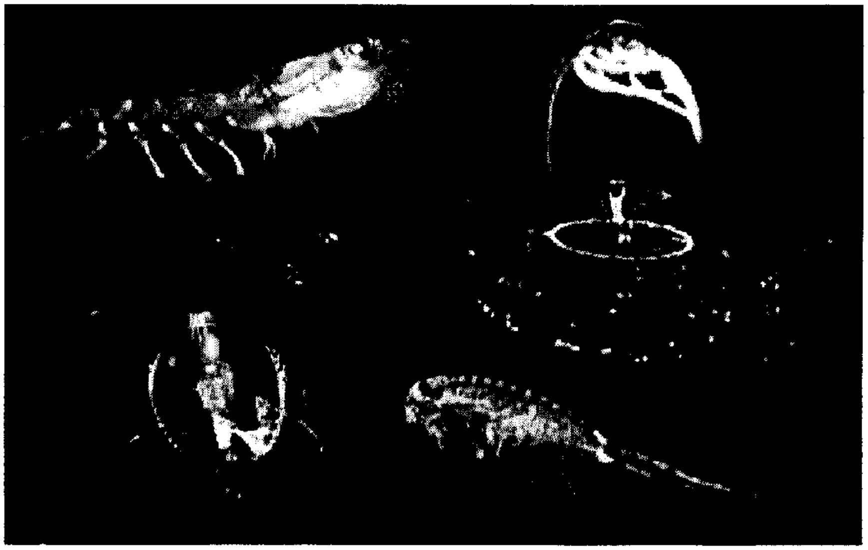
A3-1.1 Phytoplankton

Phytoplankton are free-floating plants, usually microscopic algae, which are primary producers in many aquatic environments. Primary productivity can be reduced by passage of phytoplankton through CWIS, especially during summer. In warm climates, a greater portion of the year may be affected. Some plants in lower latitudes may decrease primary productivity to some extent throughout the year.

Losses of phytoplankton rarely occur beyond the immediate vicinity of the CWIS. Possible exceptions include areas where mixing within non-entrained water is limited or slow, such as in enclosed bays or waters where substantial portions of water are withdrawn for cooling. In these cases, the effects of entrainment on algal primary productivity and biomass may persist and be apparent beyond the vicinity of CWIS.

A3-1.2 Zooplankton

Zooplankton are free-floating planktonic animals. Most zooplankton species have relatively short population regeneration times (from days to weeks), and therefore zooplankton populations are able to recover from entrainment losses relatively rapidly.



Source: USGS, 2001a

A3-1.3 Ichthyoplankton

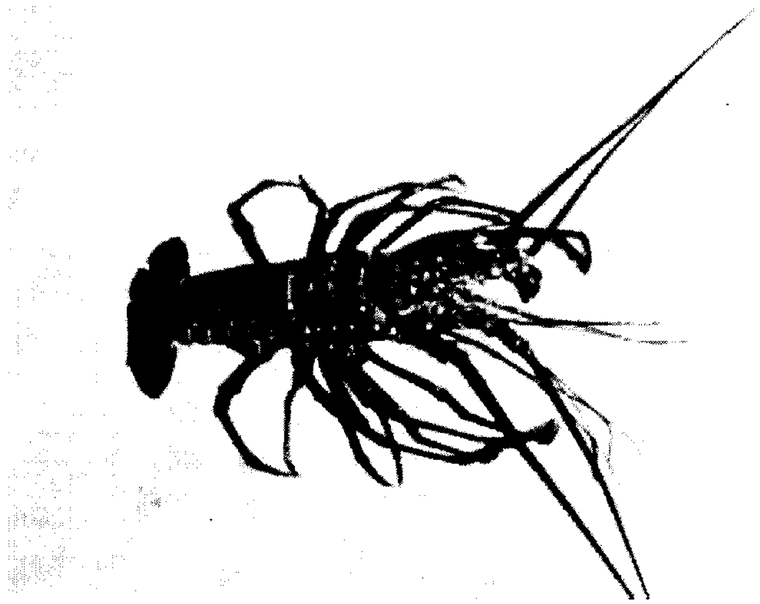
Ichthyoplankton includes egg and larval stages of fish species. When egg and larval stages are pelagic, vulnerability to entrainment is relatively high. In contrast, eggs that are demersal and attach to plants or sediments are rarely entrained.

A3-2 Macroinvertebrates

Macroinvertebrates are invertebrate organisms that are large enough to be seen with the naked eye. Macroinvertebrates include many familiar crustaceans, such as lobsters, crayfish, crabs, shrimp, and prawns. Such organisms live in sediments, the surface of sediments, hard surfaces (e.g., rock pilings), or the water column itself. It is not uncommon for macroinvertebrate species to use different habitats at different parts of their life cycle. Macroinvertebrates such as shrimps are quite mobile and capable of moving throughout the water column in large schools, increasing their susceptibility to I&E. On the other hand, crabs and lobsters live on the bottom and typically do not swim in the water column. However, early life stages of these species are frequently planktonic.

Comparatively few studies have been devoted to CWIS effects on macroinvertebrates. Available information suggests that macroinvertebrates with hard exoskeletons (e.g., blue crab) have relatively high survival rates following impingement. However, molting individuals are often found dead in impingement samples. Sessile adults of species such as clams and oysters are not typically entrained. However, because such species are often broadcast spawners with planktonic egg and larval stages, population abundance can be reduced by CWIS. In addition, because many macroinvertebrates serve as important prey items for many freshwater and marine fishes, declines as a result of CWIS can adversely affect aquatic food webs.

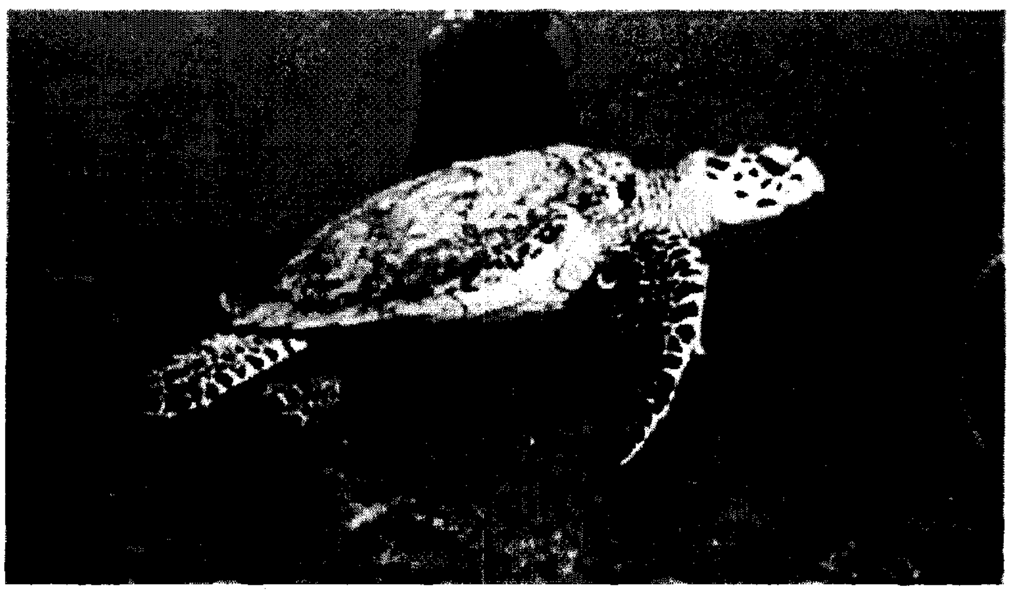
Source: NOAA, 2002b.



Source: NOAA, 2002c.

A3-3 Sea Turtles and Other Vertebrate Species

CWIS effects on vertebrates in aquatic environments are of greatest concern for sea turtles, including several species that are currently state- or federally-listed as threatened or endangered. Sea turtles, seals, and other aquatic vertebrates can die if they are drawn into intakes or are impinged on intake screens.



Source: NMFS, 2001e

A3-4 CONCLUSIONS

Although most I&E studies focus on fish species, it is important to bear in mind that many other kinds of aquatic organisms are vulnerable to I&E, either during early development or throughout their life cycle, depending on factors such as size, swimming ability, reproductive strategy, and other life history characteristics.

It is also important to note that in addition to direct harm from I&E, most aquatic organisms are also susceptible to indirect impacts as a result of the impingement or entrainment of prey items. Unfortunately, few studies consider how CWIS impacts may disrupt aquatic food webs (however, see Summers, 1989).

In addition, although indirect effects on fish species whose prey are impinged or entrained are generally acknowledged, there has been little consideration of indirect effects of CWIS on non-fish species. In an effort to address this knowledge gap, Chapter A4 discusses CWIS effects on bird species.

Chapter A4: Direct and Indirect Effects of CWIS on Birds

A4-1 Direct Effects on Birds

Chapter Contents

Although most direct effects of cooling water intake structures (CWIS) are on fish and shellfish, there are occasional cases of direct harm to birds. For example, the U.S. Fish and Wildlife Service in Green Bay, Wisconsin has recorded direct mortality of nestling double-crested cormorants (*Phalacrocorax auritus*) at the Point Beach Nuclear Power Plant (Memorandum from Environmental Contaminants Specialist to Special Agent Roy Owens, U.S. Fish and Wildlife Service Green Bay Field Office, February 4, 1993). During one incident in September and October of 1990, 74 cormorants were impinged at the facility. According to the U.S. Fish and Wildlife Service, this number represents 3.2 percent of the total potential productivity of the species. It was concluded that the geographic extent of the impact was much larger than a single colony in Wisconsin because the losses were nestlings that otherwise would have entered the free-flying population. Another incident of avian impingement occurred at the Seabrook Station in 1999. Between February 20 and March 16, twenty-nine white-winged scoters were impinged at the facility's cooling water intake structures. The intake structures are located at a depth of approximately 40 feet below the surface, and mussels often attach to the structures. It is believed that after diving down to feed on the mussels on the intake structures, the scoters were drawn into the cooling system (North Atlantic Energy Service Corporation, 1999).

A4-2 Indirect Effects on Fish-Eating Birds

Although direct mortality of birds can occur, most effects are indirect as a result of losses of fish and shellfish that provide food for birds. For some fish-eating birds, such as cormorants, kingfishers, grebes, ospreys, and terns, fish are a necessary component of the diet. For others, such as gulls, fish are a regular but less essential dietary component. More than 50 bird species out of the 600 in North America fall into the former category, and 20 fall into the latter (Tables A4-1 and A4-2). The birds listed in Tables A4-1 and A4-2 usually obtain their fish prey from freshwater ecosystems such as lakes, ponds, marshes, or rivers (e.g., ospreys and kingfishers), or from estuarine or coastal marine environments (e.g., loons and cormorants). Many species such as grebes and auks spend part of the year (typically the breeding season) in freshwater environments, but winter on the coast. These birds while in their summer or winter ranges may occupy areas that could be affected by existing or future CWIS. Some birds (e.g., shearwaters) depend on fish prey from offshore marine areas. Since these prey are unlikely to be affected by CWIS located inland or on the coast, these birds are not considered in this chapter. Also, most birds are relatively flexible and opportunistic in their choice of prey, and some birds may consume fish, but only rarely; these birds (e.g., red-winged blackbirds) are not included in the tables.

In addition to birds that depend largely on fish for their diet, many species consume aquatic invertebrate prey, such as crustaceans, annelids, mollusks, etc. Bird species that are at least partially dependent on aquatic invertebrates from freshwater wetlands or coastal marine and estuarine habitats for at least part of their annual cycles are shown in Table A4-3. These species may be vulnerable to the secondary effects of CWIS since the planktonic life stages of their prey may be impacted and the local adult communities eventually affected. However, they are probably less vulnerable than the piscivorous birds listed in Tables A4-1 and A4-2 since, unlike fish, it is less likely that most adult invertebrates, which are typically bottom-dwelling, will be directly affected by intake structures.

White winged scoters (*Melanitta fusca*) are one of the 15 species of sea ducks found in North America. They spend most of the year in costal marine waters and migrate inland to nest and raise their young as do most sea ducks. White wings nest on freshwater lakes in the boreal forests of interior Alaska and western Canada and winter in large bays and estuaries along the Pacific and Atlantic coasts.

Source: Alaska Department of Fish and Game, 1999

Photo source: Alaska Department of Fish and Game, 1999

The double-crested cormorant is a bird of salt, brackish and fresh waters. It breeds mainly along the coasts, but also around inland lakes. As soon as they return from their wintering grounds on the U.S. east coast south to the Gulf of Mexico, they appear throughout the St. Lawrence system. They are particularly fond of islands for nesting. The nest is made of a mass of branches which they build in a tree, on a ledge or on a clifftop.

Cormorants are 61-92 cm (2 to 3 ft) long, with thick, generally dark plumage and green eyes. The feet are webbed, and the bill is long with the upper mandible terminally hooked. Expert swimmers, cormorants pursue fish underwater. The young are born blind, and the parents feed the nestlings with half-digested food which is dropped into the nests. Later, the young birds poke their heads into the gullet of the adults to feed. Cormorants are long-lived; a banded one was observed after 18 years.

Average clutch size is three or four eggs. After being incubated by both parents for 24 to 29 days, the chicks hatch unprotected by any down. They grow rapidly and fledge when the are five to six weeks old. Cormorants are diving bird and feed mainly on fish caught close to the bottom. The double crested's diet consists of fish such as Capelin, American Sand Lance, gunnels, Atlantic Herring and sculpins, as well as crustaceans, molluscs and marine worms.

Source: Environment Canada, 2001

Photo source: Environment Canada, 2001

While at their breeding, migration, or wintering sites, the birds listed could be close to one or more existing or planned CWIS, and could be affected by the operation of these facilities. CWIS have the potential to adversely affect these bird populations indirectly by reducing their available food supply (eggs, larvae, juveniles and/or adult fish and invertebrates) through impingement and entrainment (I&E).

Generally, the larger the bird, the larger its prey. Ospreys or bald eagles may take fish that weigh a few pounds. However, many North American fish- and invertebrate-eating birds typically exploit smaller prey species or the younger age groups of larger fish. For example, common terns breeding in Massachusetts feed their young the age groups of species such as sandeels or silversides that are typically less than 6 inches long (Galbraith et al., 1999). CWIS could potentially reduce the availability of the birds' fish or invertebrate prey either directly, by reducing the densities of the larval and older organisms that the birds exploit (through I&E), or indirectly, by reducing the numbers of eggs or larvae to the extent that the density of the older age groups that larger birds rely on is reduced locally. Also, fewer larger fish or adult invertebrates (i.e., the breeding stock) could affect the availability of small prey in the next generation. These cause-effect interactions are displayed in Figure A4-1.

Table A4-1: North American Birds that Eat Fish as a Major Dietary Component

Major Dietary Component	
Species	**Distribution**[a]
Red-throated loon	summer: lakes in arctic Canada and Alaska; winter: Atlantic and Pacific coasts south to California and Georgia
Pacific loon	summer: lakes in arctic Canada and Alaska; winter: Pacific coast south to California
Arctic loon	summer: lakes in Alaska; winter: Pacific coast south to California
Common loon	summer: lakes in Canada and northern U.S.; winter: Atlantic and Pacific coasts south to Texas and California
Horned grebe	summer: freshwater wetlands in Canada and north-western U.S.; winter: Atlantic and Pacific coasts south to Texas and California
Pied-billed grebe	Resident in freshwater wetlands throughout U.S.
Red-necked grebe	summer: freshwater wetlands in Canada and northern Great Lakes; winter: Atlantic and Pacific coasts south to California and Georgia
Clark's grebe	summer: freshwater wetlands in western U.S.; winter: Pacific coast
Western grebe	summer: freshwater wetlands in Canada and western U.S., winter: Pacific coast
American white pelican	summer: lakes in Canada and western U.S.; winter: California and Gulf of Mexico coasts
Brown pelican	resident: Pacific and Atlantic coasts from Washington and New York south to California and Gulf of Mexico
Anhinga	resident: Atlantic coastal wetlands from South Carolina south to southern Texas
Neotropic cormorant	resident: coastal wetlands in Texas
Great cormorant	summer: maritime east Canada; winter: Atlantic coast south to South Carolina
Double-crested cormorant	summer: lakes in Great Lakes, west U.S. and north-east U.S.; winter: entire Pacific and Atlantic coasts
Brandt's cormorant	resident: Pacific coast from Canada to California
Pelagic cormorant	summer: Alaskan coast; winter: Pacific coast from southern Alaska to California
Least bittern	summer: freshwater wetlands from east coast of U.S. to midwest states; winter: Gulf coast and south Florida
American bittern	summer: freshwater wetlands throughout Canada and U.S.; winter: wetlands on both coasts south to California and Texas
Green heron	summer: freshwater wetlands from Atlantic coast to midwest states and Oregon and Washington; winter: California, gulf of Mexico and Florida coastal wetlands
Tricolored heron	resident: Atlantic coastal wetlands from New York south to Florida and Gulf of Mexico
Little blue heron	summer: freshwater wetlands in Gulf of Mexico States; resident: coasts of Gulf Coast and Florida north to New York
Reddish egret	resident: coastal wetlands in Florida and Gulf Coast
Snowy egret	summer: freshwater wetlands in western States; winter: California coast resident: coastal wetlands from Massachusetts south to Gulf Coast States
Great egret	summer: freshwater wetlands in Mississippi Valley States; resident: Atlantic coastal States from Mid-Atlantic south to Gulf of Mexico; winter: California coast
Great blue heron	summer: freshwater wetlands in northern U.S. States and Canada; winter and resident: wetlands in inland southern states and both coasts of Canada and U.S. south to California and Gulf of Mexico
Wood stork	resident: coastal wetlands in Florida and Gulf of Mexico

Table A4-1: North American Birds that Eat Fish as a Major Dietary Component (cont.)

Major Dietary Component	
Species	**Distribution**[a]
Roseate spoonbill	summer and resident: coastal wetlands in Florida and Gulf of Mexico
Common merganser	summer: lakes in Canada and north-west U.S.; winter: lakes and rivers in interior and coastal U.S. south to California and North Carolina
Red-breasted merganser	summer: lakes in Canada; winter: Atlantic and Pacific coasts from Canada south to California and Gulf of Mexico
Hooded merganser	summer: lakes and rivers in Canada and Great Lakes States; winter: Pacific coast from Canada south to California and from New York south to Gulf of Mexico. Also winters in interior states of south-east U.S.
Osprey	summer: inland and coastal wetlands from Canada south to Great Lakes, Pacific Northwest, and Florida and Gulf of Mexico; resident: Florida and Gulf Coast states
Bald eagle	summer: lakes and rivers in Canada, Great Lakes, north-eastern U.S., Pacific Northwest, and some western states; winter: Midwestern and western states and both coasts south to Mexican border
Sandwich tern	Atlantic coastal areas from Mid-Atlantic states south to Gulf of Mexico
Elegant tern	summer: Southern California coast
Royal tern	Summer and resident Atlantic coasts from Mid-Atlantic states south to Gulf of Mexico; winter: southern California coast
Caspian tern	summer: Canadian wetlands, Great Lakes, and some western states; winter: Florida and Gulf of Mexico coasts, southern California coast
Roseate tern	summer: coasts of Newfoundland south to New York
Forster's tern	summer: inland wetlands in central Canada and western States of U.S. Also summers on coastal marshes in Gulf of Mexico; winter: southern California and south Atlantic coasts south to Florida and Gulf of Mexico
Common tern	summer: inland lakes of Canada and northern U.S. states and coastal Atlantic from Newfoundland south to North Carolina
Arctic tern	summer: tundra in Arctic Canada and arctic coasts south to Newfoundland and Maine
Least tern	summer: Atlantic and California coastal dunes south to Florida and Gulf of Mexico. Also rivers in Mississippi Valley
Black skimmer	summer: inland and coastal wetlands in southern California; resident and winter: Atlantic coast from New York south to Florida and Gulf of Mexico
Common murre	winter: Atlantic and Pacific coasts south to New York and California
Razorbill	winter: Atlantic coast south to Mid-Atlantic states
Black guillemot	resident: Atlantic coast from arctic south to New England
Pigeon guillemot	resident: Pacific coast from Arctic south to California
Marbled murrelet	resident and winter: Pacific coast south to California
Rhinoceros auklet	resident and winter: Pacific coast south to California
Atlantic puffin	resident and winter: Atlantic coasts from Newfoundland south to New England
Horned puffin	resident and winter: Pacific coasts fro Alaska south to Washington
Tufted puffin	resident and winter: Pacific coasts from Alaska south to California
Belted kingfisher	summer: lakes and rivers throughout Canada; resident and winter : lakes and rivers throughout U.S.

Note: Excluded are species that are rare or have highly restricted distributions, that feed mainly offshore, or that eat fish only very rarely.
[a] These distributions are approximate. For more detailed representations see, for example, Kaufman, 1996.
Source: Kaufman, 1996.

Table A4-2: North American Birds that eat Fish as a Frequent Dietary Component

Frequent Dietary Component	
Species	**Distribution***
Clapper rail	resident: Atlantic coastal marshes fro New England south. Also San Francisco Bay
King rail	summer: inland marshes from Atlantic coast to midwest; resident and winter: Coastal marshes from Mid-Atlantic States south to Florida and Gulf of Mexico
Whooping crane	winter: Texas coast
Heerman's gull	all year: Oregon and California coasts
Laughing gull	resident: Atlantic coasts from New England south to Gulf of Mexico
Franklin's gull	summer: prairie wetlands in central Canada and northern U.S.
Bonaparte's gull	summer: forested wetlands across Canada; winter: Atlantic and Pacific coasts from Canada south to California and Gulf of Mexico
Ring-billed gull	summer: lakes in central Canada, Great Lakes and Maritime Provinces; winter Atlantic coast from New England south to Mexico, Pacific coast from Canada south to Baja, and interior southern states of U.S.
Mew gull	summer: freshwater wetlands in western Canada; winter: Pacific coast from Canada south to California
California gull	summer: lakes in central Canada and western U.S.; winter: Pacific coast from Washington south to California
Herring gull	summer: inland and coastal lakes across Canada; winter: Pacific and Atlantic coasts from Canada south to Mexican border
Glaucous gull	summer: arctic; winter: Atlantic and Pacific coasts south to Mid-Atlantic States and California
Iceland gull	summer: arctic; winter Atlantic coast from Canada south to New York
Thayer's gull	summer: arctic; winter: Pacific coast from Alaska south to California
Western gull	resident: Pacific coast from Canada south to Baja
Glaucous-winged gull	resident: Pacific coast of Canada; winter: Pacific coast of U.S.
Great black-backed gull	resident and summer: Maritime provinces south to Mid-Atlantic States
Black tern	summer prairie and forested wetlands across Canada and in Midwestern and western states of U.S.
Ancient murrelet	summer: Alaska winter: Pacific coast from Alaska south to California
American dipper	resident: rivers throughout western States of U.S.

Table A4-3: North American Birds that Eat Mainly Aquatic Invertebrates

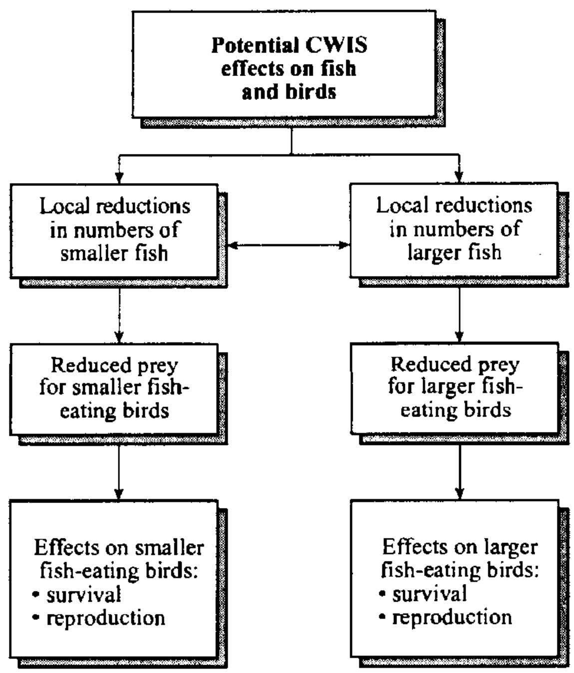
Species	Distribution[a]	Species	Distribution[a]
Eared grebe	summer: freshwater wetlands in western Canada and U.S.; winter: Pacific coast from Vancouver south to southern California	Piping plover	summer: coast, lake and river beaches in northern Midwest and New England; winter: Atlantic coastal beaches from New England south to Mexico
Black-crowned night-heron	summer: inland and coastal wetlands in southern Canada and across whole of U.S.; winter and resident: coast of Florida and Gulf of Mexico	American oystercatcher	resident: Atlantic coastal beaches from New England south to Texas
Yellow-crowned night-heron	resident and summer visitor to interior and coastal wetlands in south-eastern States of U.S.	Black oystercatcher	resident: Pacific coastal beaches from Canada south to California
White ibis	resident: south east Atlantic coast from South Carolina to Texas	Black-necked stilt	summer: alkaline marshes in western States; winter: California, Florida and Gulf of Mexico coasts
Glossy ibis	resident and winter: coastal marshes on Atlantic coast from New England south to Texas	Greater yellowlegs	summer: northern Canada; winter: Atlantic coast from New York south to Mexico
White-faced ibis	summer: lakes in some western States of U.S.; winter: Gulf of Mexico and coastal and interior California	Lesser yellowlegs	summer: northern Canada; winter: Atlantic coast from New York south to Mexico
Roseate spoonbill	resident: Florida and Gulf Coast coastal wetlands	Willet	summer: wetlands in some western States and saltmarshes on Atlantic coast from New England south to Mexico; winter: Atlantic coast from New England south to Mexico and California coast
Greater scaup	winter: throughout Atlantic and Pacific coasts of U.S.	Spotted sandpiper	summer: inland wetlands throughout Canada and mid and northern U.S. States winter: Florida and Gulf of Mexico coasts
Lesser scaup	summer: prairie wetlands in western states; winter: wetlands in southern states and Pacific and Atlantic coasts from Canada south to Mexico	Long-billed curlew	winter: Texas and California coasts
Common eider	winter: New England coast	Marbled godwit	summer: wetlands in northern prairies winter: Atlantic and Pacific coasts from Delaware to Texas and California
King eider	winter: New England coast	Ruddy turnstone	winter: Atlantic coast south of New England
Harlequin duck	summer: rivers in western Canada and Pacific Northwest winter: Atlantic and Pacific coasts as far south as California and New England	Surfbird	winter: Pacific coast from Canada to California
Oldsquaw	summer: arctic winter: Pacific and Atlantic coasts south to California and Texas	Red knot	winter: Florida coast
Black scoter	winter: Pacific and Atlantic coasts south to California and Texas	Sanderling	winter: Atlantic and Pacific coasts from New York south to Texas and Vancouver to Baja
Surf scoter	summer: northern Canada; winter: Pacific and Atlantic coasts south to California and Texas	Western sandpiper	winter: Atlantic and Pacific coasts from New York south to Texas and Vancouver to Baja
White-winged scoter	summer: northern Canada; winter: Pacific and Atlantic coasts south to California and Texas	Least sandpiper	winter: Atlantic and Pacific coasts from New York south to Texas and Vancouver to Baja
Common goldeneye	winter: freshwater and coastal wetlands throughout U.S.	Purple sandpiper	winter: Atlantic coast from Canada south to Mid-Atlantic States

Table A4-3: North American Birds that Eat Mainly Aquatic Invertebrates (cont.)

Species	Distribution[a]	Species	Distribution[a]
Barrow's goldeneye	summer: rivers in northern Rocky Mountain States; winter: Rocky Mountain States	Rock sandpiper	winter: Pacific coast from Canada south to California
Bufflehead	summer: Canadian wetlands; winter: freshwater and coastal wetlands throughout U.S.	Dunlin	winter: Atlantic coast from New York to Texas and San Francisco Bay
Limpkin	resident: Florida wetlands	Dowitcher species	winter: Atlantic and Pacific coasts from Northern U.S. south to Baja and Mexico
Black-bellied plover	winter: Pacific and Atlantic coasts south to Mexico		
Snowy plover	summer: alkali lakes in western U.S.; resident: coastal wetlands in California and Gulf Coast		
Wilson's plover	resident: Atlantic coast wetlands from New York south to Gulf Coast		
	summer: arctic; Winter Pacific and Atlantic coast wetlands from Canada south to California and Mexico		

[a] These distributions are approximate. For more detailed representations see, for example, Kaufman, 1996.

Figure A4-1: Potential CWIS Effects on Fish-Eating Birds and Their Prey



A4-3 Understanding the Effects of Food Reduction on Bird Populations

Many scientific studies have confirmed the link between the abundance of available food and the viability of bird populations. EPA reviewed recent papers published in the peer-reviewed literature that describe effects of food shortages on fish-eating birds. One of the goals of these studies was to identify linkages between food shortages and adverse impacts on birds, irrespective of the underlying cause of the shortage[1]. While EPA's review of these studies did not reveal any documented linkages between I&E and effects on bird populations, the principle remains the same: independent of the stressor, a reduction in the food supply can adversely affect bird populations. Table A4-4 summarizes a sample of the reviewed studies, and Boxes A4-1 and A4-2 describe the findings of two studies in greater detail. Several broad conclusions can be drawn from this body of literature:

- Chicks of fish-eating birds can starve and quickly die (in a few days) if food is scarce or unavailable during a short window of natal development.
- The amount of food that is available before and during the birds' breeding seasons can affect courtship and initiation of breeding, number of eggs laid, chick survival, frequency of renesting, and other important reproductive factors.
- Insufficient amounts of food may force parents to forage farther and wider, resulting in fewer and smaller feeds per chick per day. This may increase the risk of starvation.
- Food shortages can result in increased food theft, as chicks and adults steal food from each other.
- Food shortages during the breeding season usually affect chicks and fledglings before the adults.
- Inadequate nutrition during development can have significant physiological consequences (e.g., calcium deficiencies and poor skeletal development).
- Super-abundant food can lead to increased breeding success.

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[1] Causes of food shortages included spawning failure in fish, shifting weather patterns, effects of pollutants, and other factors.

Table A4-4: Examples of Studies Showing Relationships between Quantity and Quality of Fish Prey and Survival, Behavior, and Reproductive Success of Fish-Eating Birds

Country	Waterbody	Target Species	Study Description	Summary	Reference
USA	Laboratory	Belted kingfisher	Effect of food supply on reproduction	Extra food resulted in earlier nesting, heavier chicks, and greater frequency of second clutches	Kelly and Van Horne, 1997
USA	Reservoir	Double-crested cormorant	Identification of factors associated with densities of cormorants	Fish availability correlated with cormorant density	Simmonds et al., 1997
Spain	Ebro Delta	Audouin's gull	Availability of trawler discards and kleptoparasitism	Reduced discards led to increased rates of kleptoparasitism	Oro, 1996
The Netherlands	Inland waters	Black tern	Impacts of acidification on fish stocks and chick growth and survival	Reduced fish stocks led to calcium deficiencies and increased mortality	Beintema, 1997
Northern Ireland	Lough Neagh	Great cormorant	Identification of factors associated with densities of cormorants	Fish availability correlated with cormorant density	Warke et al., 1994
France	Rhone Delta	Little egret	Food abundance and reproductive success	Increased food led to increased reproductive success and fledgling survival	Hafner et al., 1993
Norway/Russia	Barents Sea	Kittiwakes, murres, puffins	Fish availability and reproduction of birds	Reductions in fish stocks impaired breeding success	Barrett and Krasnov, 1996
USA	Pacific Ocean	Kittiwakes, gulls, and puffins	Diets and breeding success	Diet switching led to reduced breeding success	Baird, 1990
Germany	North Sea	Common tern	Food supply and kleptoparasitism	Reduced food supply caused increased kleptoparasitism	Ludwigs, 1998
Germany	North Sea	Common tern	Food supply and chick survival	Reduced food caused increased chick mortality	Becker et al., 1997
South Africa	Indian Ocean	African penguin, Cape gannet, Cape cormorant, swift tern	Prey availability and breeding success	Reductions in anchovy stocks resulted in reduced breeding success	Crawford and Dyer, 1995
UK	Atlantic Ocean	Arctic tern	Fish abundance and breeding success	Reduced fish stocks lowered egg volume, clutch size, and breeding success	Suddaby and Ratcliffe, 1997

Box A4-1: Fish Availability Affects Breeding Success in Arctic Terns.

The arctic tern is a small, circumpolar, fish-eating bird that typically obtains its prey in the inshore marine environment. Unlike the closely related common tern, arctic terns do not generally breed or feed in freshwaters.

In the United Kingdom, the Shetland Islands are one of the strongholds of the species. Large breeding colonies of thousands of pairs of birds can be found there. Such large breeding colonies require an abundant and predictable food supply. In the Shetlands the most important food species is the sandeel, which occurs in vast shoals in the inshore waters. Before the 1980's, sandeels were largely ignored by the UK fishing industry. However, beginning in the late 1970's, they became an increasingly sought after catch as their value as fodder for farm animals was recognized. This led to a huge sandeel fishing industry that, since it was largely unregulated, resulted in the 1980s in massive depletion of the fish stocks. This study by Monaghan et al. (1989) investigated the effects of this stock depletion on the breeding biology of arctic terns in the Shetlands (where the sandeels were overfished) and at Coquet Island in England (where food supplies were not reduced).

Of the interesting differences found in the breeding biology of the terns from the two colonies, many could be ascribed to the reduction in prey availability at the Shetland colony. The Shetland birds delivered smaller sandeels to their nests than did the Coquet birds, indicating that the fishing industry had removed the larger (and more nutrient- and energy-rich) fish. Also, because of this, the chicks in the Shetland colony grew at a slower rate than the Coquet chicks and the majority of the chicks in the colony died a few days after hatching. The Coquet chicks had more rapid growth rates and far better survival.

The adult birds were also affected by the reduced sandeel stocks. During the breeding season, the adults in the Shetland colony lost weight and became lighter than the adults at Coquet, suggesting a food shortage effect.

This study clearly demonstrates the importance of having an adequate and predictable fish food supply for arctic terns during the breeding season and on their ability to raise chicks.

Box A4-2: Oceanic Currents, Human Fisheries, Anchovy Abundance, and the Abundance of Peruvian and Chilean Seabird Populations.

Several fish-eating seabirds breed in extremely large colonies on islands off the coasts of Peru and Chile. The breeding populations of these cormorants and boobies probably number several million in a typical year. These huge populations are made possible by an extremely rich supply of anchovies, which, in turn, depend on upwelling associated with the Humboldt current bringing nutrient-rich cold water to the surface close to the nesting islands (Harrison, 1983). In typical years, these birds can easily raise their young by exploiting the rich fish prey base.

However, every 10 or so years an El Niño event forces the upwelling south and deprives the seabirds of their anchovy prey. In these years, the birds may have reduced reproductive success or may fail to breed at all. Further, the birds may desert their normal ranges and spread north and south along the Pacific coast into areas where they are not normally seen (Murphy, 1952).

In the last few decades a new factor has complicated this pattern. The human anchovy fishery has now reduced the numbers of fish to the extent that even in good years the numbers of breeding birds and their success may be reduced.

The sensitivity of these seabirds to temporal and spatial disturbances in the dependability of their food supply highlights the critical relationship between the availability of fish prey and their population status.

This information shows that the responses of fish-eating birds to food shortages can range from behavioral changes (e.g., greater foraging efforts or increased food theft) to more dramatic responses (e.g., clutch abandonment, chick mortality, failure to attempt to breed). It is not likely that I&E by CWIS has resulted in such large-scale die-offs and reproductive failures. Such obvious responses would have been observed and reported. CWIS I&E effects are, therefore, likely to be more subtle. However, even these types of responses could have longer-term population impacts.

The studies reported in Table A4-1 show that chicks in particular are prone to rapid starvation and increased mortality during early development. During that period, sufficient amounts of high quality food (i.e., nutritionally and energetically rich) must be available to ensure successful fledging. The potential effects of I&E could be magnified if the depletion of a localized high quality fish resource forces parents to switch to a lower quality food or to forage further afield, resulting in a decrease in the rate of food delivery to the chicks and an increased starvation risk. Alternatively, I&E effects on local food supplies could affect bird populations when they are under stress from some other factor (e.g., severe weather or contaminants). Thus, the potential effects of I&E on bird populations, though perhaps subtle, cannot be discounted.

Even when enough food is available to allow a "normal" reproductive event, any additional food can increase the survival rate of nestlings and increase overall breeding success (Hafner et al., 1993; Suddaby and Ratcliffe, 1997). This at least partly rebuts the commonly used argument that surplus fish production has no ecological value and can therefore be removed without affecting the local ecosystem. It also suggests that even though the I&E of large numbers of fish might not actually adversely affect birds, the removal of that extra food resource could just as easily prevent them from realizing their full reproductive potential.

Even if a bird species can switch to another food source, significant effects are still possible if the replacement food has lower caloric or nutritional quality (Beintema, 1997). Recently hatched chicks can be particularly vulnerable to changes in food availability, starving and dying in a short time. Such risks may be of particular concern if the CWIS removes large numbers of fish or other aquatic prey in bird foraging areas during the breeding season.

In conclusion, this review of the ornithological literature underscores the link between adequate food supplies and survival and reproductive success in fish-eating birds. In particular, the low degree of behavioral flexibility combined with severe food shortages can result in reduced survival or increased reproductive failure. As the data shown in Table A4-3 suggest, localized food shortages caused by I&E are likely to affect bird populations differently depending on their dietary requirements. Species that can readily switch to an alternative prey may be less vulnerable, and those others that are entirely dependent on fish stocks may be more vulnerable. This leads to two conclusions: 1) any impacts associated with the removal of prey fish by I&E are likely to be species-specific, and 2) birds entirely dependent on fish (e.g., ospreys or loons) have a greater risk of being adversely affected compared to species with more flexible dietary requirements.

Chapter A5: Methods Used to Evaluate I&E

This chapter describes the methods EPA used to evaluate impingement and entrainment (I&E) at the case study facilities, including methods used to forecast the consequences of I&E losses of early life stages for the adult population, fishery harvests, and population biomass production. Section A5-1 outlines the overall approach, Section A5-2 describes the source data, Section A5-3 presents details of the biological models used, and Section A5-4 discusses uncertainties in the analyses. Chapters A9 (benefits transfer), A10 (Random Utility Model), and A11 (Habitat-based Replacement Cost) discuss how these loss estimates are valued for the case study benefits analyses.

CHAPTER CONTENTS

A5-1 Overview of Procedure for Evaluating I&E

The same general procedure for evaluating I&E records was followed for each facility, but with appropriate facility-specific considerations pertaining to data availability and identification of predominant species composition. The basic approach estimated losses to fishery resources resulting from species-specific and life-stage-specific I&E. Losses were expressed as (1) foregone age 1 equivalents, (2) foregone fishery yields, and (3) foregone biomass production using common fishery modeling techniques (Ricker, 1975; Hilborn and Walters, 1992; Quinn and Deriso, 1999). These foregone resources were modeled using facility-specific I&E rates combined with relevant species life history characteristics such as growth rates, natural mortality rates, and fishing mortality rates.

A5-2 Source Data

A5-2.1 Facility I&E Monitoring

The inputs for EPA's analyses included the empirical I&E counts reported by each facility. The general approach to I&E monitoring was similar at most case study facilities. Impingement monitoring involved sampling impingement screens or catchment areas, counting the impinged fish, and extrapolating the count to an annual basis. Entrainment monitoring typically involved intercepting a small portion of the intake flow at a selected location in the facility, collecting fish by sieving the water sample through nets or other collection devices, counting the collected fish, and extrapolating the counts to an annual basis. EPA used life stage-specific annual losses for assessment of entrainment losses and assumed that all fish killed by impingement were age 1 at the time of death. Although these general sampling procedures were followed by most facilities, specific methods of collecting and reporting I&E data, and the complexity and time span of analysis, differed substantially among case study facilities. To the extent possible, EPA considered and evaluated facility-specific monitoring and reporting procedures, as described in EPA's individual case study reports.

A5-2.2 Species Evaluated

EPA conducted detailed species-specific loss analyses for species that were most predominant in facility collections or had special significance (e.g., threatened or endangered status). I&E was analyzed in terms of losses to the commercial or recreational fishery (for those species that are fished), or as loss of the forage prey base (for those species that are not fished). A small fraction of species that were identified in I&E records were not evaluated on a species-specific basis by EPA because of a lack of life history information. These species were treated as an aggregate, and their I&E rates were expressed as a fraction of the total I&E.

A5-2.3 Life History Data

The life history data used in EPA's case studies usually included species-specific growth rates, the fraction of each age class vulnerable to harvest, fishing mortality rates, and natural (nonfishing) mortality rates. Each of these parameters was also stage-specific, with the exception of mortality rates which are typically constant for fish older than a given catchability threshold.

EPA obtained life history data from facility reports, the fisheries literature, and publicly available fisheries databases (e.g., FishBase). To the extent feasible, EPA used species-specific and region-specific life history data most relevant to local populations near the case study facility. Detailed citations are provided in life history tables accompanying each case study report.

A static set of life history parameters was used for all data analyses. No stochastic or dynamic effects such as compensatory mortality or growth, or random environmental variation were used.
In cases where no information on survival rates was available for individual life stages, EPA deduced survival rates for an equilibrium population based on records of lifetime fecundity using the relationship presented in C.P. Goodyear (1978) and below in Equation (1):

$$S_{eq} = 2/fa \quad \text{(Equation 1)}$$

where:

S_{eq} = the probability of survival from egg to the expected age of spawning females
fa = the expected lifetime total egg production

Published fishing mortality rates (F) were assumed to reflect combined mortality due to both commercial and recreational fishing. Basic fishery science relationships (Ricker, 1975) among mortality and survival rates were assumed, such as:

$$Z = M + F \quad \text{(Equation 2)}$$

where:

Z = the total instantaneous mortality rate
M = natural (nonfishing) instantaneous mortality rate
F = fishing instantaneous mortality rate

and

$$S = e^{(-Z)} \quad \text{(Equation 3)}$$

where:

S = the survival rate as a fraction

A5-3 BIOLOGICAL MODELS USED TO EVALUATE I&E

The methods used to express I&E losses in units suitable for economic valuation are outlined in Figure A5-1 and described in detail below.

A5-3.1 Modeling Age-1 Equivalents

The Equivalent Adult Model (EAM) is a method for expressing I&E losses as an equivalent number of individuals at some other life stage, referred to as the age of equivalency (Horst 1975a; C.P. Goodyear, 1978; Dixon, 1999). The age of equivalency can be any life stage of interest. The method provides a convenient means of converting losses of fish eggs and larvae into units of individual fish and provides a standard metric for comparing losses among species, years, and facilities. For the § 316(b) case studies, EPA expressed I&E losses as an equivalent number of age-1 individuals. This is the number of impinged and entrained individuals that would otherwise have survived to be age 1 plus the number of impinged individuals (which are assumed to be impinged at age 1).

The EAM calculation requires life-stage-specific entrainment counts and life-stage-specific mortality rates from the life stage of entrainment to the life stage of equivalence. The cumulative survival rate from age at entrainment until age 1 is the product of all stage-specific survival rates to age 1. The calculation is:

$$S_{j,1} = S_j^* \prod_{i=j+1}^{j_{max}} S_i \qquad \text{(Equation 4)}$$

where:

$S_{j,1}$ = cumulative survival from stage j until age 1
S_j = survival fraction from stage j to stage $j + 1$
S^*_j = $2S_j e^{-\log(1+S_j)}$ = adjusted S_j
j_{max} = the stage immediately prior to age 1

Equation 4 defines $S_{j,1}$, which is the expected cumulative survival rate (as a fraction) from the stage at which entrainment occurs, j, through age 1. The components of Equation 4 represent survival rates during the different life stages between life stage j, when a fish is entrained, and age 1. Survival through the stage at which entrainment occurs, j, is treated as a special case because the amount of time spent in that stage before entrainment is unknown and therefore the known stage specific survival rate, S_j, does not apply because S_j describes the survival rate through the entire length of time that a fish is in stage j. Therefore, to find the expected survival rate from the day that a fish was entrained until the time that it would have passed into the subsequent stage, an adjustment to S_j is required. The adjusted rate S^*_j describes the effective survival rate for the group of fish entrained at stage j, considering the fact that the individual fish were entrained at various specific ages within stage j.

Age-1 equivalents are then calculated as:

$$AE1_{j,k} = L_{j,k} S_{j,1} \qquad \text{(Equation 5)}$$

where:

$AE1_{j,k}$ = the number of age-1 equivalents killed during life stage j in year k
$L_{j,k}$ = the number of individuals killed during life stage j in year k
$S_{j,1}$ = the cumulative survival rate for individuals passing from life stage j to age 1 (equation 4)

The total number of age-1 equivalents derived from losses at all stages in year k is then given by:

$$AE1_k = \sum_{j=j_{\min}}^{j_{\max}} AE1_{j,k} \quad \text{(Equation 6)}$$

where:

$AE1_k$ = the total number of age-1 equivalents derived from losses at all stages in year k

These calculations were used to derive the total age-1 equivalents for each species and year of sampling at each case study facility.

A5-3.2 Modeling Foregone Fishery Yield

Foregone fishery yield is a measure of the amount of fish or shellfish (in pounds) that is not harvested because the fish are lost to I&E. EPA estimated foregone yield using the Thompson and Bell model (Ricker, 1975). The model provides a simple method for evaluating a cohort of fish that enters a fishery in terms of their fate as harvested or not-harvested individuals. The method is based on the same general principles that are used to estimate the expected yield in any harvested fish population (Hilborn and Walters, 1992; Quinn and Deriso, 1999).

The key parameters of the Thompson and Bell model are natural mortality rate (M), fishing mortality rate (F), and weight at age (in pounds) of harvested fish. The general procedure involves multiplying age-specific harvest rates by age-specific weights to calculate an age-specific expected yield (in pounds). The lifetime expected yield for a cohort of fish is then the sum of all age-specific expected yields, thus:

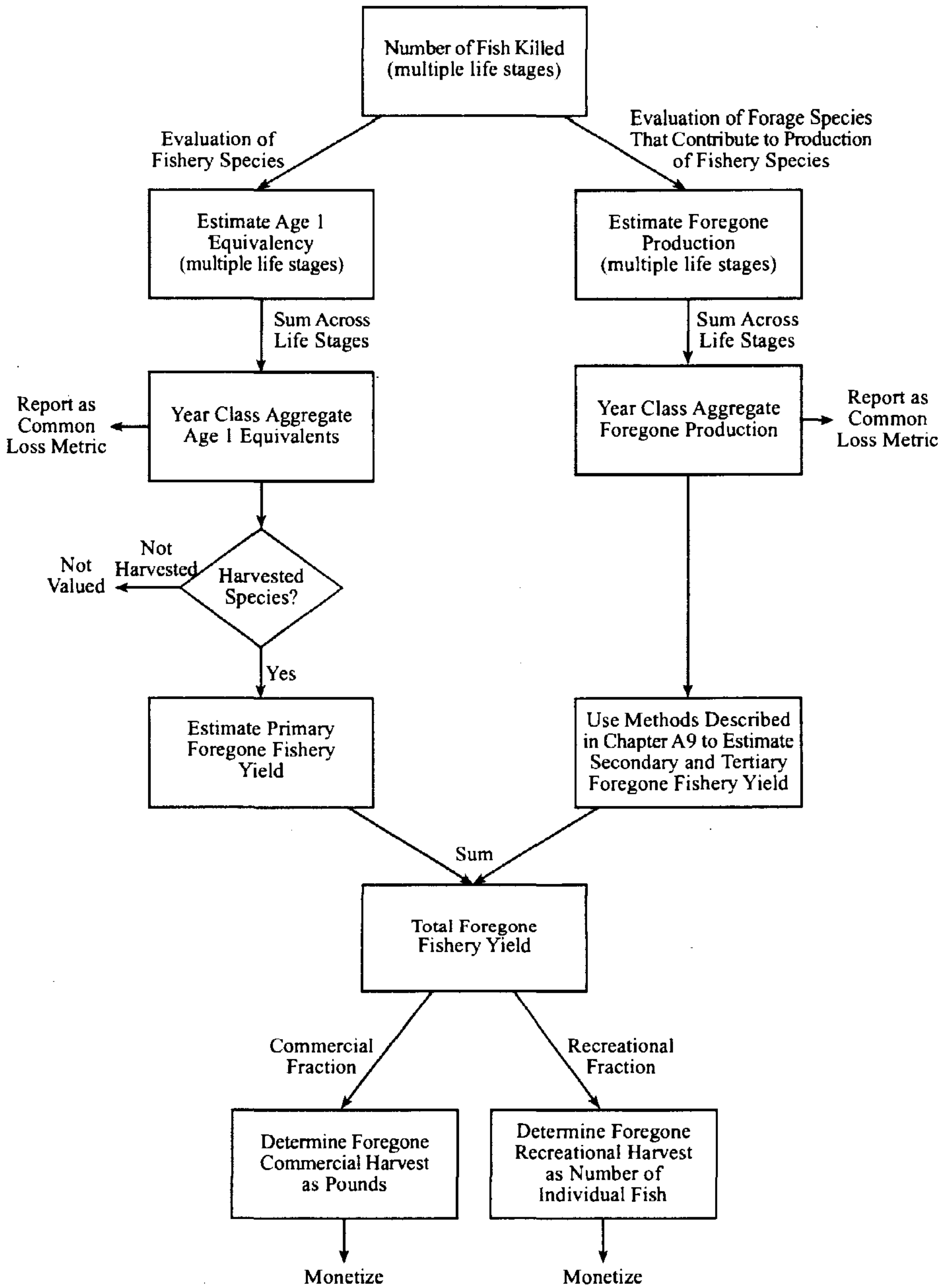
$$Y_k = \sum_j \sum_a L_{jk} S_{ja} W_a (F_a / Z_a) \quad \text{(Equation 7)}$$

where:

Y_k = foregone yield (pounds) due to I&E losses in year k
L_{jk} = losses of individual fish of stage j in the year k
S_{ja} = cumulative survival fraction from stage j to age a
W_a = average weight (pounds) of fish at age a
F_a = instantaneous annual fishing mortality rate for fish of age a
Z_a = instantaneous annual total mortality rate for fish of age a

Figure A5-1 outlines the modeling of foregone fishery yield. EPA partitioned its estimates of total foregone yield for each species into two classes, foregone recreational yield and foregone commercial yield, based on the relative proportions of recreational and commercial state-wide aggregate catch rates of that species. Pounds of foregone yield to the recreational fishery were re-expressed as numbers of individual fish based on the expected weight of an individual harvestable fish. Chapter A9 describes the methods used to derive dollar values for foregone commercial and recreational yields for the case study benefits analyses.

Figure A5-1: General Approach Used to Evaluate I&E Losses as Foregone Fishery Yield



A5-3.3 Modeling Foregone Production

In addition to expressing I&E losses as lost age 1 equivalents (and subsequent lost yield, for harvested species), I&E losses were also expressed as foregone production. Foregone production is the expected total amount of future growth (expressed as pounds) of individuals that were impinged or entrained, had they not been impinged or entrained. The foregone production of forage species (those species not harvested for recreational or commercial fisheries) is used to estimate the subsequent reduction in harvested species yield that results from a decrease in the food supply (details provided in Section A5-3.4).[1] This indirect effect on harvested species yield can then be added to estimates of foregone yield that result from direct I&E losses of harvested species to provide an estimate of total foregone yield (Figure A5-1).

Production foregone is calculated by simultaneously considering the age-specific growth increments and survival probabilities of individuals lost to I&E, where production includes the biomass accumulated by individuals alive at the end of a time interval as well as the biomass of those individuals that died before the end of the time interval. Thus, the production foregone for a specified age or size class, i, is calculated as:

$$P_i = \frac{G_i N_i W_i (e^{(G_i - Z_i)} - 1)}{G_i - Z_i} \qquad \text{(Equation 8)}$$

where:

P_i = expected production (pounds) for an individual during stage i
G_i = the instantaneous growth rate for individuals of stage i
N_i = the number of individuals of stage i lost to I&E (expressed as equivalent losses at subsequent ages)
W_i = average weight (in pounds) for individuals of stage i
Z_i = the instantaneous total mortality rate for individuals of stage i

P_j, the production foregone for all fish lost at stage j, is calculated as:

$$P_j = \sum_{i=j}^{t_{max}} P_{ji} \qquad \text{(Equation 9)}$$

where:

P_j = the production foregone for all fish lost at stage j
t_{max} = oldest age group considered

P_T, the total production foregone for fish lost at all stages j, is calculated as:

[1] Foregone production of harvested species lost through I&E (i.e., the amount of future production of harvested fish species lost because of I&E) is also calculated in this process because it is necessary for the monetization of the indirect effects of a reduction in the food supply (see Section A3-4 for details).

$$P_T = \sum_{j=t_{min}}^{t_{max}} P_j$$ (Equation 10)

where:

P_T = the total production foregone for fish lost at all stages j
t_{min} = youngest age group considered

A5-3.4 Evaluation of Forage Species Losses

Foregone production of forage species due to I&E losses may be considered a reduction in the aquatic food supply, and therefore a cause of reduced production of other species, including harvested species, at higher trophic levels. I&E losses of forage species have both immediate and future impacts because not only is existing biomass removed from the ecosystem, but also the biomass that would have been produced in the future is no longer available as food for predators (Rago, 1984; Summers, 1989). The Production Foregone Model accounts for these consequences of I&E losses by considering losses of both existing biomass and the biomass that would have been transferred to other trophic levels but for the removal of organisms by I&E (Rago, 1984; Dixon, 1999). Consideration of the future impacts of current losses is particularly important for fish, since there can be a substantial time between loss and replacement, depending on factors such as spawning frequency and growth rates (Rago, 1984).

EPA evaluated I&E losses of forage species (i.e., species that are not targets of recreational or commercial fisheries) using two general approaches. The first approach expressed losses as numbers of age 1 equivalents. These losses were valued based on hatchery replacement costs as described in Chapter A9. The second approach, referred to in this document as the "ecological approach," was developed by EPA to provide a way to value lost forage in terms of the reductions in losses of harvested species that result from loss of their prey base. In this case, the economic value of lost forage species is derived from the value of foregone production of harvested species as described in Chapter A9.

The ecological approach uses two distinct estimates of trophic transfer efficiency within two kinds of food web pathways to relate foregone forage production to foregone fishery yield. The two estimates, termed secondary and tertiary foregone yield, reflect (1) that portion of total forage production that has high trophic transfer efficiency because it is directly consumed by harvested species (secondary foregone yield), and (2) the remaining portion that has a low trophic transfer efficiency because it is not consumed directly by harvested species but instead reaches harvest species indirectly after passage through other parts of the food web (tertiary foregone yield). This is illustrated in Figure A5-2.

The basic assumption behind EPA's approach to evaluating losses of forage species is that a decrease in the production of forage species can be related to a decrease in the production of predator species through a factor related to trophic transfer efficiency. Thus, in general,

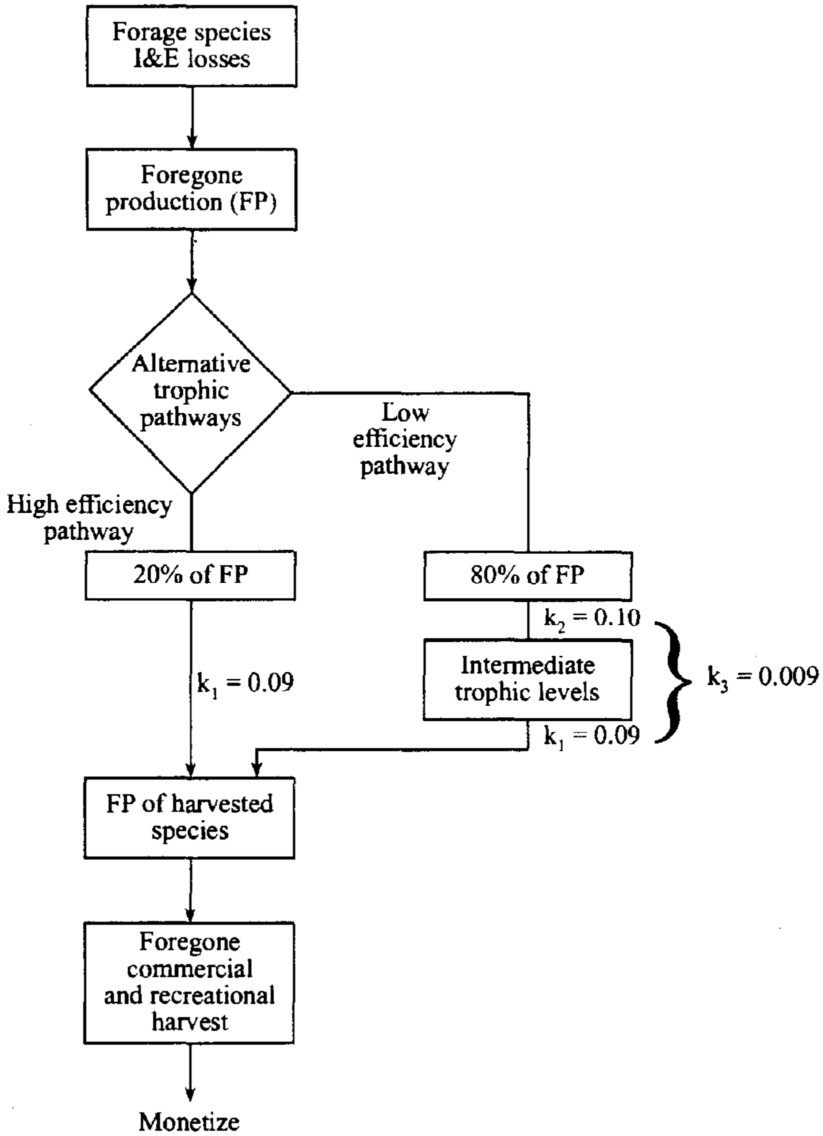
$$P_p = k\, P_f$$ (Equation 11)

where:

P_p = the biomass production of a predator species (in pounds)
k = the trophic transfer efficiency (a scalar with magnitude typically about 0.10)
P_f = the biomass production of a forage species (in pounds)

Equation 11 is applicable to trophic transfer on a species-to-species basis where one species is strictly prey and the other species is strictly a predator. For the § 316b case studies, commercially or recreationally valuable fish were considered predators.

Figure A5-2: Trophic Transfer Model for Valuation of Foregone Biomass Production (FP) of Forage Species by Estimating Consequential Reductions in Commercial and Recreational Harvest



It is difficult to determine, on a community basis, an appropriate value of k that relates aggregate forage production and aggregate predator production, since the actual trophic pathways are complicated. Therefore, for the purposes of the benefits case studies, EPA assumed a general value of $k = 0.09$ for a direct prey-to-predator transfer, and assumed that 20 percent of forage production would be consumed directly by commercially or recreationally important predators. EPA also assumed that the remaining 80 percent of forage production would be consumed indirectly by commercially or recreationally important predators (via other intermediate predators), and that k for these trophic routes would be scaled by an additional factor of 0.1. Thus:

$$P_{2p} = 0.2\ k_1 P_f \qquad \text{(Equation 12)}$$

and

$$P_{3p} = 0.8\ k_3 P_f \qquad \text{(Equation 13)}$$

where:

P_f = aggregate of foregone production of all forage species lost to I&E
P_{2p} = secondary production of commercially or recreationally important predator species
P_{3p} = tertiary production of commercially or recreationally important predator species
k_1 = trophic transfer efficiency constant with value 0.09
k_3 = trophic transfer efficiency constant with value 0.009 = $k_1 k_2$

Foregone commercial and recreational fish production estimated by these two models is referred to here as secondary production and tertiary production, respectively. The associated foregone yield is referred to as secondary foregone yield and tertiary foregone yield. The net effect of this dual pathway model for trophic transfer is an assumed trophic transfer efficiency of 0.025, which is the weighted net transfer efficiency ($0.2k_1 + 0.8k_3$).

A5-4 Uncertainty

The modeling methods used for the § 316(b) case studies, modeling assumptions, and results are presented in each case study report in a manner intended to provide the reader with a clear and complete understanding of how and why particular procedures were selected and executed. However, despite following sound scientific practice throughout, it is impossible to avoid numerous sources of uncertainty that may cause the reported results to be imprecise or to carry potential statistical bias. Uncertainty of this nature is not unique to EPA's studies of I&E effects (Finkel, 1990).

The case study analyses attempt to model a process that is enormously complex. The analyses are an interdisciplinary process that span several major fields of study, including aquatic and marine ecology, fishery science, estuarine hydrodynamics, economics, and engineering, each of which acknowledges its own complex suite of interacting factors. A formal quantification of variability and uncertainty (which could be accomplished by analytic means or by Monte Carlo methods) would require information about the variance associated with each part of this large set of factors, but much of that information is lacking. Nonetheless, because EPA took care to use the best biological models and data available for its I&E evaluations and economic analyses, EPA believes that the case study results provide a reliable, scientifically sound basis for estimating of the potential benefits of the proposed § 316(b) regulations. EPA notes that the models used are based on standard fisheries methods.

The following discussion outlines the major uncertainties in the case study analyses. Uncertainty may be classified into two general types (Finkel, 1990). One type, referred to as structural uncertainty, reflects the limits of the conceptual formulation of a model and relationships among model parameters. The other general type is parameter uncertainty, which flows from uncertainty about any and all of the specific numeric values of model parameters. The following discussion considers these two types of uncertainty in relation to the models used by EPA to evaluate I&E.

A5-4.1 Structural Uncertainty

The models used by EPA to assess the economic consequences of I&E simplify a very complex process. The degree of simplification is substantial but necessary because of the limited availability of empirical data. Table A5-1 provides examples of some potentially important considerations that are not captured by the models used in the case studies. EPA believes that these structural uncertainties will generally lead to inaccuracies, rather than imprecision, in the final results.

Table A5-1: Factors Affecting Model Uncertainty in EPA's Assessment of I&E Consequences

Type	General Treatment in Model	Specific Treatment in Model
Generally simple structure	Species lost to I&E treated independently	Fish species grouped into two categories: harvested (commercial, recreational, or both) or not harvested (forage)
Biological submodels	No dynamic elements	Life history parameters were static (i.e., growth and survival did not vary through time in response to long term trends in community); growth and survival rates in the subpopulation of fish that did not suffer I&E mortality did not change in response to possible compensatory effects
Economic submodels	No dynamic elements	Ratio of direct to indirect benefits was static through time; market values of harvested species were inelastic (i.e., were fixed and thus not responsive to market changes that may occur due to increased supply when yield is higher)
	Fish stock relevance	Fishable stock associated with I&E losses assumed to be within the state where facility is located
	Angler experience	I&E losses at a facility assumed to be relevant to angler experience (or perception) relevant to Random Utility Model (RUM) models of sport fishery economics.

A5-4.2 Parameter Uncertainty

The models used by EPA to evaluate I&E require knowledge of growth rates and mortality rates that are species-specific and often age-specific as well. Uncertainty about the values of these parameters arises for two general reasons. The first source of uncertainty is imperfect precision and accuracy of the original estimate because of unavoidable sampling and measurement errors. The second major source of uncertainty is the applicability of previous parameter estimates to the current situation. Although EPA used published parameter estimates that were judged to be most pertinent to the regions considered in the case studies, it is unlikely that growth and survival rates in case study areas would be exactly that same as survival rates developed in a different setting. The applicability of published parameter estimates may also vary through time because of changes in the local ecosystem as a whole, or because of climatological changes and other stochastic factors. All of these types of temporal changes could be manifest as significant temporary effects, or as persistent long-term trends.

Table A5-2 presents some examples of parameter uncertainty. In all these cases, increasing uncertainty about specific parameters implies increasing uncertainty about the reported point estimates of I&E losses. The point estimates are biased only insofar as the input parameters are biased in aggregate (i.e., inaccuracies in multiple parameter values that are above the "actual" values but below the "actual" values in other cases may tend to counteract). In this context, EPA believes that parameter uncertainty will generally lead to imprecision, rather than inaccuracies, in the final results.

Table A5-2: Parameters Included in EPA's I&E Assessment Model that Are Subject to Uncertainty

Type	Factors	Examples of Uncertainties in Model
Monitoring/loss rate estimates	Sampling regimes	Sampling regimes subject to numerous plant-specific difficulties; no established guidelines or performance standards for how to design and conduct sampling regimes
	Extrapolation assumptions	Extrapolation to annual I&E rates requires numerous assumptions required by monitoring designers and analysts regarding diurnal/seasonal/annual cycles in fish presence and vulnerability and various technical factors (e.g., net collection efficiency; hydrological factors affecting I&E rates)
	Species selection	Facilities responding to variable sets of regulatory demands; criteria for selection of species to evaluate not well-defined; flexible interpretation; variations in data availability in resulting time series
	Sensitivity of fish to I&E	Through-plant mortality assumed to be 100 percent; some back-calculations required in cases where facilities had reported only I&E rates that assumed <100 percent mortality
Biological/life history	Natural mortality rates	Used stage-specific natural mortality rates (M) for >10 stages per species
	Growth rates	Simple exponential growth rates or simple size-at-age parameters used
	Geographic considerations	Migration patterns; I&E occurring during spawning runs or larval out-migration? Location of harvestable adults; intermingling with other stocks
	Forage valuation	Harvested species assumed to be food limited; trophic transfer efficiency to harvested species estimated based on general models
Stock characteristics	Fishery yield	Used one species-specific value for fishing mortality rate (F) among all ages for any harvested species; used few age-specific constants for fraction vulnerable to fishery
	Harvest behavior	No assumed dynamics among harvesters to alter fishing rates or preferences in response to changes in stock size; recreational access assumed constant (no changes in angler preferences or effort)
	Stock interactions	I&E losses assumed to be part of reported fishery yield rates on a statewide basis; no consideration of possible substock harvest rates or interactions
	Compensatory growth	None
	Compensatory mortality	None
Ecological system	Fish community	Long-term trends in fish community composition or abundance not considered (general food webs assumed to be static); used simple three-compartment predation model and constant values for trophic transfer efficiency (specific trophic interactions not considered)
	Spawning dynamics	Sampled years assumed to be typical with respect to choice of spawning areas and timing of migrations that could affect vulnerability to I&E (e.g., presence of larvae in vicinity of CWIS)
	Hydrology	Sampled years assumed to be typical with respect to flow regimes and tidal cycles that could affect vulnerability to I&E (e.g., presence of larvae in vicinity of CWIS)
	Meteorology	Sampled years assumed to be typical with respect to vulnerability to I&E (e.g., presence of larvae in vicinity of CWIS)

A5-4.3 Uncertainties Related to Engineering

EPA's evaluation of I&E consequences was also affected by uncertainty about the engineering and operating characteristics of the case study facilities. It is unlikely that plant operating characteristics (e.g., seasonal, diurnal, or intermittent changes in intake water flow rates) were constant throughout any particular year, which therefore introduces the possibility of bias in the loss rates reported by the facilities. EPA assumed that the facilities' loss estimates were provided in good faith and did not include any intentional biases, omissions, or other kinds of misrepresentations.

Chapter A6: Fish Population Modeling and the § 316(b) Benefits Case Studies

CHAPTER CONTENTS

Predicting the long-term consequences of impingement and entrainment (I&E) for the populations of affected fish species requires some form of population modeling. However, because of the many uncertainties associated with population modeling, the use of fish population models to assess CWIS impacts remains a topic of ongoing debate. While this debate has many interesting dimensions, this chapter focuses only on fish population modeling as it relates to the benefits case studies. Section A6-1 introduces the general reader to concepts of population regulation that are relevant to population modeling and summarizes key features of fish stock-recruitment models, a class of models advocated by some industry groups for § 316(b) impact assessments. Section A6-2 discusses the use of stock-recruitment models in fisheries management, and Section A6-3 discusses how such models have been applied to evaluate potential CWIS impacts on fish populations. Section A6-4 discusses some of the uncertainties associated with stock-recruitment models that may limit their utility in a regulatory context. Finally, Section A6-5 discusses EPA's decision to adopt a "precautionary approach" in evaluating the biological impacts of cooling water intake structures (CWISs).

A6-1 BACKGROUND

A6-1.1 Population Regulation

The growth of biological populations is limited by natural regulatory factors such as environmental variation, random changes in rates of survival or reproduction, predator-prey relationships, disease, and competitive interactions with other individuals (Begon and Mortimer, 1986). Factors that result in population changes that are unrelated to population size are known as density independent factors. Examples include climatic variables such as temperature, floods, droughts, etc. Factors that can influence populations in relation to the size of the population, such as competition, predation or disease, are referred to as density dependent factors. The population size to which a population will tend to return in response to density dependent regulation is known as the equilibrium population.

The concept of density dependence is fundamental to the study of biological populations and to the application of population modeling in fisheries management. Compensation refers to the theoretical ability of a population to offset (compensate for) increased mortality (Goodyear, 1980; Rose et al., 2001). According to the theory of compensation, populations will grow when population density is low and will decline when density is high because competition and other density dependent processes will increase or decline in relation to population size. In this way, populations size remains relatively stable.

Inverse density dependence, or depensation, can occur when demographic rates (e.g., birth rates, survival rates) decrease at low densities (Liermann and Hilborn, 2001). Depensation can occur because of a failure to find mates when a population contains few individuals, or when fish harvest rates, impingement and entrainment, or other sources of mortality remain constant even though the population is depressed. Depensation tends to destabilize populations.

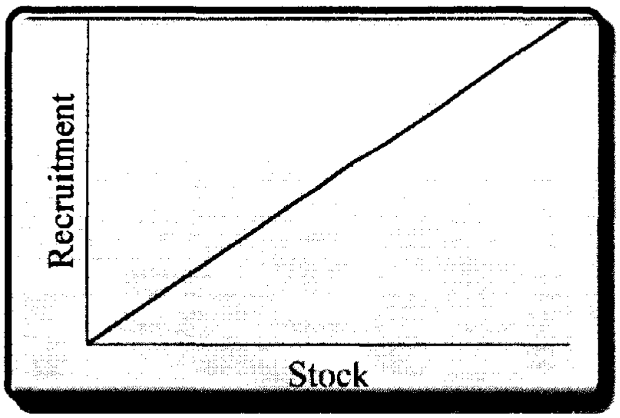
While considered likely to operate in most biological populations, compensation and other density dependent processes are difficult to observe and measure. When modeling population dynamics, this makes it difficult to identify underlying mechanisms of density dependent response and to estimate the magnitude and direction of population changes.

A6-1.2 Fish Stock-Recruitment Models

Fish stock-recruitment models are based on the assumption that some form of density dependent compensation will help maintain a stable population size despite losses of adults due to fishing (Getz and Haight, 1989; Ricker, 1975; Rothschild, 1986; Hilborn and Walters, 1992; Quinn and Deriso, 1999). Different functional forms of the stock-recruitment relationship represent different hypotheses about the response of recruitment to changes in the density of the spawning stock. There are three basic hypothetical stock-recruitment relationships, a density independent relationship, the Beverton-Holt curve, and the Ricker curve, as described below.

Density Independent Model. In the absence of any density dependent effect, it is assumed that there is a strictly linear relationship between stock and recruitment (Figure A6-1).

Figure A6-1: A Density Independent Relationship between Spawning Stock and Recruitment



This density independent relationship between stock and recruitment changes if recruitment is influenced by the number of spawners (i.e., if recruitment is density dependent). There are two general types of density dependent compensation modeled by stock-recruitment curves, the Beverton-Holt and the Ricker models.

Beverton-Holt Model. The Beverton-Holt model (Getz and Haight, 1989) depicts density dependent recruitment of a resource limited population in which resources are not shared equally. It is considered most appropriate for modeling populations characterized by within cohort cannibalism or resource competition (Wootton, 1990; Hilborn and Walters, 1992). According to the Beverton-Holt formulation, a population consists of "winners" or "losers" — each individual receives some of the available resources, or not. This means that as resources such as spawning sites become fully utilized, further increases in population size will not result in additional recruits, and when spawner abundance is reduced, there is reduced recruitment. This is expressed in the Beverton-Holt formulation as:

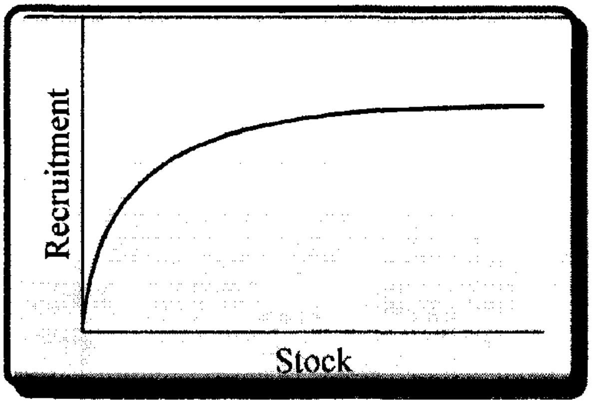
$$R = 1 / \beta + \alpha/P$$

where:

R = recruits
P = parent stock
α and β = fitted parameters

The parameters α and β are fit to field data and define the shape of the stock-recruitment curve. The slope α is considered an indication of the population's maximum reproductive rate and β represents compensatory mortality as a function of stock size. According to the Beverton-Holt model, recruitment increases in relation to stock size up to an asymptote, or maximum, at high stock abundance (Figure A6-2).

Figure A6-2: The Beverton-Holt Stock-Recruitment Relationship



Ricker Model. In contrast to the Beverton-Holt stock-recruitment model, the Ricker model (Ricker, 1975) predicts declining recruitment at high stock levels according to the equation:

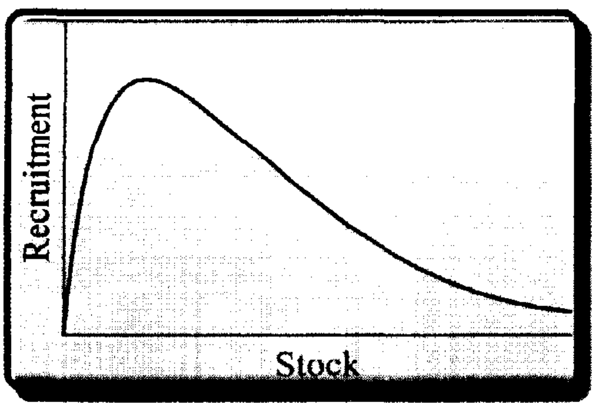
$R = \alpha P^{-\beta P}$

where, as for the Beverton-Holt model:

R = recruits
P = parent stock
α and β = fitted parameters

According to the Ricker model, the exponential term ($-\beta P$) gives the density dependent effect of parent stock on recruitment and α is the slope of the curve when P is small (Figure A6-3).

Figure A6-3: The Ricker Stock-Recruitment Relationship



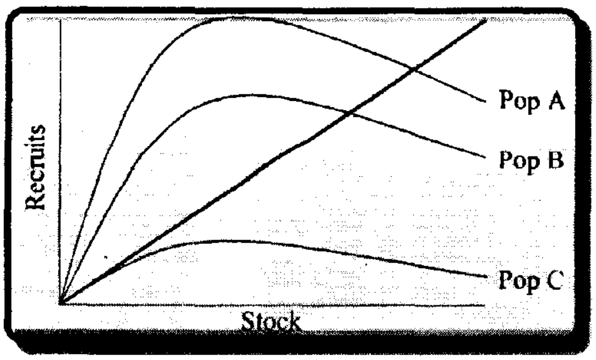
The assumption of the Ricker model is that resources are divided equally among individuals in a population. As a consequence, as density increases all members of the population receive an increasingly smaller amount of available food or other resource. The result is that at very high densities, very few individuals will survive to reproduce. Therefore, according to the Ricker equation, recruitment is controlled by αP when parent stock is small, and R increases with P in a density-independent fashion. However, when parent stock is large, R is controlled more by the density dependent term $-\beta P$, and the number of recruits declines as stock increases. The Ricker relationship is expected when there is cannibalism of the young by adults or resource competition between parents and progeny, resulting in poor survival of young at high stock sizes (Wootton, 1990; Hilborn and Walters, 1992).

A6-2 Use of Stock-Recruitment Models in Fisheries Management

Stock-recruitment models and their underlying assumptions about compensation are applied in fisheries management to estimate how much fishing mortality can be sustained on a long term basis by a commercially harvested fish population (Rothschild, 1986; Hilborn and Walters, 1992; Quinn and Deriso, 1999). This involves estimating the population's potential surplus production and compensatory reserve, as discussed below.

Surplus Production. Surplus production refers to the number of recruits produced above that needed for replacement at a given stock level and is considered the production available for harvesting (Getz and Haight, 1989; Ricker, 1975; Gulland, 1974). Surplus production is estimated by fitting stock-recruitment curves to empirical fisheries data. The 45 degree line from the origin of the stock-recruitment curve depicts exact replenishment of the population, and the area of the curve above the replacement line is the production that is available to the fishery (see Figure A6-4). The steeper the initial slope (α) of the stock-recruitment curve, the greater the expected compensatory response of the population to density changes and the larger the harvestable portion of the stock. In Figure A6-4, Population A has the strongest compensatory response. As the slope decreases, the compensatory response is less, as in Population B. As the curve approximates a straight line, the density dependent response is considered to be very weak, resulting in what is known as undercompensation, as seen in Population C.

Figure A6-4: Hypothetical Stock-Recruitment Curves



Compensatory Reserve. The slope of the spawner-recruit curve near the origin, where compensation effects are small, indicates the population's maximum reproductive rate. This gives an indication of the compensatory reserve, or the capacity of the population to offset any form of increased mortality (Myers et al., 1999; Rose et al., 2001). This is expressed as:

$$R = \alpha S\ f(S)$$

where:

R	= recruits
α	= the slope at the origin
S	= spawners
f (S)	= the relationship between survival and spawner abundance

A difficulty in estimating compensatory reserve is that there are rarely data on abundance at very low population sizes (i.e., near the origin of the spawner-recruit curve) (Myers et al., 1999; Rose et al., 2001). As a result, one of the major uncertainties in fisheries management is the actual magnitude of compensatory reserve in any given population.

A6-3 Use of Stock-Recruitment Models to Evaluate CWIS Impacts

To evaluate CWIS impacts on fish populations, stock-recruitment models have been modified to consider entrainment mortality of young instead of harvesting of adults (Goodyear, 1977a; McFadden and Lawler, 1977; Christensen et al., 1977; Fletcher and Deriso, 1988; Lawler, 1988; Savidge et al., 1988). Most of these models are based on the Ricker formulation and assume that the survival or reproduction of remaining individuals will increase in response to CWIS losses. It is thought that this will enable the population to offset or compensate for CWIS-related mortality (Jude et al., 1987a; R.G. Otto & Associates and Science Applications International Corporation, 1987; Saila et al., 1987; Systec Engineering, Inc., 1987).

In a recent paper prepared for the Utility Water Act Group for the § 316(b) rulemaking, Myers (2001) noted that the life stage at which power plant mortality occurs in relation to the timing of any compensatory response will strongly determine the degree of impact. If compensation operates in a population and power plant mortality occurs before compensation, the impact on equilibrium spawner biomass and fishery yield may be small. However, if power plant mortality occurs after compensation on juveniles, there can be a more rapid decrease in equilibrium spawner biomass with plant mortality.

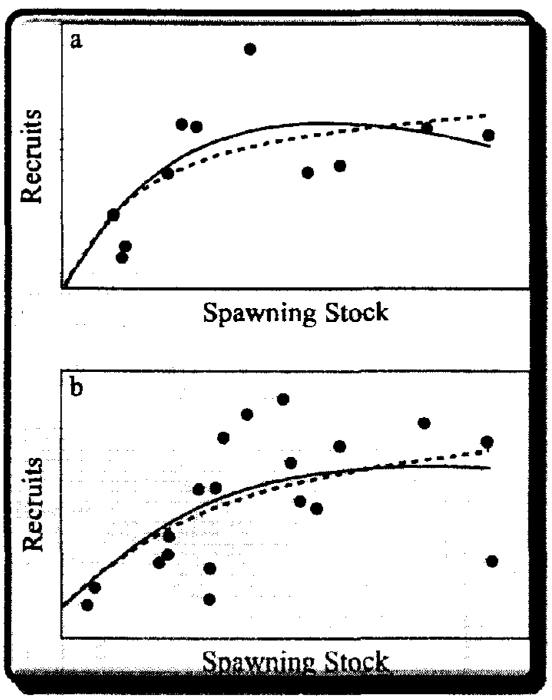
While such models can make general predictions, in practice they are limited in their ability to estimate the actual degree to which potential compensatory processes may enable any particular population to offset intake-related losses, as discussed in the following section.

A6-4 Uncertainty in Stock-Recruitment Models

A recent extensive review of available spawner-recruit data for commercially harvested marine fish stocks indicated that the recruitment of many exploited species shows a compensatory response to spawning stock (Myers et al., 1995; Myers and Barrowman, 1996; Myers et al., 1999). Data also indicate that compensation in fish species usually occurs during early life stages, although the exact timing varies by species and type of waterbody (Myers and Cadigan, 1993).

Although many fish species appear to show the potential for a compensatory response to changes in population size, in other cases a statistically significant density dependent relationship cannot be detected because of significant variability in the available population data (Shepherd and Cushing, 1990; Fogarty et al., 1991). For example, although there is a reasonably good fit of the Beverton-Holt and Ricker curves to data for coho salmon (Figure A6-5a), population data for anchoveta show considerable variation about the hypothetical stock-recruitment curves (Figure A6-5b).

Figure A6-5: The Ricker Curve (solid line) and Beverton-Holt Curve (dotted line) Fitted to Data for (a) Coho Salmon and (b) Anchoveta



Source: Modified from plots by Kimmerer, 1999, of data compiled by Myers et al., 1995.

Two major sources of recruitment variability in fish populations can cause any compensatory relationship between spawning stock and recruitment to vary unpredictably in ways that are difficult to observe and measure. These are variation in the physical environment due to fluctuations in climate and other natural conditions (Cushing, 1982; Fogarty et al., 1991) and interactions with other species (Boreman, 2000).

Competition and predation can interact in complex ways with other sources of mortality to alter stock-recruitment relationships. For example, a model of trophic dynamics among fish populations in the Patuxent River that are subject to harvesting as well as CWIS impacts predicted a significant reduction (over 25%) in striped bass, bluefish, and weakfish production as a result of power plant losses of preferred prey species such as bay anchovy and silversides (Summers, 1989). Thus, CWIS losses can contribute to reduced overall ecosystem productivity, irrespective of any potential compensation in populations directly affected by CWIS mortality (Boreman, 2000).

Most existing CWIS stock-recruitment models do not consider:

- Losses of more than one species,
- Losses from multiple CWIS,
- Other human-related sources of mortality (in addition to fishing and CWIS),
- Interactions among species, and
- Interactions among density-dependent and density-independent processes.

In practice the use of stock-recruitment curves to set fishing levels, or to determine how much I&E a population can withstand, is complicated by the many physical and biological factors that can cause the stock-recruitment relationship and potential compensatory reserve to vary over time (Christensen and Goodyear, 1988; Cushing, 1982; Fogarty et al., 1991; Boreman, 2000). It is now acknowledged that fish recruitment is a multidimensional process, and separating the variance in recruitment into its component causes remains a fundamental problem in fisheries science, stock management, and impact assessment (Hilborn and Walters, 1992; Quinn and Deriso, 1999).

Because the relationship between spawners and recruits may itself vary, applying fixed rules for achieving constant fisheries yields or taking of young by cooling water intakes can have very different effects, depending on whether population size is high or low (Clark, 1990; Myers et al., 1996).

Even if compensation operates, if and how quickly a population can recover from anthropogenic sources of mortality depends on the population's growth rate at low densities (Liermann and Hilborn, 1997; Myers et al., 1999; Liermann and Hilborn, 2001). As the degree of compensation or age at recruitment declines, there can be a dramatic reduction in the level of fishing or other anthropogenic mortality that a population can sustain (Mace, 1994). When a population at low abundance continues to be reduced by a fixed amount, the population may gradually lose resilience and may suddenly collapse in the face of disturbances that previously could have been assimilated (Goodyear, 1977a; Holling, 1996). If exploitation levels or other stressors remain high during the decline, recovery may be protracted, if it occurs at all (Fogarty et al., 1992). In the case of the winter flounder in Mt. Hope Bay, Massachusetts, substantial population decline has been associated with both overfishing and mortality associated with the operation of the Brayton Point facility (Gibson, 1996). Even though fishing restrictions have been imposed, the population has failed to recover in the face of ongoing power plant mortality.

A6-5 Precautionary Approach

Some industry representatives have argued that the environmental impacts of CWIS are adverse only if population-level impacts are demonstrated. These groups argue that compensatory processes help maintain stable fish stocks despite CWIS losses in most, if not all, affected populations. However, EPA is concerned that even in fish populations where compensatory processes are thought to operate, it has proven extremely difficult to estimate the magnitude of compensation and the form of compensatory response (Rose et al., 2001). This is a particular concern for commercially exploited marine species. A recent report by the National Marine Fisheries Service concludes that nearly a third of the 283 fish stocks under U.S. jurisdiction are currently below their maximum sustainable yield (NMFS, 1999b). For another third, the maximum sustainable yield remains uncertain. EPA notes that many of these stocks are also subject to impingement and entrainment losses.

Given that many fish stocks are at risk, EPA has adopted a "precautionary approach" in evaluating CWIS impacts because of the many uncertainties associated with modeling compensation and stock-recruitment relationships. As practiced by many natural resource agencies, the precautionary approach aims to prevent irreversible damage to the environment by implementing strict conservation measures even in the absence of unambiguous scientific evidence that environmental degradation is being caused by human stressors (NMFS, 1999b).

In this regard, many agencies now recognize that if protective measures are not initiated until effects at higher levels of biological organization are apparent, natural resources that are ecologically important or highly valued by society may not be adequately protected. In the context of the § 316(b) rulemaking, EPA notes that most CWIS cause substantial losses of aquatic organisms, and EPA believes that it is not appropriate to assume that these impacts are unimportant unless population-level consequences can be demonstrated. EPA notes that in other cases where a stressor directly affects individuals but population or higher-level effects are unclear though potentially important, individual-level endpoints often take precedence when evaluating environmental impacts (Strange et al., 2002). Indeed, in many Clean Water Act (CWA) programs EPA has found that effects on individuals can be important predictors of potential effects on populations or communities that can't be measured directly.

An example of this is provided by the National Pollutant Discharge Elimination System (NPDES) permit program. Under section 301(b)(1)(c) of the CWA, effluent limits must be placed in NPDES permits as necessary to meet water quality standards. To implement this requirement, EPA and most states rely on toxicity tests that determine the effects of discharges on individual organisms (U.S. EPA, 1991). By evaluating the effects of pollutants on growth, reproduction, and mortality of individuals, EPA uses individual impacts as surrogates and precursors of population and ecosystem impacts.

For the § 316(b) benefits case studies, EPA has chosen to evaluate multiple endpoints, including the impingement and entrainment of individuals, the most direct measures of CWIS impact. In addition, to evaluate the potential population-level consequences of these losses for economically valued endpoints, EPA has implemented several density independent models to conservatively estimate potential consequences for fishery harvests and ecosystem production, as described in detail in Chapter A5. These density independent models do not assume any compensatory response to CWIS losses. While relationships between CWIS losses, fish stocks, and fishery yields are unlikely to be strictly linear, as these models assume, EPA believes that the many uncertainties associated with modeling stock-recruitment relationships and potential compensation justify this approach, in keeping with a precautionary approach to environmental decision-making.

Chapter A7: Entrainment Survival

INTRODUCTION

This chapter addresses the issue of survival rates of aquatic organisms entrained by cooling water intake structures. Assessment of ecological and economic consequences of entrainment is based on estimates of the number of fish and shellfish killed as a result of entrainment. Entrainment monitoring programs attempt to quantify the total number of organisms entrained. If 100 percent of entrained organisms are killed by the process, then the consequences of entrainment derive solely from the total number of organisms entrained. However, if some of the organisms survive the process, then the resulting consequences may be less severe.

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Information regarding the magnitude of entrainment survival is extremely limited. To calculate benefits associated with entrainment reduction, EPA used the conservative assumption of 100 percent mortality. This same assumption was recommended in EPA's 1977 Guidance for Evaluating the Adverse Environmental Impact of Cooling Water Intake Structures on the Aquatic Environment: Section 316(b) P.L. 92-500. This chapter provides a brief review of the current knowledge regarding entrainment survival, and describes the protocols EPA believes are necessary to conduct a sound entrainment survival study for use in a cost-benefit analysis of entrainment reduction technologies.

A7-1 ENTRAINMENT MORTALITY AND ENTRAINMENT SURVIVAL

A7-1.1 Entrainment Mortality of Organisms

The most commonly entrained life stages of organisms include eggs, larvae, and juveniles. Adults are seldomly entrained. Eggs and larvae are the most common victims of entrainment because of their small size and their limited swimming ability. Eggs are extremely delicate and therefore are typically produced in high numbers to ensure that a proportion will survive to become reproducing adults. The generally high vulnerability of eggs in the natural environment ensures high mortality rates as a result of entrainment. Larvae are also typically delicate and susceptible to the physical stress of entrainment because, with the possible exception of vision and feeding apparatus, most of their major organ systems are poorly developed. Their skeletons, musculature, and integument (skin and scales) are soft and provide limited mechanical and thermal protection to vital organs. For these reasons, entrained larvae are believed to experience high mortality rates as a result of entrainment.

The presumption on the part of biologists that entrainment and passage through a cooling water intake structure would kill most if not all organisms indicates that any assertions that survival rates are appreciably greater than zero should be viewed with skepticism, and evidence in favor of that assertion must be quite strong to be convincing. Based on the "precautionary principle" in resource conservation, EPA believes that accounting for entrainment survival of entrained fish is unwarranted unless there is a strong foundation of supporting evidence that is clearly relevant to the particular features and ecological situation of the regulated facilities under consideration.

A7-1.2 Understanding Entrainment Survival

Entrainment survivability is species and life stage specific. Survivability is also be affected by the stress on an organism associated with the passage through the cooling water intake structure. Entrainment mortality is generally the result of exposure of the organisms to three types of stress (thermal, mechanical, and chemical) while passing through the cooling water intake structure. These stressors can interact with each other and are jointly affected by the operating characteristics of the power facility. These three stressors can also affect different species and life stages of entrained organisms differently. Since the extent and effect of these stressors can vary at each facility, the results of a study at one facility cannot be assumed to apply to another facility. Also, the results of a study at a facility can only be applied to time periods when the entrained organisms experience the same level of stresses and are not indicative of all times at a facility when stress levels may be different.

Thermal stress

Dose-response models that relate thermal exposure to mortality rate are critical in understanding the extent of the effect of thermal stress on aquatic organisms. The magnitude of thermal stress resulting from passage through the facility depends on several facility-specific parameters such as maximum temperature, intake temperature, discharge temperature, duration of exposure to elevated temperatures through the facility and before mixing with ambient temperature water, the maximum tolerable temperature of the species, and delta T (ΔT, i.e., the difference between ambient water temperature and maximum water temperature within the cooling system). The effect of the values of each of these parameters varies among the species and life stages of entrained organisms. Larger organisms are typically more tolerant than smaller organisms.

The Electric Power Research Institute (EPRI) sorted larval entrainment survival data by discharge temperature and determined that survivability decreased as the discharge temperature increased (EA Engineering, Science and Technology, 2000). The lowest probability of larval survival occurred at temperatures greater than 33 °C.

Mechanical stress

Entrained organisms are also exposed to significant mechanical stress, which can also lead to high mortality. Types of mechanical stress include effects from turbulence, buffeting, velocity changes, pressure changes, and abrasion from contact with the interior surfaces of the cooling water intake structure.

Chemical stress

Chemical biocides are routinely used within cooling water intake structures to remove biofouling organisms. These biocides often contain chlorine, which can negatively affect any potential entrainment survival of entrained species. The timing of any biocide application should be scheduled during times of low egg and larval abundance. The concentration and duration of biocide use need to be fully documented to gain a better understanding of the effect on entrainment survival.

A7-2 Existing Entrainment Survival Studies

Facility studies have tried to estimate entrainment survival (see Table A7-1). These studies varied in study designs and analytical methods. Important aspects of the study designs that differed between studies included sampling gear (e.g., types of nets or other collection devices), sampling locations relative to intake and outflow, sampling frequency, species collected, and observations of latent mortality. Table A7-1 provides a list of entrainment studies reviewed in this chapter by EPA.

A recent report prepared for EPRI (EA Engineering Science & Technology, 2000) summarized the results of 36 entrainment studies prepared for individual power facilities, including the 13 studies listed in Table A7-1. The report concluded that in most cases the assumption of zero entrainment survival is overly conservative. Although these studies indicate that entrainment survival may occur for certain species under certain conditions, the studies were conducted with a variety of sampling and measurement protocols. The fact that existing studies have been conducted using various methods highlights the fact that facilities have some unique features that affect monitoring procedures; it also complicates efforts to synthesize the various results in a manner that would provide useful generalizations of the results or application to other particular facilities. For these reasons, EPA believes that the results presented in the report have limited utility. A more useful analysis would include consideration of aggregated variance components, which could be used to determine confidence intervals around the mean values that the report determined for individual species. Although a description of confidence intervals is always desirable, determining valid confidence intervals in the context of an analysis can be difficult (or impossible) unless the statistics available from each individual study are complete and sufficiently comparable. In EPRI's report, it seems likely that differences among the basic studies with respect to measurement protocols were too large, or descriptions of variance components were too few, to permit a more rigorous statistical summary.

Table A7-1: Entrainment Survival Studies Reviewed by EPA

Facility	Waterbody	State	Sampling Dates	Species Studied	Survivability Calculations	Citation
Braidwood Nuclear	Kankakee River	IL	June - July 1988	*Lepomis* cyprinids	initial	EA Science and Technology, 1990
Brayton Point	Mt Hope Bay	MA	April - August 1997 February - July 1998	winter flounder, tautog, windowpane flounder, bay anchovy, American sand lance	initial and 96 hour latent	Lawler Matusky & Skelly Engineers, 1999
PSI Cayuga Generating Plant	Wabash River	IN	May - June 1979	catastomids percids cyprinids percichthyids	initial and 48 hour latent	Ecological Analysts Inc., 1980a
Indian Point Generating Station	Hudson River	NY	March - August 1979	Atlantic tomcod striped bass white perch herrings bay anchovy	initial and 96 hour latent	Ecological Analysts Inc., 1981b
Indian Point Generating Station	Hudson River	NY	April - July 1980	striped bass bay anchovy	initial and 96 hour latent	Ecological Analysts Inc., 1982
Indian Point Generating Station	Hudson River	NY	May - June 1985	bay anchovy	initial	EA Science and Technology, 1986
Indian Point Generating Station	Hudson River	NY	June 1988	striped bass white perch bay anchovy	initial and 24 hour latent	EA Engineering Science and Technology, 1989
Indian River Power Plant	Indian River Estuary	DE	July 1975 - December 1976	bay anchovy	initial and 96 hour latent	Ecological Analysts Inc., 1978a
Oyster Creek Nuclear Generating Station	Barnegat Bay	NJ	February - August 1985	bay anchovy winter flounder	initial and 96hour latent	EA Engineering Science and Technology, 1986
Port Jefferson	Long Island Sound	NY	April 1978	winter flounder, American sand lance, fourbeard rockling, American eel, sculpin	initial and 96 hour latent	Ecological Analysts Inc., 1978b
PG&E Potrero	San Francisco Bay	CA	January 1979	Pacific herring	initial and 96 hour latent	Ecological Analysts Inc., 1980b
Quad Cities Nuclear Station	Mississippi River	IL	June 1978	freshwater drum non-carp cyprinids	initial and 24 hour latent	Hazleton Environmental Science Co., 1978
Quad Cities Nuclear Station	Mississippi River	IL	April - June 1984	freshwater drum carp buffalo	initial and 24 hour latent	Lawler Matusky & Skelly Engineers, 1985

Other specific aspects of the EPRI report that limit its utility include the following (which are primarily features of the source studies rather than the review itself):

- the limited geographic areas in the studies
- the small sample sizes in the studies
- the limited species in the studies
- the variation in sampling procedures
- the absence of information on chemical stresses
- the absence of information on mechanical stress
- the limited data on latent physiological effects on species
- effects from entrainment on growth rates
- increased vulnerability to natural mortality, maturation, and fertility/fecundity.

For these reasons, EPA concludes that the sampling and data in the studies reviewed in the EPRI report are far too limited to justify their use as a screening tool at the national level.

A7-3 Analysis by EPA of 13 Existing Studies

EPA reviewed the following 13 studies to determine if they were conducted in a manner to give an adequate representation of the current probability of entrainment survival at the facility.

Braidwood Nuclear Station

Larval samples for an entrainment survival study were taken from the intake and discharge of the facility in 1988. Although sampling at the discharge determined that the peak densities of larvae and eggs occurred during May, the samples for the entrainment sampling study were taken in June and July, which may have resulted in samples that included fewer and larger entrained organisms. A no. 0 mesh plankton net with a 1.0 m opening was used to collect samples. Samples were taken in areas where the velocities were approximately 0.5 ft/sec. After the sample was taken, the net was placed in a 5 gallon bucket containing water (no water chemistry or temperature data given), untied, and rinsed into the bucket. The larvae samples were sorted within 20 minutes of collection into three classes: live, dead-transparent, and dead-opaque. The dead-opaque larvae were omitted from the calculations of survival proportions as it was suggested that these opaque larvae probably died before collection. It was also assumed that the dead-transparent larvae died during passage through the system. After sorting based on mortality, the larvae were identified by species and separated into life stages. Survival proportions were determined by dividing the number of live larvae by the number of live plus dead-transparent larvae.

The intake survival study samples were collected from the holding pond, into which river water was pumped, during the day of June 1 (10 two minute replicates) and during the night of June 7 (2 two minute replicates) and July 5 (12 two minute replicates). There were no data given to determine that conditions were similar on the three sampling dates. The three intake survival sampling dates yielded a total of 191 individuals. Of these, the primary species sampled were cyprinidae (77 percent) and *Lepomis* sp. (6.8 percent). Of the larvae sampled on the three dates, 128 individuals were classified as dead-opaque and omitted from any calculations of survival proportions, 20 were dead-transparent, and 43 were live. Samples sizes were so small that all data of all species from the three sampling dates were combined to conclude that 68 percent of the larvae survived passage from the river screen house to the holding pond. EPA recalculated this intake survival, including the dead-opaque larvae, to determine that in fact only 23 percent survived. It is misleading to assume that these individuals died prior to pumping into the holding pond. To account for those larvae that may be dead in a sample from natural conditions, EPA suggests a similarly sized sample be collected away from the intake and before the river water is pumped into the holding pond as part of the same sampling event to account for any natural and sampling equipment related mortality.

The discharge samples were taken downstream of the outfall in the discharge canal during the day on the June 1 (11 two minute replicates), June 7 (13 two minute replicates), and June 21 (14 two minute replicates). Water chemistry and facility temperature information were not given to determine if conditions were similar on the three sampling dates. These three discharge sampling dates yielded a total of 103 individuals. Again, since the number of larvae sampled was low, all data from all three sampling dates were combined. Of the larvae sampled on the three dates, 22 individuals were classified as dead-opaque and omitted from any calculations of survival proportions, 20 were dead-transparent, and 61 were live. The study concluded that overall survival rate at the discharge was 75 percent. EPA included the dead-opaque larvae and concludes that the actual overall discharge survival should be recorded in this study as 59 percent. Rather than collecting intake and discharge samples simultaneously, EPA would prefer that the discharge samples be taken after a sufficient lag time from the intake samples to simulate passage through the facility. It is also important to take discharge samples as close to the outfall as possible, rather than downstream, to ensure that the larvae sampled were in fact those that passed through the facility. If sampling mortality due to collection cannot be reduced, then EPA suggests that the percent survival of all individuals sampled from the discharge without correcting for sampling equipment related mortality be used to ensure a fair, accurate, and conservative estimate of entrainment survival.

EPA disagrees with EPRI's determination that this facility experiences 100 percent survival for *Lepomis* sp. larvae based on the 1988 study. EPRI's calculation used the study's survival proportions, which had already corrected for dead-opaque larvae that were assumed to have died prior to passage through the facility, and further corrected for dead larvae by dividing the discharge survival by the intake survival, assuming incorrectly that the intake survival was a control. EPRI calculated the initial discharge survival for *Lepomis* sp. larvae as 80 percent (60 live larvae of 75 live and dead-transparent larvae with four dead-opaque larvae omitted). EPRI then divided this initial survival rate by the intake survival rate for *Lepomis* sp. larvae calculated as 78 percent (seven live larvae out of nine live and dead-transparent larvae) to correct for natural and sampling equipment related mortality to yield an initial entrainment survival of greater than 100 percent (0.80/0.78). Since the dead-opaque larvae were already omitted from the calculation and the initial survival study was not a true control, this overstates entrainment survival of *Lepomis* sp. larvae. While EPA concludes that the entrainment survival of *Lepomis* sp. larvae is not 100 percent, EPA notes that the limited samples collected give an indication that there may be some initial larval survival. Further entrainment survival studies would be needed at this facility using EPA's suggestions above before assuming anything more than 0 percent entrainment survival. Additional studies should also be conducted to determine latent mortality of larvae and egg viability after entrainment.

Brayton Point

Samples were collected in 1977 weekly from April 30 to August 27 and in 1998 weekly from February 26 to July 29. Samples were not collected during times of biocide use. The numbers of samples taken per week varied. The time of day the samples were collected also varied, with samples collected primarily during the day before March 18, 1988 and primarily during the night after that date. A total of 889 samples in 1997 and 1,424 in 1998 were collected at the intake from mid-depth directly in front of the Unit 3 intake screens. A total of 1,803 samples in 1997 and 2,713 in 1998 were collected at the discharge approximately 2 to 4 ft below the surface from either the middle of the discharge canal for Units 1, 2, and 3 or from the Unit 4 discharge pipe. Samples were collected in larval tables by pumping water into the table for approximately 15 minutes. After each sampling period, samples were transferred into 19 L buckets, covered, and transported to the laboratory for sorting. A time of 30 minutes per sample was targeted, but it is unclear how often this target time was met. Dead larvae were counted, identified, and preserved. Live or stunned larvae were transferred to holding cups with plastic spoons, turkey basters, or other unspecified devices, with a maximum of 20 larvae per cup. The holding cups were placed in the racks in the aquariums through which ambient temperature water flowed. Live larvae were held for 96 hours to determine latent survival. This study calculated entrainment survival assuming stunned organisms did not survive entrainment due to the increased risk of predation.

In the 1997 samples, 239 individuals were collected at the intake and 18,998 individuals were collected at the discharge. Bay anchovy was the predominant species, accounting for 71 percent of the total collected. Discharge water temperatures were highly variably and ranged from 13.5 to 35 °C. In the 1998 samples, 2,017 individuals were collected at the intake and 8,576 individuals were collected at the discharge. American sand lance was the predominant species, accounting for 38 percent of the total collected. Discharge temperatures were also highly variable and ranged from 10.5 to 45 °C. The differences in numbers and species collected at the intake and discharge raise concerns regarding the comparability of the survival estimates at the two sampling locations.

Because of low sample sizes, all data from all sampling conditions from 1997 and 1998 were combined. For American sand lance, total survival at the intake was 0.13 percent and total survival at the discharge was 0.41 percent; for tautog, intake survival was 4.2 percent and discharge survival was 4.4 percent. Since intake survival for these species was lower than discharge survival, it is impossible to distinguish between mortality due to collection and handling, and mortality due to the effects of entrainment. If entrainment survival were calculated as discharge survival divided by intake survival, the result would be an erroneous 100 percent entrainment survival. Survival was negligible for bay anchovy both at the intake (0 percent) and at the discharge (0.04 percent). For windowpane flounder, intake survival was 65 percent and discharge survival was 44 percent which results in an overall entrainment survival of 68 percent. For winter flounder, intake survival was 90 percent and discharge survival was 32 percent, which results in an overall entrainment survival of 36 percent. Survival was also analyzed with regard to discharge temperatures. In general, entrainment survival decreased markedly at discharge temperatures above 20 °C. The results of this study seem to indicate that this facility has a negative effect on survival of entrained organisms. The extent of the effect is unclear because of inadequacies and inconsistencies in the sample protocols. EPA recommends that future studies at this site should pair intake and discharge sample locations, times, and sizes to accurately represent the organisms that are entrained in the units of this facility. Also, EPA recommends that only samples collected under similar conditions be combined for statistical purposes.

Cayuga Generating Plant

Larvae samples were taken from the intake and discharge of the cooling system to determine entrainment survival at the facility in May and June of 1979. Samples were also taken from a cooling tower located on the discharge canal. Both initial and 48 hour latent survival were determined. Transit time through the cooling system was given as 2,180 seconds (36.34 minutes) and the ΔT during the sampling events ranged from 8.4 to 11.8 °C, with discharge temperatures ranging from 29.4 to 33.3 °C. Chlorination occurs daily at this facility, but treatments ceased at least 2 hours before the start of each sampling event. Between 0 and 6 sample pairs were collected at night from May 17 to 31 and June 8 to 22. The highest average densities of organisms sampled were from June 8 to 10. It is unclear why sampling was discontinued June 1 to 7 when densities of organisms may have also been high. Samples were taken simultaneously at the intake and discharge sites rather than stratified to give a lag time to simulate passage through the facility. Samples were collected by pumping water through the pump/larval table collection system for 15 minute intervals, after which the tables were drained and rinsed with ambient or discharge temperature river water, as appropriate, to collect the samples into a transportation container for sorting. The collected larvae were immediately classified as live, stunned, or dead. The dead larvae were preserved for subsequent identification. The live and stunned larvae were sorted by life stage and transferred to 1 L jars containing filtered river water, with a maximum of five individuals per jar. Filtered river water may not accurately simulate the actual conditions under which organisms are exposed after discharge from the facility. The jars were aerated and maintained in an ambient temperature bath for 48 hours after collection. Initial survival at the intake and discharge station was calculated as the proportion of the larvae alive to all larvae collected. Standard error of the survival proportion was calculated, as well as Fisher's exact test for independence to determined if the discharge survival was significantly lower than the intake survival.

The 80 intake survival samples yielded a total of 1,614 individuals in three life stages of 11 families (1,010 yolk sac larvae (YSL), 597 post yolk sac larvae (PYSL), and seven juveniles). Because sample sizes were so low for each sampling event, data were combined across samples to give a total estimate of intake survival by species irrespective of the facility conditions under which the samples were taken. Because of insufficient data, survival estimates were determined for only four taxa, catostomidae (621 YSL and 363 PYSL), cyprinidae (278 YSL and 188 PYSL), percidae (94 YSL and 14 PYSL), and percichthyidae (25 PYSL). The intake samples showed high mortality resulting from either natural conditions or rough handling during sampling. For example, in one sample, 33 larvae (41.25 percent) were classified as dead or stunned out of a total of 80 catostomidae larvae collected. These high mortality rates at the intake need to be reduced to the maximum extent possible. When divided into the mortality rates at the discharge site, high sampling mortality can mask any additional mortality due to passage through the facility.

The 80 discharge survival samples yielded a total of 942 individuals in three life stages of 11 families (463 YSL, 478 PYSL and 2 juveniles). Again, due to insufficient data, survival estimates were determined for only four taxa, catostomidae (306 YSL and 343 PYSL), cyprinidae (95 YSL and 97 PYSL), percidae (53 YSL and 13 PYSL) and percichthyidae (17 PYSL). Densities were sometimes much higher in the intake samples than in the discharge samples for the top three families, ranging from 1.7 to 16.4 times higher in the intake samples. This difference in organism densities can cause problems when comparing mortality rates at the two locations. Using Fisher's Exact Test, all but the percidae PYSL showed an initial and 48 hour latent discharge survival significantly lower than the initial and 48 hour latent intake survival. However, when divided by the intake survival to calculate the survival estimate, this difference is reduced and falsely high survivability estimates without standard errors are reported in EPRI's study.

Entrainment survivability was also analyzed with regard to discharge temperature. Lower entrainment survival occurred at temperatures above 30 °C. The lowest percentage surviving discharge temperatures greater than 34 °C were observed for the cyprinidae YSL, with an average of only 4.8 percent ± 4.7 percent surviving in the discharge samples. The facility's report calculates a 17.1 percent ± 16.7 percent entrainment survivability for cyprinidae YSL at temperatures greater than 34 °C by dividing the discharge proportion by the proportion surviving the intake under all conditions of 28.0 percent ± 2.7 percent (0.048/0.280). The amount of time the discharge temperatures exceed 30 °C was not provided even though this appears to have a profound effect on survivability. Given that samples were taken at different times with different sampling sizes, it is unclear whether the use of the data in this manner results in an accurate depiction of the actual entrainment survivability.

Indian Point Generating Station

EPA reviewed entrainment survival studies conducted at this facility in 1979, 1980, 1985, and 1988.

Atlantic tomcod larvae samples were collected in late winter, March 12 - 22, 1979, using pump/larval table collection systems. Sampling was scheduled to coincide with the time period of greatest abundance of tomcod larvae. Samples were collected at night eight times over a 2 week period. One unit was not operational during three nights of sampling, March 20-22. Intake and discharge samples were collected simultaneously rather than with a lag period to simulate passage through the facility. Samples were delivered to the larval table by two pumps for 15 minutes per sample. The pumps were then turned off and the larval tables were drained and then rinsed with ambient water to concentrate the organisms into the collection box. After collection, the larvae were sorted as live, stunned, or dead based on the extent of activity observed. Live and stunned larvae were transferred with a pipette into 1 L jars containing filtered ambient river water with a maximum of five individuals per jar. The jars were aerated and maintained in an ambient temperature bath for 96 hours. Discharge temperatures during the study period ranged from 12.0 to 21.9 °C. These latent mortality experimental conditions may not accurately simulate the actual conditions under which the organisms were exposed to subsequent to entrainment. Initial survival ranged from a low of 7 percent with discharge temperatures greater than 20 °C to high of 40 percent with discharge temperatures less than 16 °C. After taking into account latent survivability, the overall entrainment survival estimates ranged from a low of 11 percent with discharge temperatures above 20 °C and a high of 64 percent with discharge temperatures below 16 °C.

Striped bass, white perch, herring, and anchovy samples were collected from April 30 through August 14, 1979, using a rear-draw plankton sampling flume at the intake and a pumpless plankton sampling flume at the discharge. These methods relied on head-induced flow (created by the pressure difference due to the difference in water levels of the river and discharge canal) instead of pumps to collect organisms in an attempt to reduce mortality from collection and handling. The floating sampling gear was also advantageous to sample from the submerged discharge ports at this facility. Only one unit operated continuously throughout the study period. This may result in discharge temperatures which were not representative of the elevated temperatures which could be expected when the facility operates at full capacity. Intake and discharge samples were collected simultaneously. Samples were collected for 15 minutes each for two consecutive nights each week for a total of 32 sampling events. After the 15 minute period, flow through the flume was stopped and ambient water flushed the organisms into collection boxes. After collection, larvae were sorted as live, stunned, or dead based on the extent of activity observed and eggs were sorted as live or dead based on coloration. Live and stunned larvae were transferred with a pipette into 1 L jars containing filtered ambient river water with a maximum of five per jar. The jars were aerated and maintained in an ambient temperature bath for 96 hours. These experimental conditions may not adequately simulate the actual conditions under which the organisms were exposed after entrainment. Eggs were transferred to cups with fine mesh screened bottoms to allow for ambient water flow. Because of insufficient sample size, all data for striped bass eggs were combined so that 124 eggs were collected at the intake and 55 eggs were collected at the discharge. The 96 hour latent intake survival of striped bass eggs was 44 percent and the discharge survival was 33 percent through a range of discharge temperatures of 24 - 28 °C. The average entrainment survival estimate for striped bass eggs, calculated as discharge survival divided by intake survival, was 74 percent (0.33/0.44). For the fish larvae samples, a difference in stress associated with the different sampling techniques at the intake and discharge was given as the reason why discharge survival was higher than intake survival for each taxa sampled. Thus, entrainment survival was not calculated. Initial discharge survival for all taxa ranged from a low of 3 percent for anchovy PYSL to a high of 75 percent for striped bass YSL at discharge temperatures ranging from 30.0 to 32.9 °C.

In 1980, additional samples were collected four consecutive nights per week from April 30 through July 10 for a total of 44 sampling events. The sampling gear is this study was modified to reduce the disproportionate stress from the different collection techniques used at the intake and discharge sampling sites. A total of 272 striped bass eggs were collected from the intake and 147 eggs were collected from the discharge over a range of discharge temperatures from 23 to 31 °C during the collection. The 96 hour latent intake survival was 82 percent while the discharge survival was 47 percent, resulting in an entrainment survival for striped bass eggs of 56 percent (0.47/0.82). Entrainment survival estimates ranged from a low of 5 percent survival for bay anchovy PYSL at discharge temperatures above 33 °C to a high of 97 percent survival for white perch PYSL at discharge temperatures below 29 °C.

In 1985, samples were collected with a barrel sampler daily from May 12 through June 29. Throughout the study a small sample set was collected; only 115 larvae and juveniles were collected from the intake and 342 from the discharge. Insufficient numbers were collected at both the intake and discharge for all taxa collected except bay anchovy PYSL, which comprised 83 percent of the total number sampled. For bay anchovy PYSL, 106 were collected at the intake and 274 were collected at the discharge. The survival at the intake was determined to be 23 percent while the survival at the discharge was determined to be 6 percent, resulting in an entrainment survival estimate of 24 percent (0.06/0.23). There was insignificant survival for both the intake and discharge samples to calculate latent survivability.

In 1988, the entrainment survival study was repeated to determine the effect of the installation of dual speed circulating water pumps in Unit 2 in 1984 and variable speed pumps in 1985. Previously calculated entrainment survivability rates demonstrated the effect of entrainment when the older single speed pumps were in use. Samples were collected for 15 minute intervals on 13 days from June 8 through June 30 during afternoon and evening hours using rear-draw sampling flumes. Intake samples were collected from in front of the intake structure and discharge samples were collected downstream from the point where the discharge flow from Units 2 and 3 join. For all samples combined, a total of 1,132 individuals were collected at the intake and 11,201 were collected at the discharge. The reason for the great disparity between intake and discharge organism densities was unclear. Bay anchovy (67 percent), striped bass (26 percent), and white perch (3 percent) were collected in the greatest proportions. At the intake, initial and 24 hour latent survival varied widely with many taxa having 0 percent survival for both. Bay anchovy PYSL was collected in the greatest numbers, 441, and had 8 percent initial survival and 0 percent 24 hour latent survival. Striped bass PYSL, 273 collected, had an initial survival of 90 percent and a 24 hour latent survival of 56 percent. At the discharge, initial and 24 hour latent survival also varied widely, with many taxa having 0 percent survival for both. Bay anchovy PYSL, 6,969 collected, had an initial survival of 2 percent and a 24 hour latent survival of 0 percent. Striped bass PYSL, 2,398 collected, had 68 percent initial survival and 44 percent 24 hour latent survival. The total entrainment survival for bay anchovy PYSL was 0 percent and for striped bass PYSL was 76 percent for initial survival and 79 percent for 24 hour latent survival (calculated as discharge survival divided by intake survival).

While these studies were the most comprehensive of all studies reviewed by EPA, they still contain several inadequacies that would need to be addressed before giving a full and accurate depiction of the actual entrainment survival of fish and shellfish at this facility. Further studies would be needed to address the problems of low sample sizes, disparate densities at sampling points, and high intake mortality.

Indian River Power Plant

Samples were taken once or twice monthly and mostly at night from July 21, 1975, to December 13, 1976, using a 0.5 m diameter plankton sled fitted with 505 μm net. The average discharge temperature ranged from a low of 7.7 °C in January 1976 to a high of 38.7 °C in August 1975, with an average ΔT that ranged from a low of 5.2 °C in July 1975 to high of 9.0 °C in November 1975. The samples were taken for approximately 5 minutes each until an appropriate number of individuals of each selected species were collected. After collection, the cod end of the net was submerged in approximately 10 L of water of unspecified type and temperature. Samples were poured into enamel pans and individuals of selected species were then removed from the pans with plastic spoons, meat basters, or eyedroppers and placed into holding containers with 10-25 individuals per container. During this process, individuals were assessed as either live or dead; however, for highly abundant species, the number of live versus dead was taken from a random sample of the total sample. To determine latent survivability, larger organisms were held in plastic Dandux boxes in tanks through which intake water flowed. Discharge water for the discharge samples flowed through those holding tanks for the first 4 to 6 hours, after which ambient water was introduced to the tanks. Smaller organisms were held in 250 mL plastic cups which floated in styrofoam frames within Dandux boxes in the holding tanks. Latent survivability was observed for 96 hours during which time the organisms were fed. Both absolute and percent survival data were presented for the seven species of fish and shellfish.

The 25 intake samples were taken from the foot bridge over the intake canal. This study used the same assumption that intake mortality was natural or caused by handling during collection. High approach velocity may also account for high mortality in the intake samples. The 21 discharge samples were taken from the discharge canal under a roadway bridge. It is unclear why discharge samples were not collected each time intake samples were collected. Appendix B, which contained the entrainment study data, was not made available to EPA. Therefore, the survivability calculations could not be verified. As in other studies, very low intake survivability masked any additional mortality due to entrainment. For example, bay anchovy experienced an average of only 21 percent intake survivability, which, when combined with low sample sizes, made it extremely difficult to determine the extent of any additional mortality due to the effects of entrainment. When samples where sorted based on discharge temperatures, all species presented experience reduced survivability at average discharge temperatures above 20 °C. Four species experienced 0 percent survival above 35 °C. The facility's study attempted to determine the relationship between the times of high facility discharge temperatures with times of greatest species abundance to gain a better insight to the facility induced mortality rates. The extent to which this affects the overall survivability for species throughout the year remains unclear. This information would have been helpful to determine the percentage of time most organisms will experience zero survival at this facility. It is also unclear if the discharge temperatures remain comparable at this time (over 25 years later). Dye studies have also been performed at this facility and recirculation of discharge water has been shown to occur. The extent to which organisms are entrained repeatedly and the effect this has on the number of organisms that were shown to have died through either natural causes or from sampling from the intake is not known, and thus some intake mortality may be due to the organism's previous passage through the facility, which may further mask entrainment mortality.

Oyster Creek Nuclear Generating Station

An entrainment survival study was performed at this facility from February through August 1985. Entrainment survival was estimated for bay anchovy eggs and larvae and winter flounder larvae. Intake samples were collected at the intake and discharge samples were collected approximately 2 minutes later to simulate the passage of the same portion of water through the facility. Samples were collected for approximately 10 minutes each with a barrel sampler which consists of two nested cylindrical tanks. The inner cylinder has 331 mm mesh screened panels that collect organisms as water is drawn into the inner cylinder and out through the screens and outer cylinder. This design intended to reduce sampling mortality through abrasion from the sampling gear and by minimizing the velocity of the water sampled to 1 cm/sec. Samples were held in flow-through water systems with either ambient or discharge temperature water as appropriate. Organisms were sorted as either live, stunned, or dead. Live and stunned organisms were transferred to flow-through or solid holding containers in water baths to determine 96 hour latent survivability. Larvae were fed throughout the observation period. Eggs were classified as live when clear or transparent in color, and dead if cloudy, opaque, or showed no development during observation. Data were grouped by 3 day long sampling events. It was unclear if conditions remained similar throughout the 3 days of each sampling event. Water quality data such as temperature, dissolved oxygen, salinity, and pH were recorded throughout the 96 hour observation period. Chlorine concentrations were measured during sample collection to determine any mortality due to biocide use, but chlorine was not detected. The raw data were not provided in any appendix to this study, so the calculation of survival estimates could not be verified.

A total of 20,227 bay anchovy eggs were collected from the intake and 26,243 were collected from the discharge from 13 sampling events. During sampling, the discharge temperature ranged from 25.9 to 38.1 °C and the ΔT ranged from -0.2 to 12.1 °C. It was unclear whether the facility was operating during sampling event 17 when the ΔT was -0.2 °C (intake temperature of 26.1 °C minus discharge temperature of 25.9 °C). Initial survival, calculated as discharge survival divided by intake survival, ranged from 21 to 83 percent. The 96 hour latent survival, calculated as discharge survival divided by intake survival, ranged from 0 to 100 percent. The total survival for bay anchovy eggs, calculated as initial survival multiplied by latent survival, ranged from a low of 0 percent at discharge temperatures above 38 °C to a high of 93 percent at a discharge temperature of 26.2 °C. Overall, the average survival was below 50 percent at discharge temperatures above 32 °C.

A total of 3,396 bay anchovy larvae were collected from the intake and 3,474 were collected from the discharge from 10 sampling events. During sampling, the discharge temperature ranged from 25.9 to 39.3 °C and the ΔT ranged from -0.2 to 11.7 °C. Initial survival, calculated as discharge survival divided by intake survival, ranged from 0 percent at temperatures above 35 °C to 99 percent at a discharge temperature of 26.2 °C. Initial survival was generally below 50 percent when discharge temperatures were above 30 °C. The 96 hour latent survival could not be calculated due to near zero survival of organisms from both the intake and discharge samples.

A total of 3,935 winter flounder larvae were collected from the intake and 2,999 were collected from the discharge from five sampling events. During sampling, the discharge temperature ranged from 13.5 to 20.3 °C and the ΔT ranged from 3.5 to 11.1 °C. Initial survival, calculated as discharge survival divided by intake survival, ranged from a low of 36 percent with a discharge temperature of 20.3 °C to a high of 96 percent with a discharge temperature of 14.8 °C. The 96 hour latent survival, calculated as discharge survival divided by intake survival, ranged from a low of 10 percent with a discharge temperature of 20.3 °C to a high of 97 percent with a discharge temperature of 14.8 °C.

This facility, like all others, would need to conduct additional studies to sample more species, with larger sample sizes, and with less intake mortality in order to calculate a fair and accurate estimate of entrainment survival. It would also be helpful to determine the percentage of time the discharge temperatures are high enough to cause low entrainment survival.

Port Jefferson Generating Station

Samples taken for an entrainment survival study were taken for four nights in April 1978. Sampling was scheduled to coincide with no biocide use at the facility. It was unclear whether these sampling dates corresponded with times of high egg and larvae abundance. Discharge temperatures ranged from 10 to 18 °C, with a ΔT that ranged from 2 to 11 °C. It was unclear whether these low discharge temperatures are typical of the facility's year round operation. Samples were analyzed for both initial and 96 hour latent survival. The intake samples were collected at 2 m below mean low water mark in front of the trash racks of the intake. The discharge samples were collected at 1 m below mean low water mark in the common seal well structure for Units 3 and 4 of the facility. Intake and discharge samples were taken simultaneously rather than with a lag time to simulate the passage of water through the facility. Samples were collected from the intake and discharge by pumping water with a Marlow pump into a larval table for 15 minutes after which the pump was turned off and the table drained. The time for the table to drain was approximately 30 minutes. The study did not mention if water was used to help flush the organisms into the transportation container; however, the study does indicate that the organisms were exposed to elevated temperatures in the table and transportation container during the time the table drained. The transportation container was taken to the laboratory where the organisms were sorted in an ambient temperature flow-through bath. Larvae and juveniles were sorted as either live, stunned, or dead. Dead larvae and juveniles were preserved for later identification. Live and stunned larvae and juveniles were transferred with a pipette to 0.9 L glass jars with a maximum of 5 individuals per jar. The jars were aerated and maintained in an ambient water bath. Throughout the 96 hour observation period for latent survivability, the organisms were not fed. The eggs were classified through observation only with the category live assigned when eggs were clear or transparent and dead assigned when eggs were cloudy and opaque. No further study on the actual viability of the live eggs was performed. Initial survival was calculated by dividing the number of live and stunned by the total number collected. Latent survival was calculated by dividing the number of organisms alive by the number of organisms initially classified as live or stunned. The statistical significance of the survivability at the intake and discharge was calculated in the facility's study. This study, like others, used the assumption that the probability of mortality from entrainment and sampling are independent stresses that do not interact, and the intake survival was used as the estimate of surviving sampling.

In the 47 intake samples, 31 winter flounder PYSL, 215 sand lance PYSL, 19 sculpin PYSL, 84 American eel juveniles, and 193 fourbeard rockling eggs were collected. Since sampling sizes were extremely low on each sampling date, all data taken at different times and under different temperature regimes were compiled to estimate survivability. Using EPRI's equation, initial intake survival was calculated as 42 percent for winter flounder PYSL (3 live, 10 stunned, 18 dead), 41 percent for sand lance PYSL (27 live, 61 stunned, 127 dead), 84 percent for sculpin PYSL (14 live, 2 stunned, 3 dead), 83 percent for American eel juveniles (64 live, 5 stunned, 14 dead), and 81 percent for fourbeard rockling eggs (157 live, 36 dead). In the 47 discharge samples, 23 winter flounder PYSL, 166 sand lance PYSL, 17 sculpin PYSL, 71 American eel juveniles, and 102 fourbeard rockling eggs were collected. Again, all samples taken at different times and under different conditions were combined to estimate survivability. Initial discharge survival was calculated as 43 percent for winter flounder PYSL (0 live, 10 stunned, 13 dead), 13 percent for sand lance PYSL (3 live, 19 stunned, 144 dead), 88 percent for sculpin PYSL (8 live, 7 stunned, 2 dead), 94 percent for American eel juveniles (67 live, 4 dead), and 93 percent for fourbeard rockling eggs (95 live, 7 dead). In each case, the sampling sizes were very low and unequal in the intake and discharge samples. Also in many cases, the discharge survival proportions were higher than the intake survival proportions. Because of the nature of the equation for entrainment survivability, this results in an erroneous reporting of 100 percent initial entrainment survival for winter flounder PYSL, sculpin PYSL, American eel juveniles, and fourbeard rockling eggs. Only sand lance PYSL had lower discharge survival than intake survival, which resulted in a calculated entrainment survival of 32 percent. Also, this study assumed that stunned larvae would survive entrainment. More likely, these stunned larvae would be more susceptible to predation after entrainment and should not be included in the proportion surviving entrainment.

Extended intake survival calculated for winter flounder PYSL was 77 percent (10 live, 3 dead), 11 percent for sand lance PYSL (10 live, 78 dead), 44 percent for sculpin PYSL (7 live, 9 dead), 98 percent for American eel juveniles (63 live, 1 dead), and 14 percent for fourbeard rockling eggs (22 live, 135 dead). Extended discharge survival was calculated as 50 percent for winter flounder (5 live, 5 dead), 9 percent for sand lance PYSL (2 live, 20 dead), 33 percent for sculpin PYSL (5 live, 10 dead), 96 percent for American eel juveniles (64 live, 3 dead), and 22 percent for fourbeard rockling eggs (21 live, 74 dead). This results in a calculated entrainment survival of 65 percent for winter flounder PYSL, 80 percent for sand lance PYSL, 76 percent for sculpin PYSL, 97 percent for American eel juveniles, and 100 percent for fourbeard rockling eggs. Again, since sample sizes were unequal in the intake and discharge samples, it is difficult to give a fair and accurate depiction of actual latent mortality from collection and holding stress.

To claim anything more than 0 percent entrainment survival, more studies would be needed at this facility to sample greater numbers of more species with less intake mortality. EPA recommends that samples be taken at times of high larvae abundance and only those samples collected at similar temperatures be combined when calculating survival.

Potrero Power Plant

Survival estimates were determined only for Pacific herring larvae. Sampling for this study was conducted daily for 11 days in January 1979 to assess both initial and latent 96 hour survivability. Sampling was scheduled to avoid periods of biocide use at the facility. It was unclear whether the month of January was the time of highest egg and larvae abundance at this location. Fish larval samples were collected by pumping water with two pumps into a larval table for 15 minutes. Filtered water at ambient temperature was withdrawn from the intake area and flowed through the larval table to aid in the concentration of organisms in the collection box. After 15 minutes, the pumps were turned off and the tables were drained; however, filtered ambient temperature water continued to flow into the collection boxes. The collection boxes were then emptied into screen topped containers for transportation to the laboratory for immediate sorting. Dead larvae where preserved for later identification. The live larvae where transferred using a pipette into 1 L jars with a maximum density of five larvae per jar. These jars where held for observation in ambient temperature water baths and aerated. The organisms were not fed during the 96 hour latent survival study.

Intake samples were taken directly in front of the intake skimmer wall at mid-depth. Discharge samples were taken at the point where the discharge enters San Francisco Bay at mid-depth. Twenty-five intake and discharge samples were analyzed for survival; however, information was not provided regarding the timing of these samples, or whether they were taken simultaneously or after a lag period to simulate passage through the facility. The range of discharge temperatures during sampling was 18.0-19.5 °C. In the 25 intake samples, 119 Pacific herring larvae were classified as initially alive and 427 were initially dead, resulting in an intake survival of 22 percent. In the 25 discharge samples, 115 Pacific herring larvae were classified as initially alive and 601 were initially dead, which resulted in a discharge survivability of 16 percent. According to EPRI's equation, entrainment survivability would be 75 percent. The 96 hour latent survivability for Pacific herring was 52 percent at the intake (62 survived out of 119 observed) and 49 percent at the discharge (56 survived out of 115 observed). According to EPRI's equation, this would result in an entrainment survivability for Pacific herring of 93 percent with discharge temperatures between 18.0 and 19.5 °C. Since samples were taken during January when discharge temperatures were low, higher mortality rates may be observed during other times of the year. Also, since samples were taken at times when biocides where not in use, high mortality rates may be observed when biocides are in use. Further studies would be needed at this location to give a fair and accurate estimate of survival for all species entrained.

Quad Cities Nuclear Station

Entrainment survival studies were performed at this facility in 1978 and 1984. This facility operates as a completely or partially close-cycle cooling system, so its entrainment survival may be very different from other facilities that have once-through cooling systems.

In 1978, samples were taken in the afternoon, evening, or nighttime hours of June 19-26, 1978, when the facility was operating in a complete open cycle mode with a generating output ranging between 41 and 99 percent power. Discharge temperatures during sampling ranged from 28.0 to 39.0 °C with ΔT that ranged from 5.5 to 14.8 °C. Samples were not taken during times of biocide use. Intake samples were collected at mid-depth from the intake forebay. Discharge samples were taken near the surface from the discharge canal common to all units. It was unclear whether surface sampling was sufficient to capture organisms that may be distributed in other parts of the water column. Samples were collected from a boat for at least 60 seconds with a 0.75 m conical plankton net with no. 0 mesh and an attached unscreened 5 L bucket. After collection, samples were transferred to the laboratory for sorting. Discharge samples were held at discharge temperatures for 8.5 minutes to simulate passage through the discharge canal and then cooled to ambient temperature plus 3.5 °C before sorting. Samples were classified within 20 minutes of collection in a sorting tray with a pipette as live, dead-translucent, and dead-opaque. This study also used the assumption that dead-opaque larvae were dead due to natural conditions prior to collection, whereas the dead-translucent larvae died from collection or from effects due to entrainment. In addition, this facility used the assumption that intake samples were a control to determine the rate of mortality from collection and handling and discharge samples indicated mortality from natural mortality, sampling mortality and entrainment mortality.

Survival estimates were determined for freshwater drum and non-carp cyprinidae. Survivability was calculated with and without the inclusion of dead-opaque larvae. EPA believes that the dead-opaque larvae should be included in the calculation because the control will correct for any mortality due to natural causes and no additional correction should be made to the data. The facility's study concluded that the lowest entrainment survival, 3 percent for all species sampled, occurred when the facility was operating near full capacity (96-99 percent) and discharge temperatures exceeded 37.9 °C. Entrainment survival was calculated for each life stage separately for each sampling date in order to reduce variability in survival associated with different operating levels of the facility and different life stages of each species. For freshwater drum, entrainment survival ranged from a low of 0 percent for juveniles at temperatures ranging from 38.0 to 39.0 °C with the facility operating at 96-99 percent to a high of 71 percent for juveniles at temperatures ranging from 32.5 to 33.0 °C with the facility operating at 74-78 percent. When discharge survival was greater than intake survival, the study indicated that entrainment survival could not be calculated, rather than assume 100 percent entrainment survival as other facilities have incorrectly done in their studies. For non-carp cyprinidae, entrainment survival ranged from a low of 4 percent for larvae at temperatures ranging from 38.0 to 39.0 °C with the facility operating at 96-99 percent, to a high of 75 percent for juveniles at temperatures ranging from 30.5 to 31.2 °C with the facility operating at 59-68 percent. Variability in entrainment survival under different conditions could also result from the low sample sizes.

In 1984, another entrainment survival study was conducted with the intention of estimating survival for all dominant taxa entrained, including walleye and sauger, which were not represented in significant numbers in the samples in the 1978 study.

However, insufficient numbers were collected to calculate entrainment survival for these species in this study as well. Sampling was conducted weekly from April 25 through June 27. Sampling was not conducted in July when discharge temperatures exceeded 37 percent and survivability was reported to be 0-3 percent in the 1978 study. The facility was operating at 40.2-50.7 percent capacity during the time of the study. The discharge temperature ranged from 12 to 37 °C and the ΔT ranged from 9.5 to 14.5 °C. On May 9 both units were offline and the ΔT was 1 °C. EPA believes that the May 9 data were not representative of normal operating conditions so this data should not be included in the survival estimates. Intake samples were collected from a depth of 1.5 m at the intake forebay and discharge samples were collected from the surface in the discharge canal. The sampling method was identical to the 1978 study. Again, biocides were not used during the study period. Half of each sample was analyzed in the laboratory in an apparent effort to reduce mortality due to collection and handling. Dead and opaque organisms were omitted from the analysis since it was assumed that these died prior to collection. EPA believes this is an erroneous assumption and that the control should correct for any which may have died prior to collection. Organisms were also sorted by life stage as yolk sac larvae, post yolk sac larvae, or juveniles. No statistical analysis was performed because of low sample sizes.

In the intake samples, 481 freshwater drum, 133 carp, and 33 buffalo were collected. In the discharge samples, 64 freshwater drum, 103 carp, and 44 buffalo were collected. In the facilities study, of a total of 3,967 organisms collected in both the intake and discharge, 2,979 opaque individuals were omitted from analysis (75 percent). When so few organisms are collected, the arbitrary elimination of 75 percent seems excessive given that the data are also corrected for natural mortality by dividing the discharge survival by the intake survival. The percentages of dead and opaque individuals ranged from 0 to 99 percent of the total in each sample. It is interesting to note that 0 percent were found to be dead and opaque in the discharge sample from May 9 when both units were offline and the ΔT was 1 °C. The specific numbers of dead opaque larvae from each sample were not available to calculate the actual entrainment survival in this study. EPA assumes that if opaque individuals were included the entrainment survival proportions would be significantly lower than those reported in the facility's study and in EPRI's report. The raw data were not provided in this report to recalculate entrainment survival including dead and opaque larvae.

A7-4 Principles to Guide Future Studies of Entrainment Survival

EPA maintains that demonstrations of entrainment survival for selected species under a limited range of experimental conditions are not a sufficient basis for assuming that entrainment survival should be routinely included in biological impact assessments. However, EPA recognizes that accurate quantification of biological impacts should include entrainment survival in cases where entrainment survival rates have been estimated by valid means, and that the conditions associated with those rate estimates are broad enough to reflect the scope of operating conditions at the regulated facilities (e.g., all ambient operating temperatures at which the facility operates, all ages at which an organism is entrained). At a minimum, future studies intended to quantify entrainment survival should address the considerations described below. These considerations are intended to indicate the kinds of factors that collectively lead to results that (a) encompass a realistic range of operating conditions and (b) allow for a thorough understanding of the statistical features (e.g., bias and precision) of entrainment survival rate estimates.

A7-4.1 Protocol for Entrainment Survival Study

To determine entrainment survival rate, a statistically and scientifically rigorous study of site-specific entrainment survival is needed. Such a study would use the best sampling practices (gear selection, sampling location and frequency to capture diel and seasonal patterns), maintain careful records, provide description and quality control of sample processing, and use the appropriate statistical analytical procedures.

Sampling should be carefully planned to minimize any potential bias. Samples should not be combined if they were collected under different environmental factors. Control samples that test the mortality associated with sampling gear should be taken as far away from the intake as possible. This will ensure that the rates of mortality determined will be solely from natural causes or sampling damage and not from potential damage due to increased velocity and turbulence near the intake. Sampling mortality should be reduced to the maximum extent possible. When control survival is less than discharge survival, no attempts should be made to calculate entrainment survival which would give an erroneous survival result of greater than 100 percent.

Organisms should be counted and sorted by both species, life stage, and size. Initial mortality and extended or latent (96 hour) mortality should both be reported to ensure the best overall survival estimate. Studies need to be conducted throughout the year to determine if the entrainment survival is dependent on life stage and size of each species entrained. Entrainment studies also need to be conducted for 24 hour intervals to determine the time of day entrainment survival will most likely occur. Entrainment survival should be calculated separately for each life stage of each species.

The physical and operating conditions of the facility need to be recorded to determine their associated impact on the three fundamental stressors that affect entrainment survival. The percentage of the maximum load at which the facility is operating needs to be recorded at the time of sampling to give an indication of the extent to which organisms are exposed to stress. To assess the effect on entrainment survival by thermal stressors, the study needs to determine the temperature regime of the facility. Specifically, the study needs to record the temperature at intake and at the discharge point for each component of the facilities system: temperature changes within the system, including the inflow temperature, maximum temperature, delta-T, and rate of temperature change, and the temperature of the water in which the organisms are discharged. It is also important to measure the duration of time an organism is entrained and thus exposed to the thermal conditions within the condenser. To determine the effect of mechanical stressors on entrainment survival, the study needs to indicate the impacts caused by speed and pressure changes within the condenser, the number of pumps in operation, the occurrence of abrasive surfaces, and the turbulence within the condenser. In addition, it is important to note the number and arrangement of units, parallel or in sequence, which may expose organisms to entrainment in multiple structures. To properly account for chemical stressors, the timing, frequency, methods, concentrations, and duration of biocide use (e.g., chlorine) for the control of biofouling need to be determined. The water chemistry conditions also need to be recorded, including dissolved oxygen, pH, and conductivity in the through-plant water, at the discharge point, and in the containers or impoundments in which the entrained organism are kept when determining latent mortality. These operating conditions can have different effects on different species. It is important to fully understand the species-specific effects of the three fundamental stressors. In particular, different fishes have different critical thermal maxima. The maximum temperature to which an organism may be exposed to while passing through the facility may cause mortality in one species yet be sublethal in another species. When possible, the organisms sampled should be categorized by their cause of death, mechanical, thermal, or chemical. This will give a better assessment of the susceptibility of each entrained species and life stages to the effects of which of the three fundamental stressors. In the future this information will be helpful in the design of cooling water intake structures to reduce entrainment mortality.

EPA recommends that entrainment survival studies be conducted under worst case scenarios, such as times of near full capacity utilization when egg and larvae abundances are high and biocides are in use.

A7-4.2 Statistical Considerations: Direct Estimates of Entrainment Survival Rates

When reporting estimates of entrainment survival rates, a study should address the following statistical considerations. Reliable studies should provide a complete description of sampling protocols as they affect:

- Range of inference (i.e., how are the results of the study relevant to future applications?).
- Identification of independent experimental units.
- Ability to provide quantitative measures of precision (e.g., prediction error and/or confidence intervals).

A7-4.3 Applicability of Entrainment Survival Studies to Other Facilities

To apply the results of an entrainment survival study to other facilities, it is necessary to determine to what degree the physical attributes of facilities are similar. Specifically, do the facilities have similar numbers of cooling water flow routes, are the lengths of flow routes similar in terms of time and linear distance, are the mechanical features the same in terms of abrasive surfaces, pressure changes and turbulence, and are the same number and types of pumps used? Similarities or differences in these physical aspects can profoundly affect the applicability of the study between facilities.

The operating characteristics of a facility can also affect the applicability of entrainment studies to other time periods at the same facility and to other facilities. To determine applicability, it is necessary to know if there is similarity and constancy of the flow rates, transit times, thermal regimes, and biocide regimes.

The ecological characteristics of the environment around the facility should also be considered when determining the degree to which a study of entrainment survival is applicable to other facilities. Specifically, its is important to determine the similarities or differences in the ambient water temperature, dissolved oxygen level, and the species and life stage present.

A7-4.4 Statistical Considerations: Development of Predictive Models of Entrainment Survival Rate

With sufficient entrainment survival data from well designed studies, a model of entrainment survival could be developed that would allow for improved evaluation of survival rates and would aid in the design of the best cooling water intake structures to minimize entrainment mortality.

Model performance objectives should be defined before developing any studies using standardized survival models. The following are examples of statistical considerations that a study should address when reporting models that describe functional relationships between facility operating conditions (e.g., thermal regimes) and entrainment survival rate. Reliable studies describe the model and the basis of modeling procedure with respect to these questions:

- How much precision is required?
- What is the scope of the intended application of the model?
- Which species, life stages, and size ranges are addressed by the model?
- What is the range of physical considerations (e.g., ambient water temperature, temperature, ΔT, maximum temperature, duration of temperature) that are addressed by the model?
- What is the model structure?
- What are the relationships among the submodels (thermal stress, mechanical stress, and chemical stress) of the general model; e.g., are different sources of mortality assumed to act independently, or not?
- What are adequate or levels of precision for estimates of individual model parameters?

A7-5 Conclusions

Although EPA agrees with the conclusion of the EPRI report that an assumption of zero entrainment survival rate for all facilities may be unwarranted for certain species and certain conditions, EPA believes the available data are insufficient to provide the basis for generalizations about entrainment survival rates. EPA concludes that it remains to be determined whether nonzero survival rates are common for cooling water intake structures in general. Furthermore, EPA does not believe that the magnitude of a positive entrainment survival rate at other facilities or under different conditions at the same facility can be predicted with reliability on the basis of existing studies.

After reviewing the EPRI report and other sources, it is clear that the number of relevant variables that collectively determine any entrainment survival rate is so large that the studies conducted to date should be viewed as a provocative set of anecdotes that demonstrate the need for further study, but do not provide a sufficient basis for making predictions. Until such time that the understanding of the general phenomenon is broadened to encompass more of the differences among facilities, including all physical and biological conditions, EPA believes that the precautionary principle with respect to regulation should be maintained: that is, in the absence of sound empirical data quantifying survival, the standard method of impact assessment should not include consideration of nonzero entrainment survival rates. In addition to providing a precautionary stance for conservation of biological resources, assuming a zero entrainment survival rate also implies that the quantification of resource impacts at different facilities should be done in a consistent manner and therefore facilitate between facility, waterbody specific, and regional comparisons.

Chapter A8: Characterization of CWIS Impacts by Water Body Type

The environmental impacts of cooling water intake structures (CWISs) are closely tied to the biological productivity of the water body from which cooling water is withdrawn. This chapter discusses CWIS impacts and potential benefits of § 316(b) regulation for specific water body types based on data compiled by EPA from existing studies. The data presented are numbers of organisms that are directly impinged or entrained. While EPA recognizes that impingement and entrainment losses may result in indirect effects on populations and other higher levels of biological organization, this chapter focuses on impingement and entrainment because these are the direct biological impacts that result from the withdrawal of cooling water by CWIS. Water body types discussed in this chapter include 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.

CHAPTER CONTENTS

A8-1 DEVELOPMENT OF A DATABASE OF I&E RATES

A8-1.1 Data Compilation

To estimate the relative magnitude of impingement and entrainment (I&E) for different species and water body types, EPA compiled I&E data from 107 documents representing a variety of sources, including previous §316(b) studies, critical reviews of §316(b) studies, biomonitoring and aquatic ecology studies, technology implementation studies, and data compilations. In total, data were compiled for 98 steam electric facilities (36 river facilities, 9 lake/reservoir facilities, 19 facilities on the Great Lakes, 22 estuarine facilities, and 12 ocean facilities). Design intake flows at these facilities ranged from a low of 19.7 to a high of 3,315.6 MGD.

EPA notes that most of these studies were completed by the facilities in the mid-1970s using methods that are now outmoded. A number of the methods used probably resulted in an underestimate of losses. For example, many studies did not adjust I&E sampling data for factors such as collection efficiency. Because of such methodological weaknesses, EPA believes that studies such as those discussed here should only be used to gauge the relative magnitude of impingement and entrainment losses. Any further analysis of the data should be accompanied by a detailed evaluation of study methods and supplemented with additional data as needed.

For the present objective of understanding the potential magnitude of I&E, EPA aggregated the data in the studies that were available to EPA in a series of steps to derive average annual impingement and entrainment rates, on a per facility basis, for different species and water body types. First, the data for each species were summed across all units of a facility and averaged across years (e.g., 1972 to 1976). Losses were then averaged by species for all facilities in the database on a given water body type to derive species-specific and water body-specific mean annual I&E rates. Finally, mean annual I&E rates were ranked, and rates for the top 15 species were used for subsequent data presentation.

A8-1.2 Data Uncertainties and Potential Biases

A number of data uncertainties and potential biases are associated with the I&E data that EPA evaluated. As with any ecological data, natural environmental variability makes it difficult to detect ecological impacts and identify cause-effect relationships even in cases where study methods are as accurate and reliable as possible. For example, I&E rates for any given population will vary with changes in environmental conditions that influence annual variation in recruitment. As a result, it can be difficult to determine the relative role of I&E mortality in population fluctuations.

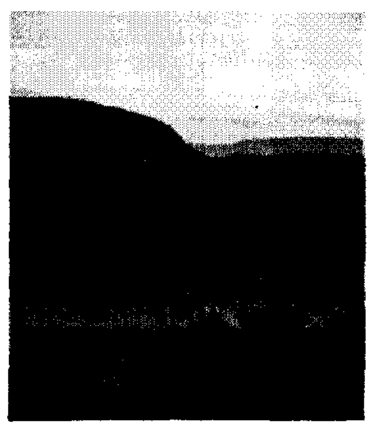
In addition to the influence of natural variability, data uncertainties result from measurement errors, some of which are unavoidable. In addition to the inefficiency of sampling gear, much of the data presented here does not account for variations in collection and analytical methods or changes in the number of units in operation or technologies in use.

Potential biases in the data were also difficult to control. For example, many studies presented data for only a subset of "representative" species, which may lead to an underestimation of total I&E. On the other hand, the entrainment estimates obtained from EPA's database do not take into account the high natural mortality of egg and larval stages and therefore are likely to be biased upwards. However, this bias was unavoidable because most of the source documents from which the database was derived did not estimate losses of early life stages as an equivalent number of adults, or provide information for making such calculations.[1] In the absence of information for adjusting egg losses on this basis, EPA chose to include eggs and larvae in the entrainment estimates to avoid underestimating age 0 losses.

With these caveats in mind, the following sections present the results of EPA's data compilation. The data are grouped by water body type and are presented in summary tables that indicate the range of losses for the 15 species with the highest I&E rates based on the limited subset of data available to EPA. I&E losses are expressed as mean annual numbers on a per facility basis. Because the data do not represent a random sample of I&E losses, it was not appropriate to summarize the data statistically. It is also important to stress that because the data are not a statistical sample, the data presented here may not reflect the true magnitude of losses. Thus, the data should be viewed only as general indicators of the potential range of I&E.

A8-2 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.

The data compiled by EPA indicate that 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 Table A8-1 shows, in order of the greatest to least impact, the annual entrainment of eggs, larvae, and juvenile fish in rivers. Table A8-2 shows, in order of greatest to least impact, the annual impingement in rivers for all age classes combined (mostly juveniles

[1] For species for which sufficient life history information is available, the Equivalent Adult Model (EAM) can be used to predict the number of individuals that would have survived to adulthood each year if entrainment at egg or larval stages had not occurred (Horst, 1975b; Goodyear, C.P., 1978). The resulting estimate is known as the number of "equivalent adults."

and young adults). These species occur in nearshore areas and/or have pelagic early life stages, traits that greatly increase their susceptibility to I&E.

Table A8-1: Annual Entrainment of Eggs, Larvae and Juvenile Fish in Rivers

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
common carp	*Cyprinus carpio*	7	20,500,000	859,000 - 79,400,000
yellow perch	*Perca flavescens*	4	13,100,000	434,000 - 50,400,000
white bass	*Morone chrysops*	4	12,800,000	69,400 - 49,600,000
freshwater drum	*Aplodinotus grunniens*	5	12,800,000	38,200 - 40,500,000
gizzard shad	*Dorosoma cepedianum*	4	7,680,000	45,800 - 24,700,000
shiner	*Notropis* spp.	4	3,540,000	191,000 - 13,000,000
channel catfish	*Ictalurus punctatus*	5	3,110,000	19,100 - 14,900,000
bluntnose minnow	*Pimephales notatus*	1	2,050,000	---
black bass	*Micropterus* spp.	1	1,900,000	---
rainbow smelt	*Osmerus mordax*	1	1,330,000	---
minnow	*Pimephales* spp.	1	1,040,000	---
sunfish	*Lepomis* spp.	5	976,000	4,230 - 4,660,000
emerald shiner	*Notropis atherinoides*	3	722,000	166,000 - 1,480,000
white sucker	*Catostomus commersoni*	5	704,000	20,700 - 2,860,000
mimic shiner	*Notropis volucellus*	2	406,000	30,100 - 781,000

Sources: Hicks, 1977; Cole, 1978; Geo-Marine Inc., 1978; Goodyear, C.D., 1978; Potter, 1978; Cincinnati Gas & Electric Company, 1979; Potter et al., 1979a, 1979b, 1979c, 1979d; Cherry and Currie, 1998; Lewis and Seegert, 1998.

Table A8-2: Annual Impingement in the Rivers for All Age Classes

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
threadfin shad	*Dorosoma petenense*	3	1,030,000	199 - 3,050,000
gizzard shad	*Dorosoma cepedianum*	25	248,000	3,080 - 1,480,000
shiner	*Notropis* spp.	4	121,000	28 - 486,000
alewife	*Alosa pseudoharengus*	13	73,200	199 - 237,000
white perch	*Morone americana*	3	66,400	27,100 - 112,000
yellow perch	*Perca flavescens*	18	40,600	13 - 374,000
spottail shiner	*Notropis hudsonius*	10	28,500	10 - 117,000
freshwater drum	*Aplodinotus grunniens*	24	19,900	8 - 176,000
rainbow smelt	*Osmerus mordax*	11	19,700	7 - 119,000
skipjack herring	*Alosa chrysochons*	7	17,900	52 - 89,000
white bass	*Morone chrysops*	19	11,500	21 - 188,000
trout perch	*Percopsis omiscomaycus*	13	9,100	38 - 49,800
emerald shiner	*Notropis atherinoides*	17	7,600	109 - 36,100
blue catfish	*Ictalurus furcatus*	2	5,370	42 - 10,700
channel catfish	*Ictalurus punctatus*	23	3,130	3 - 25,600

Sources: Benda and Houtcooper, 1977; Freeman and Sharma, 1977; Hicks, 1977; Sharma and Freeman, 1977; Stupka and Sharma, 1977; Energy Impacts Associates Inc., 1978b; Geo-Marine Inc., 1978; Goodyear, C.D., 1978; Potter, 1978; Cincinnati Gas & Electric Company, 1979; Potter et al., 1979a, 1979b, 1979c, 1979d; Van Winkle et al., 1980; EA Science and Technology, 1987; Cherry and Currie, 1998; Lohner, 1998; Michaud, 1998.

A8-3 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 water body. 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, e.g., brown trout (*Salmo trutta*), lake trout, ciscoes (*Coregonus* spp.). With few exceptions (such as ciscos), 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.

Results of EPA's data compilation indicate that fish species most commonly affected by CWIS located on lakes and reservoirs are the same as the riverine species that are most susceptible, including alewife, drum (*Aplondinotus* spp.), and gizzard shad (*Dorsoma cepedianum*) (Tables A8-3 and A8-4).

Table A8-3: Annual Entrainment of Eggs, Larvae and Juvenile Fish in Reservoirs and Lakes (excluding the Great Lakes)

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)
drum	*Aplondinotus* spp.	1	15,600,000
sunfish	*Lepomis* spp.	1	10,600,000
gizzard shad	*Dorosoma cepedianum*	1	9,550,000
crappie	*Pomoxis* spp.	1	8,500,000
alewife	*Alosa pseudoharengus*	1	1,730,000

Sources: Michaud, 1998; Spicer et al., 1998.

Table A8-4: Annual Impingement in Reservoirs and Lakes (excluding the Great Lakes) for All Age Classes Combined

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
threadfin shad	*Dorosoma petenense*	4	678,000	203,000 - 1,370,000
alewife	*Alosa pseudoharengus*	4	201,000	33,100 - 514,000
skipjack herring	*Alosa chrysochons*	1	115,000	---
bluegill	*Lepomis macrochirus*	6	48,600	468 - 277,000
gizzard shad	*Dorosoma cepedianum*	5	41,100	829 - 80,700
warmouth sunfish	*Lepomis gulosus*	4	39,400	31 - 157,000
yellow perch	*Perca flavescens*	2	38,900	502 - 114,000
freshwater drum	*Aplodinotus grunniens*	4	37,500	8 - 150,000
silver chub	*Hybopsis storeriana*	1	18,200	---
black bullhead	*Ictalurus melas*	3	10,300	171 - 30,300
trout perch	*Percopsis omiscomaycus*	2	8,750	691 - 16,800
northern pike	*Esox lucius*	2	7,180	154 - 14,200
blue catfish	*Ictalurus furcatus*	1	3,350	---
paddlefish	*Polyodon spathula*	2	3,160	1,940 - 4,380
inland (tidewater) silverside	*Menidia beryllina*	1	3,100	---

Sources: Tennessee Division of Forestry, Fisheries, and Wildlife Development, 1976; Benda and Houtcooper, 1977; Freeman and Sharma, 1977; Sharma and Freeman, 1977; Tennessee Valley Authority, 1977; Michaud, 1998; Spicer et al., 1998.

A8-4 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% 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% 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 and deepwater sculpin (*Myxocephalus thompsoni*) use waters less than 10 m deep as nursery habitat.

A large number of thermal-electric plants located on the Great Lakes draw their cooling water from the littoral zone, resulting in high I&E of several fish species of commercial, recreational, and ecological importance, including alewife, gizzard shad, yellow perch, rainbow smelt, and lake trout (Tables A8-5 to A8-8).

Table A8-5: Annual Entrainment of Eggs, Larvae and Juvenile Fish in the Great Lakes

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
alewife	*Alosa pseudoharengus*	5	526,000,000	3,930,000 - 1,360,000,000
rainbow smelt	*Osmerus mordax*	5	90,500,000	424,000 - 438,000,000
lake trout	*Salmo namaycush*	1	116,000	---

Sources: Texas Instruments Inc. and Lawler, Matusky, and Skelly Engineers, 1978; Michaud, 1998.

Table A8-6: Annual Entrainment of Larval Fish in the Great Lakes by Lake

Lake	Number of Facilities	Total Annual Entrainment (fish/year)
Erie	16	255,348,164
Michigan	25	196,307,405
Ontario	11	176,285,758
Huron	6	81,462,440
Superior	14	4,256,707

Source: Kelso and Milburn, 1979.

Table A8-7: Annual Impingement in the Great Lakes for All Age Classes Combined

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
alewife	*Alosa pseudoharengus*	15	1,470,000	355 - 5,740,000
gizzard shad	*Dorosoma cepedianum*	6	185,000	25 - 946,000
rainbow smelt	*Osmerus mordax*	15	118,000	78 - 549,000
threespine stickleback	*Gasterosteus aculeatus*	3	60,600	23,200 - 86,200
yellow perch	*Perca flavescens*	9	29,900	58 - 127,000
spottail shiner	*Notropis hudsonius*	8	22,100	5 - 62,000
freshwater drum	*Aplodinotus grunniens*	4	18,700	2 - 74,800
emerald shiner	*Notropis atherinoides*	4	7,250	3 - 28,600
trout perch	*Percopsis omiscomaycus*	5	5,630	30 - 23,900
bloater	*Coregonus hoyi*	2	4,980	3,620 - 6,340
white bass	*Morone chrysops*	1	4,820	--
slimy sculpin	*Cottus cognatus*	4	3,330	795 - 5,800
goldfish	*Carassius auratus*	3	2,620	4 - 7,690
mottled sculpin	*Cottus bairdi*	3	1,970	625 - 3,450
common carp	*Cyprinus carpio*	4	1,110	16 - 4,180
pumpkinseed	*Lepomis gibbosus*	4	1,060	14 - 3,920

Sources: Benda and Houtcooper, 1977; Sharma and Freeman, 1977; Texas Instruments Inc. and Lawler, Matusky, and Skelly Engineers, 1978; Thurber and Jude, 1985; Lawler Matusky & Skelly Engineers, 1993; Michaud, 1998.

Table A8-8: Annual Impingement of Fish in the Great Lakes

Lake	Number of Facilities	Total Annual Impingement (fish/year)
Erie	16	22,961,915
Michigan	25	15,377,339
Ontario	11	14,483,271
Huron	6	7,096,053
Superior	14	243,683

Source: Kelso and Milburn, 1979.

The I&E estimates of Kelso and Milburn (1979) presented in Tables A8-6 and A8-8 were derived using methods that differed in a number of ways from EPA's estimation methods, and therefore the data are not strictly comparable. First, the Kelso and Milburn (1979) data represent total annual losses per lake, whereas EPA's estimates are on a per facility basis. In addition, the estimates of Kelso and Milburn (1979) are based on extrapolation of losses to facilities for which data were unavailable using regression equations relating losses to plant size.

Despite the differences in estimation methods, when converted to an annual average per facility, the impingement estimates of Kelso and Milburn (1979) are within the range of EPA's estimates. For example, Kelso and Milburn's (1979) estimated average annual impingement of 675,980 fish per facility is comparable to EPA's high estimate of 1,470,000 for alewife.

On the other hand, EPA's entrainment estimates include eggs and larvae and are therefore substantially larger than those of Kelso and Milburn (1979), which are based on converting eggs and larvae to an equivalent number of fish. Because of the high natural mortality of fish eggs and larvae, entrainment losses expressed as the number that would have survived to become fish are much smaller than the original number of eggs and larvae entrained (Horst, 1975b; Goodyear, C.P., 1978). Nonetheless, when viewed together, the two types of estimates give an indication of the possible upper and lower bounds of annual entrainment per facility (e.g., an annual average of 8,018,657 fish based on Kelso and Milburn's data compared to EPA's highest estimate of 526,000,000 organisms based on the average for alewife).

A8-5 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 water body 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 the highest rates of I&E in the studies reviewed by EPA include bay anchovy (*Anchoa mitchilli*), tautog (*Tautoga onitis*), Atlantic menhaden (*Brevoortia tyrannus*), gulf menhaden (*Brevoortia patronus*), winter flounder (*Pleuronectes americanus*), and weakfish (*Cynoscion regalis*) (Tables A8-9 and A8-10).

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.

Table A8-9: Annual Entrainment of Eggs, Larvae, and Juvenile Fish in Estuaries

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
bay anchovy	*Anchoa mitchilli*	2	18,300,000,000	12,300,000,000 - 24,400,000,000
tautog	*Tautoga onitis*	1	6,100,000,000	---
Atlantic menhaden	*Brevoortia tyrannus*	2	3,160,000,000	50,400,000 - 6,260,000,000
winter flounder	*Pleuronectes americanus*	1	952,000,000	---
weakfish	*Cynoscion regalis*	2	339,000,000	99,100,000 - 579,000,000
hogchoker	*Trinectes maculatus*	1	241,000,000	---
Atlantic croaker	*Micropogonias undulatus*	1	48,500,000	---
striped bass	*Morone saxatilis*	4	19,200,000	111,000 - 74,800,000
white perch	*Morone americana*	4	16,600,000	87,700 - 65,700,000
spot	*Leiostomus xanthurus*	1	11,400,000	---
blueback herring	*Alosa aestivalis*	1	10,200,000	---
alewife	*Alosa pseudoharengus*	1	2,580,000	---
Atlantic tomcod	*Microgadus tomcod*	3	2,380,000	2,070 - 7,030,000
American shad	*Alosa sapidissima*	1	1,810,000	---

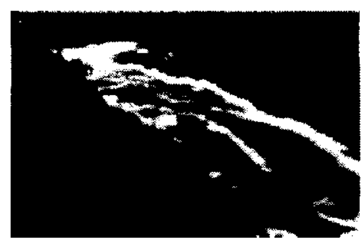
Sources: U.S. EPA, 1982a; Lawler Matusky & Skelly Engineers, 1993; DeHart, 1994; PSEG, 1999f.

Table A8-10: Annual Impingement in Estuaries for All Age Classes Combined				
Common Name	**Scientific Name**	**Number of Facilities**	**Mean Annual Impingement per Facility (fish/year)**	**Range**
gulf menhaden	*Brevoortia patronus*	2	76,000,000	2,990,000 - 149,000,000
smooth flounder	*Liopsetta putnami*	1	3,320,000	--
threespine stickleback	*Gasterosteus aculeatus*	4	866,000	123 - 3,460,000
Atlantic menhaden	*Brevoortia tyrannus*	12	628,000	114 - 4,610,000
rainbow smelt	*Osmerus mordax*	4	510,000	737 - 2,000,000
bay anchovy	*Anchoa mitchilli*	9	450,000	1,700 - 2,750,000
weakfish	*Cynoscion regalis*	4	320,000	357 - 1,210,000
Atlantic croaker	*Micropogonias undulatus*	8	311,000	13 - 1,500,000
spot	*Leiostomus xanthurus*	10	270,000	176 - 647,000
blueback herring	*Alosa aestivalis*	7	205,000	1,170 - 962,000
white perch	*Morone americana*	14	200,000	287 - 1,380,000
threadfin shad	*Dorosoma petenense*	1	185,000	---
lake trout	*Salmo namaycush*	1	162,000	---
gizzard shad	*Dorosoma cepedianum*	6	125,000	2,058 - 715,000
silvery minnow	*Hybognathus nuchalis*	1	73,400	---

Sources: Consolidated Edison Company of New York Inc., 1975; Lawler Matusky & Skelly Engineers, 1975, 1976; Stupka and Sharma, 1977; Lawler et al., 1980; Texas Instruments Inc., 1980; Van Winkle et al., 1980; Consolidated Edison Company of New York Inc. and New York Power Authority, 1983; Normandeau Associates Inc., 1984; EA Science and Technology, 1987; Lawler Matusky & Skelly Engineers, 1991; Richkus and McLean, 1998; PSEG, 1999f; New York State Department of Environmental Conservation, 2000.

A8-6 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 water body types, the littoral zone is where most marine organisms concentrate. The littoral zone of oceans is of particular concern in the context of § 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.

In addition to many of the species discussed in the section on estuaries, other fish species found in near coastal waters that are of commercial, recreational, or ecological importance, and are particularly vulnerable to I&E, include silver perch (*Bairdiella chrysura*), cunner (*Tautogolabrus adspersus*), several anchovy species, scaled sardine (*Harengula jaguana)*, and queenfish (*Seriphus politus*) (Tables A8-11 and A8-12).

Table A8-11: Annual Entrainment of Eggs, Larvae, and Juvenile Fish in Oceans

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
bay anchovy	*Anchoa mitchilli*	2	44,300,000,000	9,230,000,000 - 79,300,000,000
silver perch	*Bairdiella chrysura*	2	26,400,000,000	8,630,000 - 52,800,000,000
striped anchovy	*Anchoa hepsetus*	1	6,650,000,000	---
cunner	*Tautogolabrus adspersus*	2	1,620,000,000	33,900,000 - 3,200,000,000
scaled sardine	*Harengula jaguana*	1	1,210,000,000	---
tautog	*Tautoga onitis*	2	911,000,000	300,000 - 1,820,000,000
clown goby	*Microgobius gulosus*	1	803,000,000	---
code goby	*Gobiosoma robustum*	1	680,000,000	---
sheepshead	*Archosargus probatocephalus*	1	602,000,000	---
kingfish	*Menticirrhus* spp.	1	542,000,000	---
pigfish	*Orthopristis chrysoptera*	2	459,000,000	755,000 - 918,000,000
sand sea trout	*Cynoscion arenarius*	1	325,000,000	---
northern kingfish	*Menticirrhus saxatilis*	1	322,000,000	---
Atlantic mackerel	*Scomber scombrus*	1	312,000,000	---
Atlantic bumper	*Chloroscombrus chrysurus*	1	298,000,000	---

Sources: Conservation Consultants Inc., 1977; Stone & Webster Engineering Corporation, 1980a; Florida Power Corporation, 1985; Normandeau Associates Inc., 1994b; Jacobsen et al., 1998; Northeast Utilities Environmental Laboratory, 1999.

Table A8-12: Annual Impingement in Oceans for All Age Classes Combined

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
queenfish	*Seriphus politus*	2	201,000	19,800 - 382,000
polka-dot batfish	*Ogcocephalus radiatus*	1	74,500	---
bay anchovy	*Anchoa mitchilli*	2	49,500	11,000 - 87,900
northern anchovy	*Engraulis mordax*	2	36,900	26,600 - 47,200
deepbody anchovy	*Anchoa compressa*	2	35,300	34,200 - 36,400
spot	*Leiostomus xanthurus*	1	28,100	---
American sand lance	*Ammodytes americanus*	2	20,700	886 - 40,600
silver perch	*Bairdiella chrysura*	2	20,500	12,000 - 29,000
California grunion	*Caranx hippos*	1	18,300	---
topsmelt	*Atherinops affinis*	2	18,200	4,320 - 32,300
alewife	*Alosa pseudoharengus*	2	16,900	1,520 - 32,200
pinfish	*Lagodon rhomboides*	1	15,200	---
slough anchovy	*Anchoa delicatissima*	3	10,900	2,220 - 27,000
walleye surfperch	*Hyperprosopon argenteum*	1	10,200	---
Atlantic menhaden	*Brevoortia tyrannus*	3	7,500	861 - 20,400

Sources: Stone & Webster Engineering Corporation, 1977; Stupka and Sharma, 1977; Tetra Tech Inc., 1978; Stone and Webster Engineering Corporation, 1980a; Florida Power Corporation, 1985; Southern California Edison Company, 1987; SAIC, 1993; EA Engineering, Science and Technology, 1997; Jacobsen et al., 1998.

A8-7 Summary and Conclusions

The data evaluated by EPA indicate that 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).

EPA's data review also indicates that fish species in estuaries and oceans experience the highest rates of I&E. These species tend to have planktonic eggs and larvae, and tidal currents carry planktonic organisms past intakes multiple times, increasing the probability of I&E. In addition, 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.

Chapter A9: Economic Benefit Categories and Valuation Methods

INTRODUCTION

CHAPTER CONTENTS

Valuing the changes in environmental quality that arise from the § 316(b) regulations for existing facilities is a principal desired outcome for the Agency's policy assessment framework. Changes in Cooling Water Intake Structure (CWIS) design or operations reduce impingement and entrainment (I&E) rates. These changes in I&E can potentially yield significant ecosystem improvements in terms of the number of fish and other aquatic organisms that avoid premature mortality. This in turn is expected to increase the numbers of individuals present, increase local and regional fishery populations, and ultimately contribute to the enhanced environmental functioning of affected waterbodies (rivers, lakes, estuaries, and oceans) and associated ecosystems. The economic welfare of human populations is expected to increase as a consequence of the improvements in fisheries and associated aquatic ecosystem functioning.

Below, we identify the types of economic benefits that are likely to be generated from the proposed existing facilities rulemaking's anticipated reductions in adverse effects of CWIS. We explain the basic economic concepts applicable to the economic benefits, including benefit categories and taxonomies associated with market and nonmarket goods and services that are likely to flow from reduced I&E. Also described are the methods and data sources used to develop empirical estimates of the benefits of proposed regulatory actions. These methods are applied to the case studies reported in Parts B through I of this document.

A9-1 ECONOMIC BENEFIT CATEGORIES APPLICABLE TO THE § 316(B) RULE

To estimate the economic benefits of reducing I&E at existing CWIS, all the beneficial outcomes need to be identified and, where possible, quantified and assigned appropriate monetary values. Estimating economic benefits can be challenging because many steps need to be analyzed to link a reduction in I&E to changes in impacted fisheries and other aspects of relevant aquatic ecosystems, and to then link these ecosystem changes to the resulting changes in quantities and values for the associated environmental goods and services that ultimately are linked to human welfare.

Key challenges in benefits assessment include uncertainties and data gaps, as well as the fact that many of the goods and services beneficially affected by the proposed change in existing facility I&E are not traded in the marketplace. Thus there are numerous instances — including this proposed § 316(b) rule for existing facilities — when it is not feasible to confidently assign monetary values based on observed market transactions (e.g., prices) for some of the important beneficial outcomes. In such instances, several types of benefits need to be estimated using nonmarket valuation techniques. Where this cannot be done in a reliable manner, the benefits need to be described and considered qualitatively.

For the proposed existing facilities rule, the benefits are likely to consist of several categories (as discussed below), some of which are linked to direct use of market goods and services, and several of which pertain to nonmarket goods and services. Accordingly, some are quantified and valued using secondary nonmarket valuation data (e.g., benefits transfer), and some benefits are described only qualitatively. In addition, some nonmarket benefits are estimated using primary research methods. In specific, recreational values are estimated for some of the case studies (those that are examined on a watershed-scale) using a Random Utility Model (RUM), which is described in Chapter A10. Also, some benefits estimates are developed using habitat-based restoration costing (HRC) as an innovative alternative to using replacement costs as a proxy for beneficial values (see Chapter A11).

In addition to the methodological complexities of estimating benefits, many of the factors that contribute to generating benefits are highly site-specific. For example, the extent of recreational or commercial fishing benefits will depend on baseline levels of I&E for a facility, which fish species are present, how the I&E impacts for those species are reduced by regulatory options (relative to baseline), and the size, preferences, and socio-economic characteristics of human populations in proximity to the affected aquatic systems (i.e., those individuals likely to have a demand for an improved fishery in the affected waters). Thus, the benefits assessment is based on a series of facility- and site-specific case studies that are intended to provide representative and plausible estimates of the benefits of the rulemaking.

A9-2 Benefit Category Taxonomies

The term "economic benefits" here refers to the dollar value associated with all the expected positive impacts of the § 316(b) regulation being proposed for existing facilities. Conceptually, the monetary value of benefits is the sum of the predicted changes in "consumer and producer surplus." These surplus measures are standard and widely accepted terms of applied welfare economics, and reflect the degree of well-being derived by economic agents (e.g., people or firms) given different levels of goods and services, including those associated with environmental quality.[1]

The economic benefits of activities that improve environmental conditions can be categorized in many different ways. The various terms and categories offered by different authors can lead to some confusion with semantics. However, the most critical issue is to try not to omit any relevant benefit, and at the same time avoid potential double counting of benefits.

One common classification for benefits of environmental programs is to divide them into three main categories of (1) economic welfare (e.g., changes in the well-being of humans who derive use value from market or nonmarket goods and services such as fisheries); (2) human health (e.g., the value of reducing the risk of premature fatality due to changing exposure to environmental exposure); and (3) nonuse values (e.g., stewardship values for the desire to preserve T&E species). For the § 316(b) regulation, however, this classification does not convey all the intricacies of how the rule might generate benefits. Further, human health benefits are not anticipated. Therefore, another categorization may be more informative.

Figure A9-1: Benefits Categories for § 316(b)

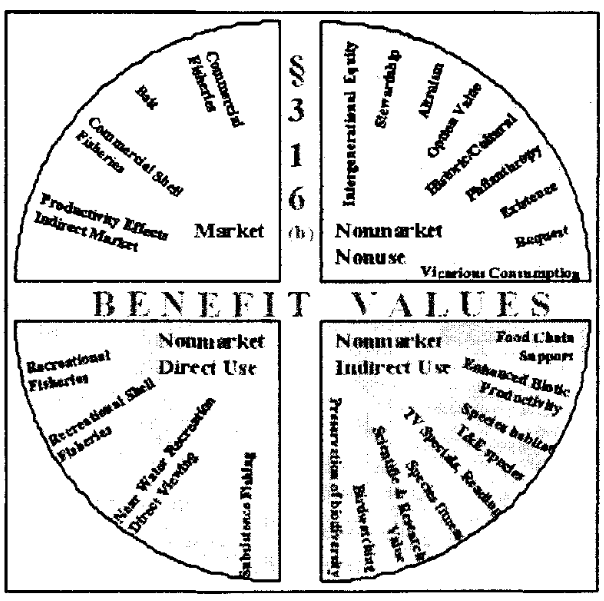


Figure A9-1 outlines the most prominent categories of benefit values for the § 316(b) rule. The four quadrants are divided by two principles: (1) whether the benefit can be tracked in a market (i.e., market goods and services) and (2) how the benefit of a nonmarket good is received by human beneficiaries (either from direct use of the resource, from indirect use, or from nonuse).

Market benefits for § 316(b) are best typified by commercial fisheries, where a change in fishery conditions will manifest itself in the price, quantity, and/or quality of fish harvests. The fishery changes thus result in changes in the marketplace, and can be evaluated based on market exchanges.

Direct use benefits also include the value of improved environmental goods and services used and valued by people (whether or not these services or goods are traded in markets). A typical nonmarket direct use would be recreational angling, in which participants enjoy a welfare gain when the fishery improvement results in a more enjoyable angling experience (e.g., higher catch rates).

[1] Technically, consumer surplus reflects the difference between the "value" an individual places on a good or service (as reflected by the individual's "willingness to pay" for that unit of the good or service) and the "cost" incurred by that individual to acquire it (as reflected by the "price" of a commodity or service, if it is provided in the marketplace). Graphically, this is the area bounded from above by the demand curve and below by the market clearing price. Producer surplus is a similar concept, reflecting the difference between the market price a producer can obtain for a good or service and the actual cost of producing that unit of the commodity.

Indirect use benefits refer to changes that contribute, through an indirect pathway, to an increase in welfare for users (or nonusers) of the resource. An example of an indirect benefit would be when the increase in the number of forage fish enables the population of valued predator species to improve (e.g., when the size and numbers of prized recreational or commercial fish increase because their food source has been improved). In such a context, reducing I&E of forage species will indirectly result in welfare gains for recreational or commercial anglers.

Nonuse benefits — also known as passive use values — reflect the values individuals assign to improved ecological conditions apart from any current, anticipated, or optional use by them. The most commonly cited motives for nonuse values include bequest and existence values. Bequest values reflect the willingness to pay to ensure that applicable environment-related goods and services are available to future generations at a given level of quality and quantity. It reflects concerns over intergenerational equity with respect to leaving a given level of environmental quality as an endowment for those who follow after us in time. Existence value (sometimes referred to as stewardship value) reflects the willingness to pay that humans place on preserving or enhancing ecosystem integrity or a given aspect of environmental quality. This motive applies not only to protecting endangered and threatened species (i.e., avoiding an irreversible impact), but also applies (though perhaps at lesser values) for impacts that potentially are reversible or that affect relatively abundant species and/or habitats.[2]

As noted above, the key to any benefits taxonomy is to try to clearly capture all the types of beneficial outcomes that are expected to arise from a policy action, while at the same time avoiding any possible double counting. Hence, it makes little difference where some of the specific types of benefits are categorized within Figure A9-1. An additional complication with using any single taxonomy for benefits categories is that some valuation approaches may capture more than one benefit category or reflect multiple types of benefits that exist in more than one category or quadrant in the diagram. For example, habitat restoration may enhance populations of recreational, commercial, and forage species alike. Hence if habitat restoration costs are used as a proxy for the value of reduced I&E impacts, the benefits estimates derived embody values for a mix of direct and indirect uses, including both market and nonmarket goods and services. Accordingly, care is used in the case studies to preclude double counting when monetized benefits estimates are compiled, since in some instances monetary estimates from one approach may overlap with values captured by another methodology. All monetized values included in all categories if not given in year 2000 dollars are inflated to year 2000 dollars using an index from Friedman (2002).

A9-3 Direct Use Benefits

Direct use benefits are the simplest to envision. The welfare of commercial, recreational, and subsistence fishermen is improved when fish stocks increase and their catch rates rise. This increase in stocks may be induced by reduced I&E of species sought by fishermen, or through reduced I&E of forage and bait fish, which leads to increases in populations of commercial and recreational species that prey on the forage species. For subsistence fishermen, the increase in fish stocks may reduce the amount of time spent fishing for their meals or increase the number of meals they are able to catch. For recreational anglers, more fish and higher catch rates may increase the enjoyment of a fishing trip and may also increase the number of fishing trips taken. For commercial fishermen, larger fish stocks may lead to

> Allocating Fish to Commercial and Recreational Harvests
>
> Many of the I&E-impacted fish species at CWIS sites are harvested both recreationally and commercially. To avoid double-counting the economic impacts of I&E of these species, we determine the proportion of total species landings attributable to recreational and commercial fishing, and apply this proportion to the number of impacted fishery catch. For example, if 30 percent of the landed numbers of one species are harvested commercially at a site, then 30 percent of the estimated catch of I&E-impacted fish are assigned to the increase in commercial landings. The remaining 70 percent of the estimated total landed number of I&E-spared adult equivalents are assigned to the recreational landings.
>
> The National Marine Fisheries Service (NMFS) provides both commercial and recreational fishery landings data by state. To determine what proportion of total landings per state occur in the commercial or recreational fishery, we sum the landings data for the commercial and recreational fishery together, and then divide by each category to get the corresponding percentage. This is done on a case study by case study basis.

[2] Some economists consider option values to be a part of nonuse values because the option value is not derived from actual current use. Alternatively, some other writers place option value in a use category, because the option value is associated with preserving opportunity for a future use of the resource. Both interpretations are supportable, but for this presentation we place option value in the nonuse category in Figure A9-1.

increased revenues through increases in total landings and/or increases in the catch per unit of effort (i.e., lower costs per fish caught). Increases in catch may also lead to growth in related commercial enterprises, such as commercial fish cleaning/filleting, commercial fish markets, recreational charter fishing, and fishing equipment sales.[3]

Evidence that these use benefits are highly valued by society can be seen in the market and other observable data. For example, in 1996, over 35 million recreational anglers spent nearly $38 billion on equipment and fishing trip related expenditures (US DOI, 1997), and the 1996 GDP from fishing, forestry, and agricultural services (not including farms) was about $39 billion (BEA, 1998). Americans spent an estimated 626 million days engaged in recreational fishing in 1996, an increase of 22 percent over the 1991 levels (U.S. DOI, 1997). If the average consumer surplus per angling day were only $20 — a conservative figure relative to the values derived by economic researchers over the years (e.g., Walsh et al., 1990), review 20 years of research and derive an average value of over $30 per day for warm water angling, and higher values for cold water and salt water angling) — then the national level of consumer surplus enjoyed because of 1996 levels of recreational angling would be approximately $12.6 billion per year (and probably is appreciably higher).

Clearly, these data indicate that the fishery resource is very important. These baseline values do not give us a sense of how benefits change with improvements in environmental quality, such as due to reduced I&E and increased fish stocks. However, even a change of 1.0 percent would translate into potential benefits of approximately $100 million per year or more, based on the limited metrics noted above that relates only to recreational angling consumer surplus.

Commercial fisheries. The social benefits derived from increased landings by commercial fishermen can be valued by examining the markets through which the landed fish are sold. This entails a series of steps that are detailed below. The first step of the analysis involves a fishery-based assessment of I&E-related changes in commercial landings (pounds of commercial species as sold dockside by commercial harvesters) in each case study. The changes in landings are then valued according to market data from relevant fish markets (dollars per pound) to derive an estimate of the change in gross revenues to commercial fishermen. The final steps entail converting the I&E-related changes in gross revenues into estimates of social benefits. These social benefits consist of the sum of the producers' and consumers' surpluses that are derived as the changes in commercial landings work their way through the multi-market commercial fishery sector. Each step is described below.

To estimate the impact that § 316(b) regulations may have on commercial landings, the biological assessment described in Chapter A5 provided éstimates of the change in commercial catch of adult equivalent fish in a given CWIS-impacted waterbody. Yields to the commercial fishery were derived by estimating the number of fish (and species-associated pounds) of commercial species reaching harvest age, and then increasing landings in accordance with species- and location-specific fishery mortality rates (i.e., the percent of the given stock that fishery experts believe is harvested). For species that are harvested by both recreational and commercial anglers, the historical allocation of landings was used to split the yield into each sector. The change in catch was used to infer a like-sized change in landings, on a species- and site-specific basis.

This approacb embodies an assumption that there is a linear relationship between changes in the fishery stock and changes in landings, with the slope based on fishery (harvest) mortality rates. The actual stock-to-harvest relationship may be not be linear for some species and/or locations (i.e., it is uncertain whether harvest is an increasing, decreasing, or constant function of stock size). However, the linear approach is likely to provide a reasonable approximation for the marginal changes in the fisheries that are being evaluated in this analysis. In addition, it is likely that the fisheries-related approach develops underestimates of the changes in stocks attributable to I&E. This is because I&E monitoring often depicts impacts to already depleted fisheries, and fishery mortality rates used to assign a small portion of the stock to landings (yields) also reflect conditions of fisheries that often are in decline. Therefore, the linear estimates are based on projections of changes in stocks that are probably underestimated. Since stock change estimates are probably understated, the linear extrapolations are likely to provide results that are comparable to a declining stock-to-harvest function.

The next step is the assign a market value to the estimated change in commercial landings. In the case studies, presented in Parts B through I of this document, all market values were obtained for each state from the National Marine and Fisheries Service (NMFS), based on data located at the NMFS website (www.st.nmfs.gov). NMFS obtained market values for each state from a census of the volume and value of finfish and shellfish landed and sold at the dock. Principal landing statistics that are collected consist of the pounds and dockside (ex-vessel) dollar value of landings identified by species, year, month,

[3] Increased revenues are often realized by commercial ventures whose businesses are stimulated by environmental improvements. These revenue increases do not necessarily reflect gains in national level "economic welfare" and, therefore, are not usually included in a benefit-cost analysis. However, these positive economic impacts may be sizable and of significance to local or regional economies — and also of national importance — in times when the economy is not operating at full capacity (i.e., when the economic impacts reflect real gains and not transfers of activity across regions or sectors).

state, county, port, water and fishing gear. Most states get their landings data from seafood dealers who submit monthly reports of the weight and value of landings by vessel (NMFS, 2001a). A ten year average (1990-1999) of the market values were used to even out inter-annual fluctuations, and where a facility's surrounding watershed boundaries were included in multiple states, an average of the states' market values were used. All values are stated in year 2000 dollars.

The final set of steps entails converting the dockside market value of changes in commercial landings into the measures of economic surplus that constitute social benefits. These surplus measures include producer surplus to the watermen who harvest the fish, as well as the rents and consumer surplus that accrue to buyers and sellers in the sequence of market transactions that apply in the commercial fishery context. To do this with primary analysis would be an extremely complex process for each fish market. However, several primary research efforts exist that can be used in a benefits transfer that enables EPA to estimate the total economic surplus (social benefits) that arise from changes in commercial landings.

An important portion of commercial fishing benefits is the producer surplus generated by the estimated marginal increase in landings, but typically the data required to compute the producer surplus are unavailable. Various researchers, however, have developed empirical estimates that can be used to infer producer surplus for watermen based on gross revenues (landings times wholesale price). The economic literature (Huppert, 1990; Rettig and McCarl, 1985) suggests that producer surplus values for commercial fishing ranges from 50 to 90 percent of the market value. That is, the wholesale landings values are a close proxy for producer surplus because the commercial fishing sector has very high fixed costs relative to its variable costs. Therefore, the marginal benefit from an increase in commercial landings can be estimated to be approximately 50 to 90 percent of the anticipated change in commercial fishing revenues. In assessments of Great Lakes fisheries, an estimate of approximately 40% has been derived as the relationship between gross revenues and the surplus of commercial fishermen (Cleland and Bishop, 1984; Bishop, personal communication, 2002; and Holt and Bishop, 2002).[4]

The 90 percent estimate of producer surplus relative to gross landings revenue implies a situation in which supply is relatively inelastic and demand is relatively unaffected by changes in supply. This may be suitable in the short run for many fisheries (and perhaps long term for some fisheries) in which watermen experience an increase in landings while: (1) there is no change in harvesting behavior or effort (e.g., due to high fixed costs relative to marginal costs), and (2) there is no appreciable change in price (e.g., where changes local landings have no appreciable impact on broader market prices).[5] For the purposes of this study, however, EPA believes producer surplus estimates in the range of 40% to 70% of landings values (rather than up to 90%) probably are a more suitable reflection of longer-term market conditions.

Producer surplus is one portion of the total economic surplus impacted by increased commercial stocks — the total benefits are comprised of the economic surplus to producers, wholesalers, processors, retailers, and consumers (Norton et al., 1983; Holt and Bishop, 2002). Primary empirical research deriving "multi-market" welfare measures for commercial fisheries have estimated that surplus accruing to commercial anglers amount to 22.2% of the total surplus accruing to watermen, retailers and consumers combined in the striped bass markets in New York and Baltimore (Norton et al., 1983); and 22.3% in the Great Lakes (Bishop, personal communication, 2002, and Holt and Bishop, 2002). This relationship is applied in the case studies to estimate total surplus from the projected changes in commercial landings. Figure A9-2 displays the composition of the total economic surplus.

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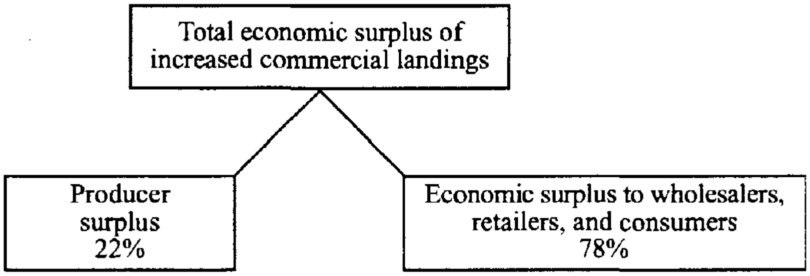
[4] Cleland and Bishop indicate nearly 30% (1981 fishery), but a more recent empirical investigation by Bishop (personal communication, January 2002, pertaining to a confidential litigation support report developed by Bishop in 2000) provides updated fishery estimates that indicate producer surplus was approximately 42% of the 1999 dockside landings value for the relevant fisheries).

[5] Alternative assumptions and scenarios are plausible, but the net impact on total economic surplus would probably not be appreciable (for example, if market prices decreased with increased catch, then commercial fishermen may enjoy less producer surplus, but this would be offset — at least in part — by gains in consumer surplus).

Figure A9-2: Components of Total Surplus



The methods described above are summarized in Table A9-1, in an example on how EPA estimated the baseline economic impact from I&E losses of striped bass at Salem Nuclear Generating Station (Salem) in New Jersey. First, per pound dockside values were obtained for striped bass in Delaware and New Jersey, and then a weighted average of the two values was obtained, weighted by the total landings in each state. Then this per pound value is multiplied by the annual I&E rates to obtain an annual market value of the losses from I&E. Then, 40 percent to 70 percent of the market value is estimated as the producer surplus. Finally, the total economic social benefit from the striped bass commercial fishery is obtained by dividing the producer surplus by 22 percent.

Table A9-1: Annual I&E Commercial Fishing Impacts on Striped Bass at Salem (baseline)

Step 1. Derive per pound market value of landed shad	
a. Derive DE $/lb	
Catch DE (lb) (total 1990-1999)	3,762,358
Value DE	$3,474,742
DE $/lb	$0.92
b. Derive NJ $/lb	
Catch NJ (lb) (total 1990-1999)	10,437,399
Value NJ	$6,396,137
NJ $/lb	$0.61
c. Derive weighted DE/NJ average $/lb	
% catch DE	36.5%
% catch NJ	63.5%
Weighted average (per lb)	$0.73
Step 2. Determine market value of I&E landings impacts	
a. Baseline I&E impact of commercial landings (lbs)	612,715
b. Market value of I&E impact (weighted ave $ * I&E lbs)	$444,973
Step 3. Develop surplus estimates	
a. Producers surplus low (mkt value * 0.4)	$177,989
b. Producers surplus high (mkt value * 0.7)	$311,481
c. Total social benefit - low (prod surplus /0.22)	$809,041
d. Total social benefit - high (prod surplus /0.22)	$1,415,823

Recreational users. The benefits of recreational use cannot be tracked in the market, since much of the recreational activity associated with fisheries occurs as nonmarket events. However, there is an extensive literature on valuing recreational fishing trips and valuing increased catch rates on fishing trips. Participants in recreational activities other than fishing may also benefit from a reduction in I&E. For example, bird watchers may find more abundance and diversity of piscivorus species if the fishery populations are enhanced. Likewise, boaters may receive added recreational value to the degree that enjoyment of their surroundings is an important part of their recreational pleasure or that fishing is a secondary reason for boating.

Primary studies of sites throughout the United States have shown that anglers value their fishing trips and that catch rates are one of the most important attributes contributing the quality of their trips. Higher catch rates may translate into two components of recreational angling benefits: (1) an increase in the value of existing recreational fishing trips, and (2) an increase in recreational angling participation. The most promising and practical approaches for quantifying and monetizing these two benefits components are random utility modeling or RUM (as a primary research method) and benefits transfer (as a secondary method applied when data and other constraints limit the feasibility of doing site-specific primary research). The RUM approach has been applied in the watershed-level case studies, and is described in greater detail in Chapter A10.

For each case study (including the watershed-level sites for which a RUM approach was also deployed), a benefits transfer approach was used as a basis for estimating recreational benefits. There is a large literature that provides willingness-to-pay values for increases in recreational catch rates. These increases in value are benefits to the anglers and reflect their "consumer surplus" which in some instances are reported on the basis of value per additional fish caught.[6] For each case study, monetary values for increased angler consumer surplus were drawn from those credible research efforts that estimated consumer surplus for locations closest in geographic area and relevant species to the I&E-impacted sites. To estimate a unit value for recreational landings, lower and upper values were established for the recreational species, based on values revealed in the suitable literature. Table A9-2 shows some of the studies that were used in the case study analyses, the case studies and aquatic species these studies were applied to, the range of dollar values used, and the economic method(s) used in the study (e.g., contingent valuation, travel cost, or random utility modeling).[7]

The incremental increase in recreational landings is estimated based on the biological modeling of how reduced I&E will change the catch of adult equivalent fish (as described in Chapter A5). Willingness-to-pay estimates for increases in catch are then applied to these changes in catch to obtain monetary estimates of total recreational value of fish lost through I&E.

In some cases it may be reasonable to assume that increases in fish abundance (attributable to reducing I&E) will lead to an increase in recreational fishing participation. The expected value of an increase in participation is directly related to the amount of degradation occurring at baseline. For example, the greatest changes are likely to occur in a location that has experienced such a severe impact to the fishery that the site is no longer an attractive location for recreational activity. Estimates of potential recreational activity post-regulation can be made based on similar sites with healthy fishery populations, on conservative estimates of the potential increase in participation (e.g., a 5 percent increase), or on recreational planning standards (densities or level of use per acre or stream mile). A participation model (as in a RUM application) provides a more robust alternative to predict changes in the net addition to user levels from the improvement at an impacted site. The economic benefit of the increase in angling days then can be estimated using values derived from the RUM analysis itself (as is done in the case studies presented in Parts B, C, and D of this document), or by drawing from the economic literature for a similar type of fishery and angling experience. Where primary research is not feasible, estimates of potential recreational activity post-regulation can sometimes be made based on similar sites with healthy fishery populations, on conservative estimates of the potential increase in participation, or on recreational planning standards (densities or level of use per acre or stream mile).[8]

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[6] In some studies, estimated consumer surplus is based on other metrics, such as dollar per user day. However, such measures can be translated into consumer surplus values per fish caught if sufficient catch data are available.

[7] Note that the recreational angling valuation studies used in this benefits analysis for § 316(b) differ from the studies recently applied by EPA in several other water quality regulations. For example, the metal products and machinery effluent guidelines rulemaking was evaluated using eight studies that were used to infer a percent change in recreational consumer surplus (relative to baseline levels) for a change in water quality and/or fish toxicity levels. For § 316(b), however, the benefits analysis is driven by estimated changes in fish abundance rather than a change in chemical concentrations. Accordingly, different literature is used in the benefits transfer.

[8] EPA has not yet attempted to factor in increased participation as part of its benefits transfer analysis of recreational fishing benefits, but such impacts are embedded in the RUM applications provided in this document.

Table A9-2: Economic Literature Applied in Case Studies for Recreation Angling Valuation.

Study	Some Case Studies Applied to:	Some Species Applied to:	Range of Values Used per Fish ($2000) Low	Range of Values Used per Fish ($2000) High	Study Type
Agnello, 1989	Delaware, Brayton	Weakfish	$2.72	$2.72	Travel cost method: multi-site; regional / hedonic
Boyle et al., 1998	Ohio	Bass (largemouth, white, red, rock, smallmouth, spotted, yellow), rainbow trout	$1.58	$3.95	Contingent valuation: dichotomous choice
Charbonneau and Hay, 1978	Ohio	Catfish (channel, blue, flathead, white), crappie (black, white), perch (white, yellow), sauger, walleye, bluegill, pumpkinseed, green sunfish, longear sunfish, redear sunfish, warmouth, grass pickerel, northern pike, muskellunge, paddlefish	$1.00	$7.92	Travel cost method: single site; Contingent valuation: open ended
Hicks et al., 1999	Delaware, Pilgrim, Seabrook, Brayton	American shad, Atlantic cod, Atlantic croaker, Atlantic mackerel, black sea bass, bluefish, cunner, pollock, red hake, searobin, spot, striped bass, summer flounder, tautog, weakfish, white perch, winter flounder	$2.01	$5.29	Simple travel cost method and contingent valuation
Huppert, 1989	California	Striped bass	$9.11	$14.14	Travel cost and contingent valuation
Loomis, 1988	Ohio	Coho salmon	$12.39	$12.39	Travel cost: multi-site
McConnell and Strand, 1994	Delaware, Pilgrim, Seabrook, Brayton, Ohio	American shad, Atlantic cod, Atlantic croaker, Atlantic mackerel, black sea bass, bluefish, cunner, pollock, red hake, searobin, spot, striped bass, summer flounder, tautog, white perch, winter flounder	$0.62	$8.59	Contingent valuation and Random Utility Modeling
Milliman et al., 1992	Ohio	Perch (white, yellow), bluegill, pumpkinseed, green sunfish, longear sunfish, redear sunfish, warmouth	$0.31	$0.31	Contingent valuation: dichotomous choice
Norton et al., 1983	Delaware, Ohio	Striped bass	$11.08	$15.55	Travel cost method: multi-site; regional / hedonic
Samples and Bishop, 1985	Ohio	Coho salmon	$16.01	$16.01	Travel cost method: multi-site; regional / hedonic
Sorg et al., 1985	Ohio	Catfish (channel, blue, flathead, white), crappie (black, white), walleye, sauger, grass pickerel, northern pike, muskellunge, paddlefish	$5.02	$5.02	Travel cost method: multi-site; regional / hedonic; Contingent valuation: iterative bidding

Subsistence anglers. Subsistence use of fishery resources can be an important issue in areas where socioeconomic conditions (e.g., the number of low income households) or the mix of ethnic backgrounds make such angling economically or culturally important to a component of the community. In cases of Native American use of impacted fisheries, the value of an improvement can sometimes be inferred from settlements in legal cases (e.g., compensation agreements between impacted tribes and various government or other institutions in cases of resource acquisitions or resource use restrictions). For more general populations, the value of improved subsistence fisheries may be estimated from the costs saved in acquiring alternative food sources (assuming the meals are replaced rather than foregone). This may underestimate the value of a subsistence-fishery meal to the extent that the store-bought foods may be less preferred by some individuals (for reasons of cultural background or simply as a matter of taste) than consuming a fresh-caught fish. Subsistence fishery benefits are not included in the case studies to date, due to a lack of data available within the time constraints of the general analysis. However, impacts on subsistence anglers may constitute an important environmental justice consideration.

A9-4 INDIRECT USE BENEFITS

Indirect use benefits refer to welfare improvements that arise for those individuals whose activities are enhanced as an indirect consequence of fishery or habitat improvements generated by the proposed existing facility standards for CWIS. For example, the rule's positive impacts on local fisheries may generate an improvement in the population levels and/or diversity of fish-eating bird species. In turn, avid bird watchers might obtain greater enjoyment from their outings, as they are more likely to see a wider mix or greater numbers of birds. The increased welfare of the bird watchers is thus a legitimate but indirect consequence of the proposed rule's initial impact on fish.

Another example of potential indirect benefits concerns forage species. A rule-induced improvement in the population of a forage fish species may not be of any direct consequence to recreational or commercial anglers. However, the increased presence of forage fish will have an indirect affect on commercial and recreational fishing values if it increases food supplies for commercial and recreational species. Thus, direct improvements in forage species populations can result in a greater number (and/or greater individual size) of those fish that are targeted by recreational or commercial anglers. In such an instance, the increment in recreational and commercial fishery benefits would be an indirect consequence of the proposed rule's initial impacts on lower trophic levels of the aquatic food web.

For the case studies, two general approaches were used to estimate the indirect value of forage fish. The first approach used two distinct estimates of trophic transfer efficiency to relate foregone forage production to foregone fisheries yield that would result from two kinds of food web pathways. The two estimates, referred to as secondary and tertiary forgone yield in this document, reflect (a) that portion of total forage production that has a high trophic transfer efficiency because it is directly consumed by harvested species and (b) the remaining portion of total forage production that has a low trophic transfer efficiency because it is not consumed directly by harvested species, but instead reaches harvested species indirectly after passage through other parts of the food web. The dollar value of foregone commercial and recreational production was estimated using the same monetary values as for the direct use benefits estimates.[9] The indirectly consumed production enhancement from forage species that is not embodied in the landed recreational and commercial fish was examined in a similar manner, but values were adjusted downwards to reflect a much lower trophic efficiency transfer rate. This approach is described in greater detail in Chapter A5. A serious limitation with this approach is that I&E data collected for CWISs often overlook impacts on forage species (focusing instead on recreational and commercial species). Therefore, the results developed using this approach generally reflect considerable underestimates of forage species values, because forage species impacts data generally are lacking in CWIS biological assessments.

The second approach considers the costs associated with direct replacement of individual fish with hatchery-reared individuals. Replacement costs typically can be used as a lower bound estimate of value because costs generally are a lower-bound proxy for values, and because in this application the approach does not consider how reduction in forage stocks may affect other species.[10] Estimates of replacement costs used in the case studies are based on the cost to produce the site-specific set of relevant forage species of North American fish for stocking, as presented by the American Fisheries Society (AFS, 1993). These costs reflect the expense of rearing a fish in a hatchery to the size of release, but do not include other costs associated with the transport or release of the fish to I&E-impacted waters. The AFS (1993) estimates these costs at approximately $1.13 per mile, but does not indicate how many fish (or how many pounds of fish) are transported for this price. Lacking relevant data, EPA does not include the transportation costs in this valuation approach. For this reason, coupled with the fact that forage species I&E impacts tend to be under-reported or omitted in CWIS field data, the replacement cost approach is likely to produce an under-estimate of the value of the forage species. In addition, it is not known at this time if there is increased mortality of stocked fish, or whether some I&E impacted species can be successfully raised in hatcheries, or if there are long term problems due to decreasing genetic variety by using hatchery-reared fish. Each of these factors would compound the degree to which hatchery costs might underestimate values.

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[9] Note that while this approach is based on the value contributed by forage fish to landings of commercial and recreational species, the estimates pertain to the forage species that are impacted by I&E and are shown as an indirect use benefit (in other words, these benefit estimates are separate from and are not included in the direct use benefit estimates described above for commercial and recreational fisheries).

[10] Using replacement costs as a proxy for the value of the forage fish impacts might also overstate benefits if society's willingness to pay is less than the cost of replacement. However, there is no empirical evidence that supports this possibility, and limited evidence using the Habitat Restoration Costing (HRC) approach (Chapter A11) suggests that WTP exceeds such costs.

A9-5 NONUSE BENEFITS

Nonuse (passive use) benefits arise when individuals value improved environmental quality apart from any past, present, or anticipated future use of the resource in question. Such passive use values have been categorized in several ways in the economic literature, typically embracing the concepts of existence (stewardship) and bequest (intergenerational equity) motives. Passive use values also may include the concept that some ecological services are valuable apart from any human uses or motives. Examples of these ecological services may include improved reproductive success for aquatic and terrestrial wildlife, increased diversity of aquatic and terrestrial species, and improved conditions for recovery of T&E species.

Passive use values can only be estimated in primary research through the use of stated preference techniques such as the contingent valuation method (CVM) surveys and related stated preference techniques (e.g., conjoint analysis using surveys). In the case of the § 316(b) proposed existing facilities rule, no primary research was feasible within the budgeting, scheduling, and the other constraints faced by the Agency. Accordingly, estimates were developed by EPA based on benefits transfer, with appropriate care and caveats clearly recognized.

One long-standing benefits transfer approach for estimating nonuse values is to apply a ratio between certain use-related benefits estimates and the passive use values anticipated for the same site and resource change. Freeman (1977) applied a rule of thumb in which he inferred that national-level passive use benefits of water quality improvements were 50 percent of the estimated recreational fishing benefits. This was based on his review of the literature in those instances where nonuse and use values had been estimated for the same resource and policy change. Fisher and Raucher (1984) undertook a more in-depth and expansive review of the literature (included those studies reviewed by Freeman) and found a comparable relationship between recreational angling benefits and nonuse values. They concluded that since nonuse values were likely to be positive, applying the 50 percent "rule of thumb" was preferred over omitting nonuse values from a benefits analysis entirely.

The 50 percent rule has since been applied frequently in EPA water quality benefits analyses (e.g., effluent guidelines RIAs for the benefits analysis of rulemakings for the pulp and paper sectors and metal products and machinery, and the RIA for the Great Lakes Water Quality Guidance). At times the rule has been applied to all recreational benefits (not just angling),[11] and there are studies in the literature that imply nonuse values may not only be half of recreational fishing benefits, but might be as large as or greater than recreational values (e.g., Sutherland and Wash, 1985; Sanders et al., 1990). Thus, using the 50% rule might very well lead to an understatement of nonuse values.

The overall reliability and credibility of applying the 50 percent rule approach is, as for any benefits transfer approach, dependent on the credibility of the underlying study and the comparability in resources and changes in conditions between the research survey and the § 316(b) rule's impacts at selected sites. The credibility of the nonuse value estimate also is contingent on the reliability of the recreational angling estimates to which the 50 percent rule is applied.

Using the 50 percent rule poses several concerns and includes several limitations. On the one hand, there is long-standing precedence in using this easy to apply rule of thumb and, as noted in earlier literature reviews, using this approach is probably better than omitting nonuse values entirely. Still, EPA recognizes that legitimate concerns arise because of (1) the dated nature of the literature reviews upon which the approach is founded (several more recent studies are now available and need to be reviewed and incorporated in how the body of literature is interpreted); (2) the key differences in the studies underlying the initial reviews (as noted in Fisher and Raucher, 1984, the studies vary considerably in what they are attempting to measure, even though they consistently derive ratios in their value estimates approximating 50 percent); and (3) the problems inherent in how the results of individual studies (or the collective body of research) should be applied in order to be as consistent as possible with the underlying literature (for example, applying the study by Mitchell and Carson, 1986, implies that the 50 percent rule may reflect the nonuse component of the total value held by users, but would overlook the nonuse values held by the large number of individuals or households that are NOT users of the impacted water resources – resulting in a significant omission from the total nonuse value estimates).

Therefore, despite the longstanding and widespread application of the 50 percent rule, EPA intends to revisit the body of research on this topic and re-evaluate how to apply benefits transfer in developing estimates of nonuse value benefits in the future. In the interim, the Agency will continue to apply the 50 percent rule for this proposed rule, acknowledging the limitations of the approach.

[11] E.g., the EEBA for the Metal Products and Machinery rulemaking, Chapter 15.

A second potential approach to deriving estimates for § 316(b) passive use values is to use benefits transfer to apply an annual willingness-to-pay estimate per nonuser household (e.g., Mitchell and Carson, 1986; Carson and Mitchell, 1993) to all the households with passive use motives for the impacted waterbody.[12] The challenges in this approach include defining the appropriate "market" for the impacted site (e.g., what are the boundaries for defining how many households apply), as well as matching the primary research scenario (e.g., "boatable to fishable") to the predicted improvements at the § 316(b)-impacted site.

As a third potential approach, for some specific impacted fish species, nonuse (or total) valuation may be deduced using restoration-based costs as a proxy for the value of the change in stocks. For example, for T&E species, the costs of restoration programs and various resource use restrictions indicate the revealed preference value of preserving the species. Where a measure of the approximate cost per preserved or restored individual fish can be deduced, and the number of individuals spared via BTA can be estimated, this is a viable approach. This approach is examined in the § 316(b) case study of the San Francisco Bay/Delta Estuary (Part E of this document). Improvements have been made to fish habitats by increasing stream flows, installing screening devices and fish passages, removing dams, and controlling temperatures. These changes in operations and technologies all entail significant costs, which society has shown to be willing to pay for the protection and restoration of healthy fish populations, particularly the T&E species of the Sacramento and San Joaquin Rivers. These investments provide a means to evaluate the loss imposed on society when a portion of these same fisheries are adversely impacted by I&E. Because the species involved in this restoration costing approach have no use value (due to their status as threatened or endangered), the approach yields an estimate of nonuse values.

A9-6 SUMMARY OF BENEFITS CATEGORIES

Table A9-3 displays the types of benefits categories expected to be affected by the § 316(b) rule. The table also reveals the various data needs, data sources, and estimation approaches associated with each category. Economic benefits can be broadly defined according to direct use and indirect use, and are further categorized according to whether or not they are traded in the market. As indicated in Table A9-3, "direct use" benefits include both "marketed" and "nonmarketed" goods, whereas "nonuse" and "indirect use" benefits include only "nonmarketed" goods.

[12] Note that Mitchell and Carson estimate "total value," including use and nonuse components. However, one can interpret the total value estimates for nonusers as their nonuse value (i.e., there is no difference between their total and nonuse value). One could also apply the Mitchell and Carson total use values to resource users to obtain both use and nonuse values (combined) for those households.

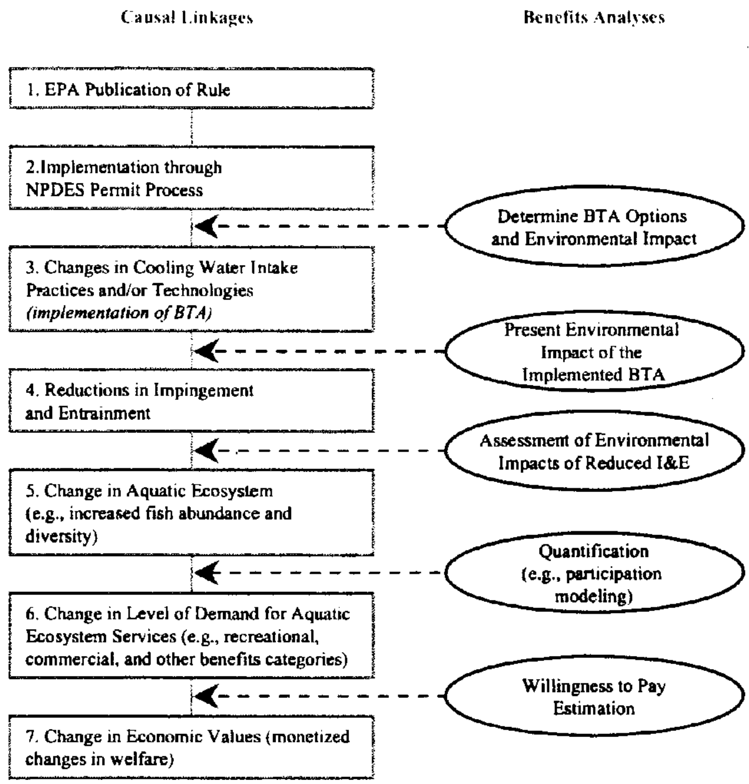
Table A9-3: Summary of Benefit Categories, Data Needs, Potential Data Sources, and Approaches.

Benefits Category	Basic Data Needs	Potential Data Sources/Approaches
	Direct Use, Marketed Goods	
Increased commercial landings	▸ Estimated change in landings of specific species ▸ Estimated change in total economic impact	▸ Based on facility specific I&E data and ecological modeling ▸ Based on available literature
	Direct Use, Nonmarket Goods	
Improved value of a recreational fishing experience	▸ Estimated number of affected anglers ▸ Value of an improvement in catch rate	▸ Site-specific studies, national or statewide surveys ▸ Based on available literature
Increase in recreational fishing participation	▸ Estimated number of affected anglers or estimate of potential anglers ▸ Value of an angling day	▸ Use of RUM analysis, where feasible
Increase in value of near-water recreational experience	▸ Estimated number of affected near-water recreationists ▸ Value of a near-water recreation experience	▸ Use of RUM analysis, where feasible
Increase in near-water recreational participation	▸ Estimated number of affected near-water recreationists ▸ Value of a near-water recreation experience	▸ Use of RUM analysis, where feasible
	Nonuse and Indirect Use, Nonmarketed	
Increase in indirect values	▸ Estimated I&E impacts on forage species (as data permit)	▸ Based on facility specific I&E data (to degree available) and ecological modeling ▸ Site-specific studies, national or statewide surveys ▸ Application of hatchery replacement costs or biomass converted to recreational or commercial species
Increase in nonuse use values	▸ Primary research using stated preference approach (not feasible within EPA constraints) ▸ Applicable studies upon which to conduct benefits transfer	▸ Site-specific studies or national stated preference surveys ▸ Benefits transfer (e.g., application of 50 percent rule of thumb) ▸ Restoration-based costs as proxy for valuation of common and/or endangered species

A9-7 CAUSALITY: LINKING THE § 316(B) RULE TO BENEFICIAL OUTCOMES

Understanding the anticipated economic benefits arising from changes in I&E requires understanding a series of physical and socioeconomic relationships linking the installation of Best Technology Available (BTA) to changes in human behavior and values. As shown in Figure A9-3, these relationships span a broad spectrum, including institutional relationships to define BTA (from policy making to field implementation), the technical performance of BTA, the population dynamics of the aquatic ecosystems affected, and the human responses and values associated with these changes.

Figure A9-3: Causal Linkages in the Benefits Analysis



The first two steps in Figure A9-3 reflect the institutional aspects of implementing the § 316(b) rule. In step 3, the anticipated applications of BTA (or a range of BTA options) must be determined for the regulated entities. This technology forms the basis for estimating the cost of compliance, and provides the basis for the initial physical impact of the rule (step 4). Hence, the analysis must predict how implementation of BTAs (as predicted in step 3) translates into changes in I&E at the regulated CWIS (step 4). These changes in I&E then serve as input for the ecosystem modeling (step 5).

In moving from step 4 to step 5, the selected ecosystem model (or models) are used to assess the change in the aquatic ecosystem from the pre-regulatory baseline (e.g., losses of aquatic organisms before BTA) to the post-regulatory conditions (e.g., losses after BTA implementation). The potential output from these steps includes estimates of reductions in I&E rates, and changes in the abundance and diversity of aquatic organisms of commercial, recreational, ecological, or cultural value, including T&E species.

In step 6, the analysis involves estimating how the changes in the aquatic ecosystem (estimated in step 5) translate into changes in level of demand for goods and services. For example, the analysis needs to establish links between improved fishery abundance, potential increases in catch rates, and enhanced participation. Then, in step 7, as an example, the value of the increased enjoyment realized by recreational anglers is estimated. These last two steps are the focal points of the economic benefits portion of the analysis.

A9-8 Conclusions

The general methods described here are applied to the case studies which are provided in Parts B and C of this document. Variations may occur to these general methodologies to better reflect site-specific circumstances or data availability.

Chapter A10: Estimating Benefits with a Random Utility Model (RUM)

INTRODUCTION

CHAPTER CONTENTS

This chapter describes the random utility model (RUM) and trip frequency model for recreational fishing used in the case study analyses of recreational fishing benefits from the proposed §316b rule. The model's main assumption is that anglers will get greater satisfaction, and thus greater economic value, from sites where the catch rate is higher, all else being equal. This benefit may occur in two ways: first, an angler may get greater enjoyment from a given fishing trip when catch rates are higher, and thus get a greater value per trip; second, anglers may take more fishing trips when catch rates are higher, resulting in greater overall value for fishing in the region.

EPA relied on two primary data sources in the case study analyses:

- the National Marine Fisheries Service (NMFS) Marine Recreational Fishing Statistics Survey (MRFSS) combined with the Add-On MRFSS Economic Survey (AMES) (NMFS, 1994 and 1997); and
- the National Demand Survey for Water-Based Recreation (NDS), conducted by U.S. EPA and the National Forest Service (U.S. EPA, 1994a).

The Delaware Estuary and Tampa Bay case studies rely on the 1994 and 1997 MRFSS data, respectively. The Ohio River case study uses the NDS data. The two datasets provide information on where anglers fish, what fish they catch, and their personal characteristics. When anglers choose among fishing sites they reveal information about their preferences. The case studies use information on recreational anglers' behavior to infer anglers' economic value for the quality of fishing in the case study areas.

EPA used a random utility model to investigate the impact of site characteristics on angler's site choice for single-day trips. Key determinants of site choice include site-specific travel cost, fishing quality of the site, and additional site attributes such as presence of boat ramps and aesthetic quality of the site. EPA used two measures of fishing quality in the case studies. The first measure, the 5-year historic catch rates per hour of fishing, is used in the Delaware Estuary and Tampa Bay case studies. The second measure, fish stock density, is used in the Ohio River case study.

The random utility models generate welfare measures resulting from changes in catch rates on a per trip basis. To capture the effect of changes in catch rates on the number of fishing trips taken per recreational season, EPA combined a RUM model and a trip participation model. The trip participation model estimates the number of trips that an angler will take annually. The combined model is used to estimate the economic value of changes in catch rates or in fish abundance of important fish species in the case study areas.

A10-1 SITE CHOICE MODEL

The site choice model estimates how anglers value access to specific sites, and estimate per trip economic values for changes in catch rates or fish abundance for different species. The study uses a RUM for its site choice model. The RUM assumes that the cost of travel to a recreational site may be used as a proxy for the "price" of visiting that site. The RUM is therefore a form of travel cost model, using travel costs to estimate economic values for unpriced recreational activities.

The RUM assumes that anglers maximize their utility by choosing the fishing site, mode of fishing (i.e., from shore, private or rental boat, and charter boat), and species that give the greatest level of satisfaction, compared with all other available substitutes. Angler *k* chooses site *j* if the utility from that site is greater than utility from all other substitute sites:

$$u_j(k) > u_h(k) \text{ for } h \neq j \text{ and } h = 1,\ldots J \qquad \text{Eq. A10-1}$$

where:

$u_j(k)$ = utility of visiting site *j* for angler *k*,
$u_h(k)$ = utility of visiting a substitute site *h* for angler *k*, and
J = the total number of feasible sites in the angler's choice set.

The RUM travel cost model includes the effects of substitute sites on site values. For any particular site, assuming that it is not totally unique in nature, the availability of substitutes makes the value for that one site lower than it would be without available substitutes.

An angler choosing to fish on a particular day chooses a site based on site attributes. The angler weighs the attributes for various "choice set" sites against the travel costs to each site. These travel costs include both the cost of operating a vehicle and the opportunity costs of time spent traveling. The angler then weighs the value given to the site's attributes against the cost of getting to the site when making a site selection.

The RUM therefore assumes that the probability of selecting a particular site is a function of the site attributes, including catch rates, and travel costs to the site:

$$Prob\ (site_j) = f(catch\ rates,\ other\ site\ attributes,\ travel\ cost) \qquad \text{Eq. A10-2}$$

The RUM assumes that there is a non-random component (v_j) and a random component (ϵ_j) to each angler's utility. The random component is not observable by the researcher (Maddala, 1983; and McFadden, 1981). The model therefore assumes that the utility function has a fixed component and a random component, so that:

$$u_j(k) = v_j(k) + \epsilon_j \qquad \text{Eq. A10-3}$$

where:

$u_j(k)$ = utility of visiting site *j* for angler *k*;
$v_j(k)$ = the observable component of utility; and
ϵ_j = the random, or unobservable component.

The conditional logit model, most often used to estimate the RUM, is based on the assumption that the random error terms ϵ_j, have independently and identically distributed extreme value distributions, and are additive with the observable part of utility (McFadden, 1981; Ben-Akiva and Lerman, 1985).

The logit model therefore becomes:

$$Prob(site_{kj}) = \frac{\exp[v_j(k)]}{\sum_h \exp[v_h(k)]} \text{ for } h \neq j \text{ and } h = 1,\ldots,J \qquad \text{Eq. A10-4}$$

where:

$Prob(site_{kj})$ = the probability that angler *k* will select site *j*;
$\exp[v_j(k)]$ = the anglers utility from visiting site *j*;
$\Sigma_h \exp[v_h(k)]$ = the sum of angler's utility at each site for all sites (for $h \neq j$) in the opportunity set for a given region.

The conditional logit model imposes the assumption that adding or deleting a site does not affect the probability ratio for choosing any two sites. This so-called independence of irrelevant alternatives (IIA) property follows from the assumption that the error terms are independent (Ben-Akiva and Lerman, 1985). Sites sharing characteristics not included in the model (e.g., salt water vs freshwater sites) will have correlated error terms, thus violating the IIA property. In these cases a nested logit model, which groups sites with similar characteristics, is more appropriate.

The nested logit model assumes that anglers first choose the group and then a site within that group. Recreational fishing models generally assume that anglers first choose a mode and species, and then a site. The case study datasets, however, do not clearly distinguish similarities between sites in terms of species and/or fishing mode. Anglers fish various mode/species combinations at the same sites. The nested model therefore does not appear to be appropriate in this case, and the study used a single conditional logit model for site choice estimation.

In the conditional logit model estimated here, the measurable component of utility is estimated as:

$$v_j(k) = \beta_1 tc_j(k) + \beta_2\ tt_j(k) + \beta_3\ X(k) + \sum_s \gamma_s q_{js}(k) \qquad \text{Eq. A10-5}$$

where:

- $v_j(k)$ = the utility realized from a conventional budget constrained utility maximization model conditional on choice *j* by angler *k*;
- $tc_j(k)$ = the travel cost to site *j* for angler *k*;
- $tt_j(k)$ = the travel time to site *j* for angler *k*;
- $X_j(k)$ = a vector of site characteristics for site alternative j as perceived by angler *k*. These characteristics may include various site amenities (e.g., presence of boat ramps) and aesthetic quality of the site;
- $q_{js}(k)$ = the fishing quality of site *j* for species *s*, measured in terms of catch rate or fish abundance; and
- β and γ = the marginal utilities for each variable.

The probability of choosing site *j* is therefore modeled as:

$$Prob(j) = \frac{\exp[\beta_1 tc_j(k) + \beta_2 tt_j(k) + \beta_3 X_j(k) + \sum \gamma_s q_{js}(k)]}{\sum_h \exp[\beta_1 tc_h(k) + \beta_2 tt_h(k) + \beta_3 X_h(k) + \sum \gamma_s q_{hs}(k)]} \qquad \text{Eq. A10-6}$$

for $h \neq j$ and $h = 1,\ldots,J$, where J is the total number of feasible sites in the angler's choice set.

The study assumes that anglers in the estimated model consider site quality based on the catch rate for their targeted species and additional site attributes, such as presence of boat ramps. Theoretically, an angler may catch any of the available species at a given site (Morey, 1999). If, however, an angler truly has a species preference, then including the catch variable for all species available at the site would inappropriately attribute utility to the angler for species not pursued (Haab et al., 2000; Hicks, et al., 1999; McConnell and Strand, 1994). To avoid this problem, EPA multiplied a dummy variable for each species targeted by the catch rate, so that each angler's observation in the data set includes only the targeted species' catch rate. All other catch rates are set to zero. The NDS data do not provide sufficient information to estimate species specific catch rates at all sites in angler's choice set. Thus, for the Ohio case study, EPA specified quality of fishing sites in terms of fish abundance reflecting all species commonly caught at the site (see Chapter C5 for detail).

A10-2 TRIP FREQUENCY MODEL

The trip frequency model estimates changes in days fished, when site or individual characteristics change. The model assumes that the number of days fished in a year is a function of the travel costs, site characteristics, and characteristics of the individual anglers:

$$T = f(p,x,z) \qquad \text{Eq. A10-7}$$

where:

T = the number of days fished in a year,
p = a vector of travel costs,
x = a vector of site characteristics, and
z = a vector of angler characteristics.

To connect this model to the RUM, the trip frequently model is often specified as:

$$T = f(I(p,x),z) \qquad \text{Eq. A10-8}$$

where:

I = the inclusive value for each angler, calculated from the RUM.
p = a vector of travel costs,
x = a vector of site characteristics, and
z = a vector of angler characteristics.

The inclusive value can be interpreted as a measure of the expected utility of a set of choice alternatives (Ben-Akiva and Lerman, 1985). The participation model uses the inclusive value from the conditional logit model as a measure of the expected utility of the sites available to anglers in the study region. This is measured by:

$$I_k = \log \sum_j \exp(V_j\ (q_{js})) \qquad \text{Eq. A10-9}$$

where:

I_k = the inclusive value for fishing sites in the study area for angler *k*;
$\exp(V_j(q_{js}))$ = angler's utility from visiting site *j*; and
q_{js} = catch rate for species *s* at site *j*.

This study therefore estimates the trip frequency model by first estimating the site choice model (RUM), then using the model results to estimate the inclusive value I_k for each angler. Finally, the study estimates the participation model using the inclusive value and other variables to explain trip frequency. The number of days fished becomes a function of the value per trip, indicated by the inclusive value and individual angler characteristics. This model assumes that changes in site quality and travel costs do not directly influence the number of trips, but that changes in site quality will change trip values, thereby indirectly affecting the number of trips.

The study uses a Poisson regression model to estimate trip frequency. This model is one of those most commonly used for count data: discrete data where the dependent variable is a count or frequency. The Poisson regression model explicitly recognizes the non-negative integer character of the dependent variable. (Winkelmann, 2000).

The Poisson regression model assumes the Poisson distribution:

$$f(y_k) = \frac{\exp(-\lambda_k)\lambda_k^{y_k}}{y_k!} \quad for\ y = 0,\ 1,\ 2,\ldots \qquad \text{Eq. A10-10}$$

where:

y_k = the actual number of trips taken by an individual angler in the sample;
λ = both the mean and variance of the distribution (this parameter must be positive); and
k = 1, 2,...K, the number of individuals in the sample.

If the expected value of the demand for trips in a given time period is E(Y), and:

$$E(Y) = f(I, z, \beta) \qquad \text{Eq. A10-11}$$

where:

I = the inclusive value,
z = a vector of angler characteristics, and
β = the vector of estimated coefficients,

then the Poisson probability distribution of demand for trips is:

$$Prob\ (Y_k = y_k) = \frac{e^{-\lambda_k}\lambda_k^{y_k}}{y_k!}, \quad y = 0,\ 1,\ 2,\ldots \qquad \text{Eq. A10-12}$$

where:

Y_k = the estimated number of trips taken by an individual in the sample;
y_k = the actual number of trips taken by an individual in the sample;
k = 1, 2,...K the number of individuals in the sample; and
$\lambda = f(I, z, \beta)$ = the expected number of trips for an individual in the sample, where *I, z,* β are variables affecting the demand for recreational trips (i.e., inclusive value and socioeconomic characteristics, and β is the vector of estimated coefficients.

Generally, λ is specified as a log-linear function of the explanatory variables x_i, so that:

$$\ln\lambda_k = \beta x_k \qquad \text{Eq. A10-13}$$

or:

$$\lambda_k = \exp(\beta x_k) \qquad \text{Eq. A10-14}$$

This function ensures that λ_k will be positive. The parameters of the Poisson regression are estimated by maximum likelihood.

This model's primary limitation is the requirement that the mean equals the variance. The variance often exceeds the mean, resulting in overdispersion. Overdispersion may be viewed as a form of heteroskedasticity (Winkelmann, 2000). If overdispersion exists but the model is otherwise correctly specified, the Poisson estimator will still be consistent. The standard errors will be biased downwards, however, leading to inflated t-statistics. When this occurs, researchers often use the negative binomial which allows for the variance to be greater than the mean. The negative binomial distribution is derived as a compound Poisson distribution, where the Poisson distribution is the limiting form of the negative binomial distribution.

The Poisson model may be modified to derive the negative binomial model by respecifying λ_i so that:

$$\ln\lambda_k = \beta x_k + \epsilon \qquad \text{Eq. A10-15}$$

where $\exp(\epsilon)$ has a gamma distribution with mean 1 and variance α (Greene 1995), yielding the conditional probability distribution:[1]

[1] The study chose this particular parameterization because it is used by the LIMDEP™ software package.

$$Prob[Y = y_k|\epsilon] = \frac{\exp(-\lambda_k)\ \exp(\epsilon)\ \lambda_k^{y_k}}{y_k!} \qquad \text{Eq. A10-16}$$

where:

- $Prob[Y=y_k]$ = the probability that the estimated number of trips equals the actual number of trips, if ϵ has a gamma distribution with mean 1 and variance α;
- y_k = 0,1,2... number of trips taken by individual *k* in the sample;
- k = 1,2,..., *K* number of individuals in the sample; and
- λ_k = expected number of trips for an individual in the sample.

Integrating out ϵ from equation 2-16 gives the unconditional distribution for y_k, which is used in model's optimization:

$$Prob\ (Y = y_k) = \frac{\Gamma(\theta + y_k)}{\Gamma(\theta)\ y_k!]\ u_k^{\theta}\ (1 - u_k)^{y_k}} \qquad \text{Eq. A10-17}$$

where:

- $Prob[Y=y_k]$ = the probability that the estimated number of trips equals the actual number of trips;
- y_k = 0,1,2... number of trips taken by individual *k* in the sample;
- $\Gamma(.)$ = gamma function;[2]
- θ = $1/\alpha$, where α is an overdispersion parameter; and
- u_i = $\theta/(\theta+\lambda)$.

The negative binomial model has an additional parameter, α, which is an overdispersion parameter, such that:

$$Var\ [y_k] = E\ [y_k]\ (1 + \alpha\ E\ [y_k]) \qquad \text{Eq. A10-18}$$

The overdispersion rate is then given by the following equation:

$$Var\ \frac{y_k}{E\ [y_k]} = 1 + \alpha\ E\ [y_k] \qquad \text{Eq. A10-19}$$

(Greene, 1995).

EPA used the negative binomial model to predict the seasonal number of recreation trips for each recreation activity based on the inclusive value, individual socioeconomic characteristics, and the overdispersion parameter, α. If the inclusive value (i.e., the measure of the expected utility of site alternatives) has the anticipated positive sign, then increases in the inclusive value stemming from improved fishing quality at the sites in the study area will lead to an increase in the number of trips. The combined multinomial logit (MNL) model site choice and count data trip participation models allowed the Agency to account for changes in per-trip welfare values, and for increased trip participation in response to improved ambient water quality at recreation sites.

A10-3 Welfare Estimation

The case studies estimate changes in economic values when catch rates for different species change. Changes in catch rates will affect economic values in two ways. First, the value per trip will change; and second, the number of trips taken may change. The study measures the total economic value for a change in the quantity or quality of particular sites by the number of days fished per angler times the economic value per trip per angler. This value varies with the quality and number of available sites. The total value of a change in catch rate is measured as:

[2] Gamma function is a notation for a definite integral that appears in the equation. For detail on gamma function see Mood et al., 1974.

$$TEV = N \times X \times WTP \qquad \text{Eq. A10-20}$$

where:

- TEV = the total economic value for a specified period of time, such as a season or year;
- N = the number of participants;
- X = the number of trips per participant; and
- WTP = the value per angler per trip, measured by the amount of money that the angler would be willing to pay for a fishing trip.[3]

The study first estimates the value per trip using the RUM, and then estimates the number of trips per angler using the trip frequency model. The results of these models must be combined to measure the total economic value for a given change.

The value of an improvement in site quality, in this case the catch rate or fish abundance, can be measured by the compensating variation (CV) that equates the expected value of realized utility under the baseline and post-compliance conditions. If the catch rate increases from q^0 to q^1, then the CV will be measured by:

$$v_j(p_j, q_j^1, y - CV) + \epsilon_j = v_j(p_j, q_j^0, y) + \epsilon_j \qquad \text{Eq. A10-21}$$

where:

- p_j = the fishing price, or travel cost, for site j;
- q_j^1 = the quality, measured by catch rate, for site *j* under the post policy conditions
- q_j^0 = the quality, measured by catch rate, for site *j* under the baseline conditions; and
- y = the angler's income.

To calculate CV, the angler's utility (V_j (k)) must be estimated as a function of price, quality, and income. Income cannot be estimated in the logit model because it does not change across alternatives. Price (travel cost), however, enter the indirect utility function V(j), so that the model can assume the estimated coefficient on travel cost to be the negative of the coefficient on income (Bockstael et al., 1991).

The RUM predicts only the probability of choosing a specific site. The measure of CV must therefore account for the researcher's uncertainty in predicting site choice. Measuring CV in terms of expected value yields:

$$E[v(p, q^1, y - CV)] = E[v(p, q^0, y)] \qquad \text{Eq. A10-22}$$

where:

- v(p, q, y)= expected maximum utility of being able to choose among J sites on a given fishing trip;.
- p = the fishing price, or travel cost;
- q^1 = sites' quality, measured by catch rate, under the post policy conditions;
- q^0 = sites' quality, measured by catch rate, under the baseline conditions; and
- y = the angler's income.

If the marginal utility of income is constant, CV for the logit model is (Bockstael et al., 1991; Parsons et al., 1999):

$$\begin{aligned} CV_k &= (-1/\beta_1)\ [[\ln\sum \exp[v_j(q^1)] - \ln\sum \exp[v_j\ (q^0)]] \\ &= (-1/\beta_1)\ [I^1 - I^0] \end{aligned} \qquad \text{Eq. A10-23}$$

[3] The estimated model and resulting welfare estimates rely on the assumptions that the number of participants is fixed in the short run, and that the value per trip is independent of the number of trips.

where:

CV_k = the compensating variation for individual k at site j on a given day;
j = 1,...J represents a set of alternative sites in the study region;
β_I = the marginal utility of income, measured by the coefficient on travel cost;
I^0 = the baseline inclusive value; and
I^1 = the post-policy inclusive value.

This result gives the expected compensating variation for a choice occasion. To obtain the value per season, EPA multiplied the result by the number of trips estimated with the participation model. The two models are linked through the inclusive value, which weights the indirect utilities associated with different sites and their prices and qualities by the probabilities of choosing each site (Bockstael et al., 1991).

Parsons et al. (1999) compare several models that link site choice and trip frequency models, and find that they produce similar welfare estimates. Two methods for estimating seasonal welfare estimates are relevant to the models estimated in this case study. The first, proposed by Bockstael et al. (1987), calculates the per trip welfare measure from the RUM, using the measure of CV presented above (Eq. A10-24). The authors then use the trip frequency model to predict the change in the number of trips taken under the proposed policy change. Finally, they calculate a seasonal welfare measure in one of two ways:

$$W_{low} = CV \times Pred(T^0) \qquad \text{Eq. A10-24}$$

$$W_{high} = CV \times Pred(T^1) \qquad \text{Eq. A10-25}$$

or

$$W = CV \times \frac{[Pred(T^0) + Pred(T^1)]}{2} \qquad \text{Eq. A10-26}$$

where:

W_{low} = low bound estimate of the seasonal welfare gain;
W_{high} = upper bound estimate of the seasonal welfare gain;
CV = the compensating variation for an individual on a given day;
$Pred(T^0)$ = the predicted numbers of trips before the policy change., and
$Pred(T^1)$ = the predicted numbers of trips after the policy change.

The second method, based on Hausman et al. (1995), calculates seasonal welfare based on the trip frequency model.

EPA used the first method to estimate lower and upper bound values for the seasonal welfare gain per individual. The Agency extrapolated the estimates of seasonal value per individual to the regional level based on estimates of the total participation level in the region. Procedures for estimating total regional participation are case study specific and discussed in the relevant chapters.

A10-4 Data Sources

The data used for the three case studies of recreational benefits are from the NMFS MRFSS in the Southeastern and Northeastern regions in the U.S. and the EPA's NDS database. The following sections provide a general description of each data source, sampling methods, and key variables. More detailed information on the sub-sample used in each case study can be found in the relevant case study sections.

A10-4.1 Marine Recreational Fisheries Statistics Survey (MRFSS)

MRFSS is a long-term monitoring program that provides estimates of effort, participation, and finfish catch by recreational anglers. The MRFSS survey consists of two independent, but complementary, surveys: a random digit-dial telephone survey of households and an intercept survey of anglers at fishing access sites. Sampling is stratified by state, fishing mode (shore, private/rental boat, party/charter boat), and wave, and allocated according to fishing pressure. Fishing sites are randomly selected from an updated list of access sites.

The intercept survey distinguishes between the modes of fishing (i.e., shore, private/rental boat, party/charter boat), and is designed to elicit information about fishing trips just completed by anglers. The basic intercept survey collects information about anglers' home zip code, the length of their fishing trip, the species they were targeting on that trip, and the number of times anglers have been fishing in the past two and twelve months. Trained interviewers record the species and number of fish caught that are available for inspection and weigh and measure the fish. Anglers report the number and species of each fish they caught on the trip that are not available for inspection (e.g., fish that were released alive or used for bait). The intercept survey provides the species composition used to estimate the historic catch rates at the case study sites for the individual species.

The random telephone survey is used to estimate the number of recreational fishing trips during a two-month basis (as opposed to annual participation) for coastal households. Households with individuals who have fished within two months of the phone call are asked about the mode of fishing, the gear used, and the type of water body where the trip took place for every trip taken within that period. NMFS estimates total catch and participation by state using the MRFSS telephone and intercept surveys, combined with Census and historical data (NMFS, 1999a). The effort estimates (i.e., number of trips) are used in the economic valuation work to expand mean trip-level recreational fishing values to aggregate, population values for recreational fishing. More details about the intercept and the random phone surveys can be found in the MRFSS Procedures Manual (NMFS, 1999a).

NMFS supplemented the routine MRFSS with socio-economic data from anglers in Southeastern and Northeastern regions. The economic survey was designed as an add-on to the MRFSS to take advantage of sampling, survey design, and quality control procedures already in place. Economic questions were added to the intercept survey and a follow-up survey conducted over the telephone was designed to elicit additional socio-economic information from anglers who completed the add-on economic intercept survey. The AMES was implemented from Maine to Virginia in 1994 and from North Carolina to Louisiana in 1997.

The economic field intercept survey of anglers solicited data about trip duration, travel costs, distance traveled, and on-site expenditures associated with the intercepted trip. The survey was conducted by a private survey firm and administered to all marine recreational anglers aged 16 and older intercepted in the field. Data were collected according to the field sampling procedures specified in the MRFSS Procedures Manual. The economic questionnaire was administered either at the completion of the routine MRFSS questions (before inspection of fish) or after all available fish were identified and biological measurements had been obtained. As in the MRFSS, all survey participants, with the exception of beach-bank shore anglers, must have completed their fishing for the day.

Anglers were screened for willingness to participate in the telephone follow-up survey at the time of field intercept. Only those anglers agreeing to the add-on economics field survey or a telephone follow-up survey were interviewed. The telephone follow-up survey solicited additional data and information about anglers' recreational fishing avidity, attitudes, and experience.

A total of 14,868 follow-up surveys were attempted in the Northeast Region in 1994, of which 8,226 (55 percent) were completed. Refusals, wrong numbers, and households that could not be reached in four calls accounted for the 45 percent non-response rate. The 1994 questionnaire targeted two distinct groups of anglers: (1) anglers who targeted -- not merely caught -- bluefish, striped bass, black sea bass, summer flounder, Atlantic cod, tautog, scup or weakfish, and (2) anglers that targeted other species and happened to catch any of these eight species. These species were chosen because they were either under management in 1994 or were expected to come under management in the near future. Approximately 10,000 AMES telephone interviews were completed in the Southeast Region in 1997. The interview consisted of anglers intercepted from March 1997 through December 1997 and who agreed to be interviewed. More extensive details regarding the final results of the telephone follow-up survey are provided in Hicks et al. (1999).

The Agency used data from the 1994 and 1997 AMES to model recreational fishing behavior in the Delaware Estuary and Tampa Bay case studies, respectively.

A10-4.2 NDS for Water-Based Recreation

The Ohio River study used data from the 1994 NDS for Water-Based Recreation (U.S. EPA, 1994a). The NDS survey collected data on demographic characteristics and water-based recreation behavior using a nationwide stratified random sample of 13,059 individuals aged 16 and over. Respondents reported on water-based recreation trips taken within the past 12 months, including the primary purpose of their trips (e.g., fishing, boating, swimming, and viewing), total number of trips, trip length, distance to the recreation site(s), and number of participants. Where fishing was the primary purpose of a trip, respondents were also asked to state the number of fish caught and the type of fish targeted (i.e., warm water, coldwater, or anadromous). For the Ohio River case study analysis, EPA used observations for fishing participants who took single-day trips within the study area zone. Part C, Chapter C5 of the Case Studies Document provides descriptive statistics for the Ohio sample.

A10-5 Limitations and Uncertainties

The RUM analyses rely on the unweighted MRFSS data, not correcting for stratification. The MRFSS data is prone to avidity bias where the probability of being interviewed increases with the number of fishing trips (Haab et al., 2000). EPA did not correct for avidity bias, which may result in overestimation of the predicted number of trips per season. This bias is unlikely to have a significant effect on benefit estimates, because the predicted number of trips was used only for estimating changes in fishing participation due to improved fishing opportunities. The estimated change in the number of trips was very small (see Chapters B5, C5, and D5 of the Watershed Case Studies report for detail). The baseline level of participation used in the analysis was taken from NMFS. This estimate was corrected for avidity bias by NMFS.

The NDS survey results can suffer from the same bias as other studies of this type---recall bias, non-response bias, and bias due to sampling effects:

- Recall bias can occur when respondents are asked the number of days in which they recreate over the previous season, such as in the NDS survey. Some researchers believe that recall bias tends to lead to an overstatement of the number of recreation days, particularly for more avid participants. Avid participants tend to overstate the number of recreation days, since they count days in a "typical" week and then multiply them by the number of weeks in the recreation season. They often neglect to consider days missed due to bad weather, illness, travel, or when fulfilling "atypical" obligations. Some studies also found that the more salient the activity, the more "optimistic" the respondent tends to be in estimating number of recreation days. Individuals also have a tendency to overstate the number of days they participate in activities that they enjoy and value. Taken together, these sources of recall bias may result in an overstatement of the actual number of recreation days.

- Non-response bias. A problem with sampling bias may arise when extrapolating sample means to population means. This could happen, for example, when avid recreation participants are more likely to respond to a survey than those who are not interested in the forms of recreation, are unable to participate, assume that the survey is not meant for them, or consider the survey not worth their time.

- Sampling effects. Recreational demand studies frequently face two types of observations that do not fit general recreation patterns: non-participants and avid participants. Non-participants are those individuals who would not participate in the recreation activity under any conditions. Assuming that an individual is a non-participant in a particular activity if he or she did not participate in that activity at any site tends to understate benefits, since some individuals may not have participated during the sampling period simply by chance, or because price/quality conditions were unfavorable during the sampling period. Avid participants can also be problematic because they claim to participate in an activity an inordinate number of times. This reported level of activity is sometimes correct, but often overstated, perhaps due to recall bias. These observations tend to be overly influential in the model and may lead to overestimation of the total number of trips.

Chapter A11: Habitat-Based Replacement Cost Method

INTRODUCTION

This chapter provides an overview of the habitat-based replacement cost (HRC) method for valuing losses of aquatic resources that result from I&E of organisms by a CWIS. The HRC method can be used to value a broad range of ecological and human service losses associated with I&E of aquatic species at facilities regulated under Section 316(b) of the Federal Water Pollution Control Act (Clean Water Act) [33 U.S.C. § 1251 *et seq.*]. It can be used as an alternative to conventional valuation approaches that are based on recreational and commercial fishing impacts. In addition, HRC can supplement conventional valuation results by providing a full valuation of species with I&E losses that are not fished (e.g., forage species).

CHAPTER CONTENTS

A11-1 OVERVIEW OF HRC VALUATION OF I&E RESOURCE LOSSES

A11-1.1 The Need for an Alternative to Conventional I&E Valuation Techniques

Conventional techniques to value the benefits of technologies that reduce I&E losses at § 316(b) facilities can omit important ecological and public services. For example, valuations based on expected recreational and commercial fishing impacts rely on indirectly derived nonmarket value estimates (e.g., consumer surplus per angling outing as estimated by travel cost models) and direct market values, respectively. In both instances, all benefits are based solely on direct use values of the impacted fish, and the physical impacts are characterized by the adult life stage of the species targeted by the recreational and commercial anglers. However, many I&E losses at many § 316(b) facilities are eggs and larvae, which are vital to a well-functioning ecological system but have no obvious direct use values in and of themselves. These facilities may have relatively small numbers of species and individuals that are targeted by anglers, so commercial and recreational losses may constitute only a small subset of the species lost to I&E. Even when losses of early life stages are included by conversion to adult equivalents, the ecological services and associated public values provided by early life stages that don't make it to adulthood in the environment are omitted.

Another conventional valuation technique bases the value of I&E impacts on the costs of restoring aquatic organisms using hatchery and stocking programs. However, the cost of restoring fish through stocking does not address several ecological services, and addresses others inefficiently. Moreover, biologists question whether stocked fish are equivalent to wild species, and have expressed concerned about ecological problems that have resulted from existing stocking programs (Meffe, 1992; White et al., 1997). Shortcomings associated with the use of hatchery and stocking costs to estimate the value of I&E losses include the following:

- Reliable stocking costs are available only for the few species targeted by existing hatcheries, and these tend to be the same species addressed by recreational and commercial fishing valuations.
- The reported costs often do not include transportation costs (see Chapter A9).

- The costs associated with hatchery and stocking programs do not include the value of many ecological services affected by I&E losses, because hatchery fish are released at different life stages, in different numbers, and in different places than they would be produced in the natural environment.
- Hatcheries usually produce naive fish, which do not function as well as wild fish in the environment.
- Hatchery fish lack genetic diversity and disease resistance compared to fish produced in the natural environment.
- Hatchery and stocking programs must continue as long as I&E losses occur, whereas natural habitat produces fish indefinitely once properly restored and protected.
- At a number of locations where fish stocking programs are in place, significant questions remain about whether the programs actually supplement the native fish populations, and if they do, the extent to which this occurs
- Hatchery fish can introduce diseased organisms and parasites to native populations.

A11-1.2 HRC Coverage of a Broader Range of Services and Values

The HRC method can be used in benefit-cost analyses to value a broad range of ecological and human services associated with I&E losses that are either undervalued or ignored by conventional valuation approaches. Economists and policy makers widely acknowledge that the public values environmental benefits well beyond beneficial impacts on direct uses (Boyd et al., 2001; Fischman, 2001; Fisher and Raucher, 1984; Heal et al., 2001; Herman et al., 2001; Ruhl and Gregg, 2001; Salzman et al., 2001; Wainger et al., 2001). While much of the professional literature, especially empirical investigations, focuses on recreational and other direct use values, most Americans value water resource protection and enhancement, including reduction of I&E losses, for reasons that go well beyond their desire for recreational anglers to enjoy a larger consumer surplus (or commercial anglers to enjoy greater producer surplus). Furthermore, many studies have documented public values (including passive values) from ecological services provided by a variety of natural resources sustaining (potential) environmental impacts, including: fish and wildlife (Stevens et al., 1991; Loomis et al., 2000); wetlands (Woodward and Wui, 2001); wilderness (Walsh et al., 1984); critical habitat for threatened & endangered species (Hagen et al., 1992; Loomis and Ekstrand, 1997; Whitehead and Blomquist, 1991); overuse of groundwater (Feinerman and Knapp, 1983); hurricane impacts on wetlands (Farber, 1987); global climate change on forests (Layton and Brown, 1998); bacterial impacts on coastal ponds (Kaoru, 1993); oil impacts on surface water (Cohen, 1986); and toxic substance impacts on wetlands (Hanemann et al., 1991), shoreline quality (Grigalunas et al., 1988), and beaches, shorebirds, and marine mammals (Rowe et al., 1992). In fact, a recent study (Costanza et al., 1997) estimated that Worldwide ecosystem services have a value of $16-54 trillion, a range that exceeded the Global Product of $18 trillion.

For direct use benefits such as recreational angling, the predicted change in the stock of a recreational fishery affects recreational participation levels and the value of an angling day (see also Chapter A3). However, I&E losses affect the aquatic ecosystem and public use and enjoyment in many ways not addressed by typical recreational valuation methods, creating a gap between known disruption of ecological services and what economists usually translate into monetary values or anthropocentric motives. Examples of ecological and public services (Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmlund and Hammer, 1999; Strange et al., 1999) disrupted by I&E, but not addressed by conventional valuation methods, include:

- decreased numbers of ecological keystone, rare, or sensitive species;
- decreased numbers of popular species that are not fished, perhaps because the fishery is closed;
- decreased numbers of special status (e.g., threatened or endangered) species;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E;
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of organic carbon and nutrient transfer through the food web;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships (e.g., Summers, 1989);
- disruption of age class structures of species;
- disruption of natural succession processes;
- disruption of public uses other than fishing, such as diving, boating, and birding; and
- disruption of public satisfaction with a healthy ecosystem.

The HRC method differs fundamentally from the commercial and recreational impact valuation method because the latter accounts for only those species and life stages that can be valued directly, such as those species targeted by recreational or commercial anglers. In contrast, the HRC method defines the value of all I&E losses in terms of the expenditures that would be required to replace all organisms lost to I&E at a CWIS through enhanced natural production in the environment. In short, the HRC method values lost resources by the costs of the programs required to naturally replace those same resources. The replaced organisms would then be available not only for commercial and recreational human use but also as prey for a wide range of aquatic and terrestrial organisms, as well as the full range of complex ecological functions provided by those organisms. As a result, the HRC method, by focusing on replacement of natural habitats, values fish and other organisms that are truly equivalent to those lost by allowing species to reproduce in their natural habitats using their native strategies. In addition, the HRC results are based on the natural replacement of all relevant species, life stages, behaviors, and ecological interactions, for as long as the habitats remain viable, and so the resulting valuations of I&E losses effectively incorporate the complete range of ecological and human services, even when those services are difficult to measure or poorly understood.

A11-1.3 How the HRC Method Works

The HRC method values natural resource losses based on the costs of ecological habitat-based restoration activities, as opposed to approaches not based on habitat such as fish stocking, that are scaled to increase natural production as an offset to the I&E losses. Thus, HRC uses resource replacement costs as a proxy for the value of resources lost to I&E. Where restoration costs are very high, or where public values might be much lower than costs, economic studies can be conducted to determine the value of habitat replacements[1]. Few comparisons of restoration costs and restoration value have been made. However, the Green Bay Natural Resource Damage Assessment (U.S. Fish and Wildlife Service and Stratus Consulting, 2000) estimated both the cost and the value of habitat (and other) restorations. Public values were determined using stated preference surveys and conjoint analyses (Breffle and Rowe, 2002). Restoration costs (to offset PCB-caused injuries to the environment) totaled $111-268 million, whereas willingness-to-pay for elimination of the same PCB injuries was $254-610 million. Thus, restoration costs were considerably less than public values.

In addition to addressing a wider range of I&E losses in terms of life stages and species, the HRC method also provides regulators with information needed to evaluate proposals from the regulated party to voluntarily provide relief for expected future I&E losses associated with various permitted technologies. This information consists of a prioritized set of restoration alternatives for each species affected by I&E, estimates of the potential benefits of implementing those alternatives, and estimates of the effective unit costs for those alternatives. Figure A11-1 presents the steps required to implement an HRC valuation of I&E losses (see Parts H and I of the Case Study Document for examples of a streamlined HRC valuation).

The HRC method is a new approach for valuing losses of aquatic organisms from a CWIS, and is consistent with and related to lost resource valuation techniques such as habitat equivalency analysis (HEA) that federal courts have recognized as appropriate for use in valuing lost resources (for examples, see U.S. District Court, 1997, and U.S. District Court, 1999). Further, the principle of offsetting resource and ecosystem losses through restoration actions is incorporated in other components of the Clean Water Act, such as those addressing the losses of wetland areas (i.e., Section 404). The following subsections discuss the steps for conducting an HRC valuation of I&E losses.

[1] Although controversial, the contingent valuation method and other related techniques, such as conjoint analyses, include ecological services and passive values and have been upheld in federal court [State of Ohio v. U.S. Department of the Interior (U.S. Circuit Court, 1989)] and supported by a NOAA panel co-chaired by 2 Nobel Laureate economists (Arrow et al., 1993).

Figure A11-1: Steps for conducting an HRC valuation of I&E losses.

Step 1: Quantify I&E losses by species

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Step 2: Identify habitat requirements of I&E species

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Step 3: Identify potential habitat restoration actions that could benefit I&E species

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Step 4: Consolidate, categorize, and prioritize identified habitat restoration alternatives

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Step 5: Quantify the expected increases in species production for the prioritized habitat restoration alternatives

↓

Step 6: Scale the habitat restoration alternatives to offset I&E losses

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Step 7: Estimate "unit costs" for the habitat restoration alternatives

↓

Step 8: Develop total cost estimates for I&E losses

A11-2 STEPS IN THE HRC

A11-2.1 Quantify I&E Losses by Species

The first step in an HRC valuation quantifies the I&E losses from a § 316(b) facility by species. This defines a CWIS's absolute and relative impacts on various species, including temporal variations when multiple years of data are available. The quantified I&E losses by species define the gains of aquatic organisms that restoration actions should achieve. However, EPA's analyses are generally based on data provided by the facility and therefore do not include losses of species not targeted by monitoring programs. In these cases, estimates of potential benefits of regulation will be underestimates. The HRC method partially alleviates this problem because restoring habitats for monitored species is likely to benefit other species lost but not monitored.

Because measured I&E losses often include multiple life stages (e.g., eggs, larvae, juveniles, adults) of any given species, total losses for each species are generally expressed as equivalent losses in a single, common life stage (see Chapter A5). This conversion is accomplished through the use of survival and production rates between life stages (younger life stages are always more abundant than older life stages because of mortality rates). A common life stage is generally chosen to facilitate the scaling of the restoration alternatives. For instance, early life stages are highly relevant for determining how much spawning habitat is required in cases where the productivity of spawning habitats is estimated. Adjusting the raw I&E loss data to a common life stage does not bias HRC results because many eggs are equivalent to fewer adults on both the I&E loss and the restoration gain side of the HRC equation. In other words, losing an adult to I&E is equivalent to losing many eggs because the adult represents survival through many life stages, and restoring an adult is equivalent to restoring many eggs for the same reason. Therefore, the life stage selected for reporting the losses should be chosen to be highly relevant to the life stages affected by (and measurable in) restoration activities. Typically, early life stages such as eggs, larvae, or juveniles are chosen because they tend to be less mobile than adults, and abundance will be better related habitat productivity estimates for replaced habitats.

A11-2.2 Identify Habitat Requirements of I&E Species

The second HRC step identifies the habitat requirements of the aquatic organisms lost to I&E. A species' habitat requirements are usually identified through literature searches and discussions with local resource managers, biologists, conservationists, and restoration experts with specific knowledge of the species.[2] HRC valuation uses local species characteristics and local habitat requirements and opportunities because of variation of local habitat conditions and constraints.

Because many aquatic organisms experience I&E in their earlier life stages (e.g., eggs, larvae, and juveniles), this step emphasizes habitat requirements for these stages, including spawning habitats. This emphasis is important because reducing constraints on adequate spawning is critical to increasing species production, is practical to achieve, and addresses directly the life stages most at risk from impingement and entrainment.

Habitat requirements for a species are typically described in very general terms (e.g., near-shore areas, wetlands, open water areas), but additional characteristics required or preferred by the species (e.g., specific ranges of water depth and temperature, substrate composition) further define the required habitats and improve the match between the habitat requirement and a restoration alternative. For example, a number of species benefit from a general wetland restoration program, but very different species and populations would benefit from a program of prairie pothole restoration compared to the restoration of cattail marshes hydraulically connected to the Great Lakes.

A11-2.3 Identify Potentially Beneficial Habitat Restoration Alternatives

The third step in an HRC valuation identifies actual habitat restoration alternatives that potentially increase the local production of the I&E species. As with identifying habitat requirements, thorough literature searches and discussions with local resource managers will provide optimal information. Special attention should be paid to any remedial action plans for local water bodies or local species management plans that present a series of projects or actions needed to address both specific and general constraints on the populations of aquatic organisms experiencing I&E losses.

Fully addressing I&E costs requires that this step not limit consideration to restoration actions already completed or already planned. Information about projects planned or under way is valuable, but more comprehensive information about what restoration activities improve the production of the affected species sufficient to fully offset I&E losses is essential to understand the full cost to society of I&E losses to the environment and the public. In other words, costs should be constrained only by biological understanding and engineering capability rather than existing funding and administrative opportunities.

The difference between what is being done or planned and what could be done may in some cases be small; in other cases it may be quite significant. For example, there may be little administrative opportunity for local wetland restoration in a location zoned for urbanized development. However, if available information and expert opinion suggest that increasing wetland acreage would be highly effective for increasing local production for a subset of affected species, a wetland restoration program should not be eliminated from consideration even if it could not be implemented locally.

A11-2.4 Consolidate, Categorize, and Prioritize Identified Habitat Restoration Alternatives

The fourth step in an HRC valuation consolidates and categorizes the identified restoration alternatives and provides a prioritized list of alternatives for each species, including designation of a preferred restoration alternative for the species. This step addresses both overlapping restoration alternatives and alternatives that vary widely in specificity. Consolidation and categorization eliminates redundancy in the proposals while producing a clearly defined set of restoration alternatives without prescribing specific actions to be taken.

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[2] Very little may be known about life stage characteristics and needs of some species, and information about taxonomically related species or functionally related life stages may be used. Where relevant information is extremely limited, best professional judgment must be applied, including the possibility of omitting the species from the analysis due to lack of information (and further underestimating benefits).

For example, "restore cattail marshes that are hydraulically connected to Lake Erie" could emerge as a restoration alternative from this process, and "restore the10-acre tract of former wetlands adjacent to marina X" would not be considered because of its specificity. At the other extreme, overly simplified proposals such as "improve water quality" are too general to determine restoration actions with definable costs.

The second part of this step, prioritizing the restoration alternatives, requires identifying a preferred alternative for each I&E species. This identification and prioritization of a preferred alternative is critical for developing a clear restoration program with a hierarchy of actions required to address the losses for a species. Otherwise, because a species may realize varying degrees of increased production from a number of restoration alternatives, an unmanageably large number of combinations of restoration alternatives with varying scales of implementation could be developed.

Prioritizing the categorized restoration alternatives benefits from close coordination with local resource managers. One effective strategy for completing this task convenes relevant resource managers and stakeholders for an open review and discussion of the categorized restoration alternatives with a goal of consensus on the preferred restoration alternative for each species with I&E losses.

A11-2.5 Quantify the Expected Increases in Species Production for the Prioritized Habitat Restoration Alternatives

Quantifying the benefits of the preferred restoration alternatives to I&E species, the fifth HRC step, is critical for scaling the amount of restoration needed to offset calculated I&E losses. Rigorous, peer-reviewed studies that quantify production increases of I&E species which result from particular restoration activities are the best sources of data. These studies measure pre- and post-restoration production in the habitat. Identifying suitable control habitats to substitute for the pre-restoration state is reasonable but less preferred than using pre- and post-measurement from the same site.

Estimates of the potential increases in species production following habitat restoration are more typically based on sampling data from studies that measure the population density of species in various habitats. This estimates increases in species production per unit of restored habitat by assuming that restoration provides similar habitat with similar productivity to that sampled. Estimates of the increased species production following restoration activities should account for lower initial (and perhaps permanent) productivity in restored versus pristine or unimpaired habitats. Estimates of increases in species production should include adjustments for factors that distinguish measured habitats from sites which could be restored (for a discussion of some of the factors that can affect productivity estimates in restored habitats, see Strange et al., 2002). Again, local resource managers are essential to making realistic adjustments. In practice, these adjustments are usually integrated as a percentage of estimated baseline benefits in the HRC equation.

Neither restoration productivity data nor habitat density data are available for some I&E species. For these species, estimates of the increase in species production can come from models of habitat-species relationships such as Habitat Suitability Indices (HSI), data or studies on other habitats or other species with similar functional characteristics, or the best professional judgment of local resource managers.

A11-2.6 Scale the Habitat Restoration Alternatives to Offset I&E Losses

The sixth step scales the selected habitat restoration actions so that the magnitude of their expected increases in species production offsets I&E losses. This step combines the estimated increases in species production associated with the restoration actions (step 5) with the quantified I&E losses (step 1). In the simplest case, one fish species experiences I&E losses in one life stage and wide agreement exists on how implementing the preferred restoration alternative would increase the production of the species for the affected life stage. Dividing the I&E loss by the expected increase in species production associated with a unit area of restoration determines the number of units (and thus the scale) of restoration required (this assumes the I&E losses and the expected increases in species production are expressed in the same time units, e.g., annual average). For example, if a facility's CWIS impinges and entrains 1 million year-one gizzard shad per year and local wetland restorations produce 500 year-one gizzard shad per acre per year (and wetland restorations are recognized as the most effective and cost-effective restoration alternative for gizzard shad), then offsetting these I&E losses requires successful, sustained restoration of 2,000 acres of wetlands.

The typical case involves multiple species with I&E losses across several life stages, variation between species in the expected increases in species production per unit of restoration area, and multiple restoration alternatives to benefit all affected species. In these cases, dividing I&E losses for each species by its expected increases in species production per unit of restoration area still results in the required scale of restoration for each species. However, where a single restoration activity is the primary means to benefit multiple species, enough habitat must be restored to produce all of the species' losses. This means that the species with the lowest per unit production benefit value determines the amount of that restoration required. For example, if 1 million year-one gizzard shad and 1 million year-one emerald shiners are lost to I&E every year, if wetland restoration is the most effective and cost-effective restoration alternative for both species, and if local wetland restorations have been documented to produce 500 gizzard shad per acre per year but only 100 emerald shiners per acre per year, then offsetting the I&E losses of both species requires 10,000 acres (not 2,000 acres) of successful, sustained wetland restoration.

Whether multiple restoration activities will benefit species with disparate habitat needs or whether restoration requirements vary widely among species benefitting from the same restoration activity, production of one species will not offset losses of another species because each species provides unique ecological services through its interactions with other species and has an associated public existence value as a unique species. Therefore, all I&E losses are treated as significant in the HRC method. However, particular species may benefit from activities other than the preferred alternative where multiple restoration activities must address all species, reducing the amount of the preferred alternative required for the particular species. Further, great uncertainty about the amount of a restoration alternative required for many species will require the use of a median, 90th percentile, or other reasonable upper bound likely to offset the I&E losses for most of the species. Here, the risk of underestimating total I&E costs by inadequately restoring some species must be compared to the risk of artificially inflating I&E costs because of uncertainty alone. Using the highest restoration cost to ensure that all species' I&E losses are offset may not be justified, particularly if very few of the species drive the cost orders of magnitude higher. For example, wetland restoration may be the only alternative with cost estimation data and species density data at a site, but the productivity estimates for many species are highly variable and based on limited data or extrapolations.

Both I&E losses and the expected increase in species production associated with a unit area of restoration are expressed as average annual losses for a species at a specific life stage. However, the expected annual average increase in production from a restoration action may be obscured by variability in the flow of benefits, especially in the early years when changes to existing habitats and ecosystem responses are expected to occur. Therefore, a benefits path must describe when and to what extent expected benefits will accrue, and an annual discount rate must be applied (as in the HEA applications described in Peacock, 1999). Benefits of restoration can be expressed in perpetuity, as an annual value, or for a discrete time period.[3]

A11-2.7 Develop Unit Cost Estimates

In the seventh step, an HRC valuation monetizes the unit costs (e.g., costs per acre) for restoration alternatives. Unit cost estimates include all expenses associated with the design, implementation, administration, maintenance, and monitoring of each restoration alternative. These costs include agency oversight costs and all required materials and labor purchased on the open market.

Similar completed projects provide an excellent source of cost information since they reflect real-world experiences. An alternative source of information is the cost estimates from proposed projects not yet implemented or partially completed projects. In either case, factors that can affect per unit restoration costs, such as fixed costs (e.g., administration, permitting) or donated services and materials, should be accounted for by carefully examining the available cost information. The cost analysis of each restoration alternative should also include the costs for an effective program to monitor the increases in species production. Monitoring costs for a restoration alternative should be listed separately, should include all relevant species, and should be of a sufficient length and duration to show the effectiveness of the chosen alternative in different years that capture natural variability. Where costs are not developed on a per unit restored basis, total costs can be divided by the scale of the project to develop the required unit costs. Finally, unit costs are converted to their present value equivalents to simplify addressing costs that may be incurred over a number of years.

A11-2.8 Develop Total Value Estimates for I&E Losses

After the required scale for restoration and the associated unit costs have been determined, the eighth step estimates the total value of all I&E losses. Multiplying the maximum required scale of implementation to offset I&E losses for a species by the unit cost for the restoration alternative produces the costs of a single restoration alternative. The total cost of offsetting the

[3] However, accurate and complete measurement of annual variation of I&E losses is often unavailable, limiting the utility of annualizing HRC.

I&E losses is then equal to the sum of the costs of each restoration alternative implemented, following their prioritization for each species.

The total estimated cost of replacing all of the organisms lost is a discrete, present value representing the current cost for providing a stream of increased production benefits for the affected species in perpetuity. In other words, the HRC valuation estimate reflects the cost now for increasing the production of I&E species at an average annual level that would offset the losses in the current year and all future years, all else being equal.

A11-3 Use of the HRC Method for § 316(b) Evaluations

EPA Region 1 is currently applying the HRC method at the Pilgrim Nuclear Power Generating Station in Plymouth, Massachusetts, and the Brayton Point Station in Somerset, Massachusetts. In addition, EPA applied a streamlined HRC valuation for the benefits case studies of the J.R. Whiting facility on Lake Erie and the Monroe facility on the River Raisin, a tributary to Lake Erie, to test the applicability of the method under time and budget constraints often faced by NPDES permit writers (see Parts H and I of this document).

A11-4 Strengths and Weakness of the HRC Method

The primary strength of the HRC method is the explicit recognition that I&E losses have impacts on the aquatic ecosystem and the public's use and enjoyment of that ecosystem beyond that estimated by reduced commercial and recreational catches. The HRC method provides a supplemental or alternative option for determining the value of I&E losses of all species, including forage species overlooked by conventional methods, so that the public (i.e., those directly and indirectly affected by I&E) and the regulators who represent them can have greater confidence in the true range of values associated with I&E losses. The need for detailed restoration alternatives for the HRC method provides permitting agencies with a way to scale the mitigation level to offset residual I&E losses associated with a permitted technology. Finally, the HRC method has a strong intuitive appeal as a valuation tool because it uses the costs associated with enhancing natural habitats so that they will produce the equivalent number and type of resources necessary to offset the I&E losses produced by the CWIS.

Public confidence in HRC valuations will be determined by the quality of input data for identifying preferred restoration alternatives, estimating increased production following restorations, estimating complete unit costs for restorations, and monitoring the relative success of restoration efforts. In this sense the HRC method does not have a methodological weakness. However, failure to identify all species lost to I&E, lack of information about life histories and habitat needs for some species lost, and abundance data poorly linked to restored habitat productivity are likely to continue to force cost-saving assumptions that undervalue the total benefits of minimizing I&E.

EPA's studies are limited by the quality and extent of the I&E data collected by the facility. This weakness can be addressed in future analyses by using appropriate guidelines for monitoring I&E, and by planning a more active program of defining expected production increases for species following implementation of different restoration activities. In practice, implementing appropriate monitoring programs for both the harm done by a CWIS and the benefits gained from restoration projects will produce a more comprehensive database. This comprehensive database will then facilitate scaling restoration projects to replace I&E losses. By ensuring that the costs associated with such monitoring programs are incorporated in the unit costs used to value I&E losses, the HRC method will help develop the information needed to address this limitation.

Chapter A12: Threatened & Endangered Species Analysis Methods

INTRODUCTION

Threatened and endangered (T&E) and other special status species can be adversely affected in several ways by cooling water intake structures (CWISs). T&E species can suffer direct harm from impingement and entrainment (I&E), they can suffer indirect impacts if I&E at CWISs adversely affects another species upon which the T&E species relies within the aquatic ecosystem (e.g., as a food source), or they can suffer impacts if the CWIS disrupts their critical habitat.[1] The loss of individuals of listed species from CWISs is particularly important because, by definition, these species are already rare and at risk of irreversible decline because of other stressors.

This chapter provides information relevant to an analysis of listed species in the context of the §316(b) regulation; defines species considered as threatened, endangered, or of special concern; gives a brief overview of the potential for I&E-related adverse impacts on T&E species; and describes methods available for considering the economic value of such impacts.

CHAPTER CONTENTS

A12-1 LISTED SPECIES BACKGROUND

The federal government and individual states develop and maintain lists of species that are considered endangered, threatened, or of special concern. The federal trustees for endangered or threatened species are the Department of the Interior's U.S. Fish and Wildlife Service (U.S. FWS) and the Department of Commerce's National Marine Fisheries Service (NMFS). Both departments are also are referred to herein as the Services. The U.S. FWS is responsible for terrestrial and freshwater species (including plants) and migratory birds, whereas the NMFS deals with marine species and anadromous fish (U.S. Fish and Wildlife Service, 1996a). At the state level, the departments, agencies, or commissions with jurisdiction over T&E species include Fish and Game; Natural Resources; Fish and Wildlife Conservation; Fish, Wildlife and Parks; Game and Parks; Environmental Conservation; Conservation and Natural Resources; Parks and Wildlife; the states' Natural Heritage Programs, and several others.

[1] To simplify the discussion, in this chapter EPA uses the terms "T&E species" and "special status species" interchangeably to mean all species that are specifically listed as threatened or endangered, plus any other species that has been given a special status designation at the state or federal level.

A12-1.1 Listed Species Definitions

a. Threatened and endangered and species

A species is listed as "endangered" when it is *likely to become extinct* within the foreseeable future throughout all or part of its range if no immediate action is taken to protect it. A species is listed as "threatened" if it is *likely to become endangered* within the foreseeable future throughout all or most of its range if no action is taken to protect it. Species are selected for listing based on petitions, surveys by the Services or other agencies, and other substantiated reports or field studies. The 1973 Endangered Species Act (ESA) outlines detailed procedures used by the Services to list a species, including listing criteria, public comment periods, hearings, notifications, time limits for final action, and other related issues (U.S. Fish and Wildlife Service, 1996a).

A species is considered to be endangered or threatened if one or more of the following listing criteria apply (U.S. FWS, 1996):

- the species' habitat or range is currently undergoing or is jeopardized by destruction, modification, or curtailment;
- the species is overused for commercial, recreational, scientific, or educational purposes;
- the species' existence is vulnerable because of predation or disease;
- current regulatory mechanisms do not provide adequate protection; or
- the continued existence of a species is affected by other natural or man-made factors.

b. Species of concern

States and the federal government have also included species of "special concern" to their lists. These species have been selected because they are (1) rare or endemic, (2) in the process of being listed, (3) considered for listing in the future, (4) found in isolated and fragmented habitats, or (5) considered a unique or irreplaceable state resource.

A12-1.2 Main Factors in Listing of Aquatic Species

Numerous physical and biological stressors have resulted in the listing of aquatic species. The major factors include habitat destruction or modification, displacement of populations by exotic species, dam building and impoundments, increased siltation and turbidity in the water column, sedimentation, various point and non-point sources of pollution, poaching, and accidental catching. Some stresses, such as increased contaminant loads or turbidity, can be alleviated by water quality programs such as the National Pollutant Discharge Elimination System (NPDES) or the current EPA efforts to develop Total Maximum Daily Loads (TMDLs). Other factors, such as dam building or habitat modifications for flood control purposes, are relatively permanent and therefore more difficult to mitigate. In addition to these major factors, negative effects of CWISs on some listed species have been documented.

Congress amended the ESA in 1982 and established a legal mechanism authorizing the Services to issue permits to non-federal entities — including individuals, private businesses, corporations, local governments, state governments, and tribal governments — who engage in the "incidental take" of federally-protected wildlife species (plants are not explicitly covered by this program). Incidental take is defined as take that is "incidental to, and not the purpose of, the carrying out of an otherwise lawful activity under local, state or federal law." Examples of lawful activities that may result in the incidental take of T&E species include developing private or state-owned land containing habitats used by federally-protected species, or the withdrawal of cooling water that may impinge or entrain federally-protected aquatic species present in surface waters.

An integral part of the incidental take permit process is development of a Habitat Conservation Plan (HCP). An HCP provides a counterbalance to an incidental take by proposing measures to minimize or mitigate the impact and ensuring the long-term commitment of the non-federal entity to species conservation. HCPs often include conservation measures that benefit not only the target T&E species, but also proposed and candidate species, and other rare and sensitive species that are present within the plan area (U.S. Fish and Wildlife Service and National Marine Fisheries Service, 2000). The ESA stipulates the major points that must be addressed in an HCP, including the following (U.S. Fish and Wildlife Service and National Marine Fisheries Service, 2000):

- defining the potential impacts associated with the proposed taking of a federally-listed species;

- describing the measures that the applicant will take to monitor, minimize, and mitigate these impacts, including funding sources;[2]

- analyzing alternative actions that could be taken by the applicant and reasons why those actions cannot be adopted; and

- describing additional measures that the Services may require as necessary or appropriate.

HCP permits can be issued by the Services' regional directors if:

- the taking will be incidental to an otherwise lawful activity,
- any impacts will be minimized or fully mitigated,
- the permittee provides adequate funding to fully implement the permit,
- the incidental taking will not reduce the chances of survival or recovery of the T&E species, and
- any other required measures are met.

The Services have published a detailed description of the incidental take permit process and the habitat conservation planning process (U.S. Fish and Wildlife Service and National Marine Fisheries Service, 2000). The federal incidental take permit program has only limited application within the context of the §316(b) regulation because many T&E species (fish in particular) are listed mainly by states, not by the Services, and hence fall outside of the jurisdiction of this program.

A12-2 Framework for Identifying Listed Species Potentially at Risk of I&E

Evaluating benefits to listed species from the proposed §316(b) regulation requires data on the number of listed organisms impinged and entrained and an estimate of how much the impingement and entrainment of listed species will be reduced as a result of the regulation. Estimating I&E for candidate and listed species presents significant challenges due to the following:

- Most facilities operating CWISs do not monitor for I&E on a regular basis,

- T&E populations are generally restricted and fragmented so that their I&E may be sporadic and not easy to detect by conventional monitoring activities, and

- Entrained eggs and larvae are often impossible to identify to the species level, making it difficult to know the true number of losses of a species of concern.

Some facilities have knowledge about the extent of their impact on T&E species. These facilities require incidental take permits and must develop HCPs (e.g., the Pittsburg and Contra Costa facilities in California, see Part E of this document). Where specific knowledge of I&E rates does not exist, risks to T&E species must be estimated from other information. The remainder of this section discusses EPA's methodology of estimating the numbers of listed species potentially at risk of I&E. The framework involves four main steps (see Figure A12-1).

- Step 1 identifies all state- or federally-listed species for the states that border the CWIS source water body.

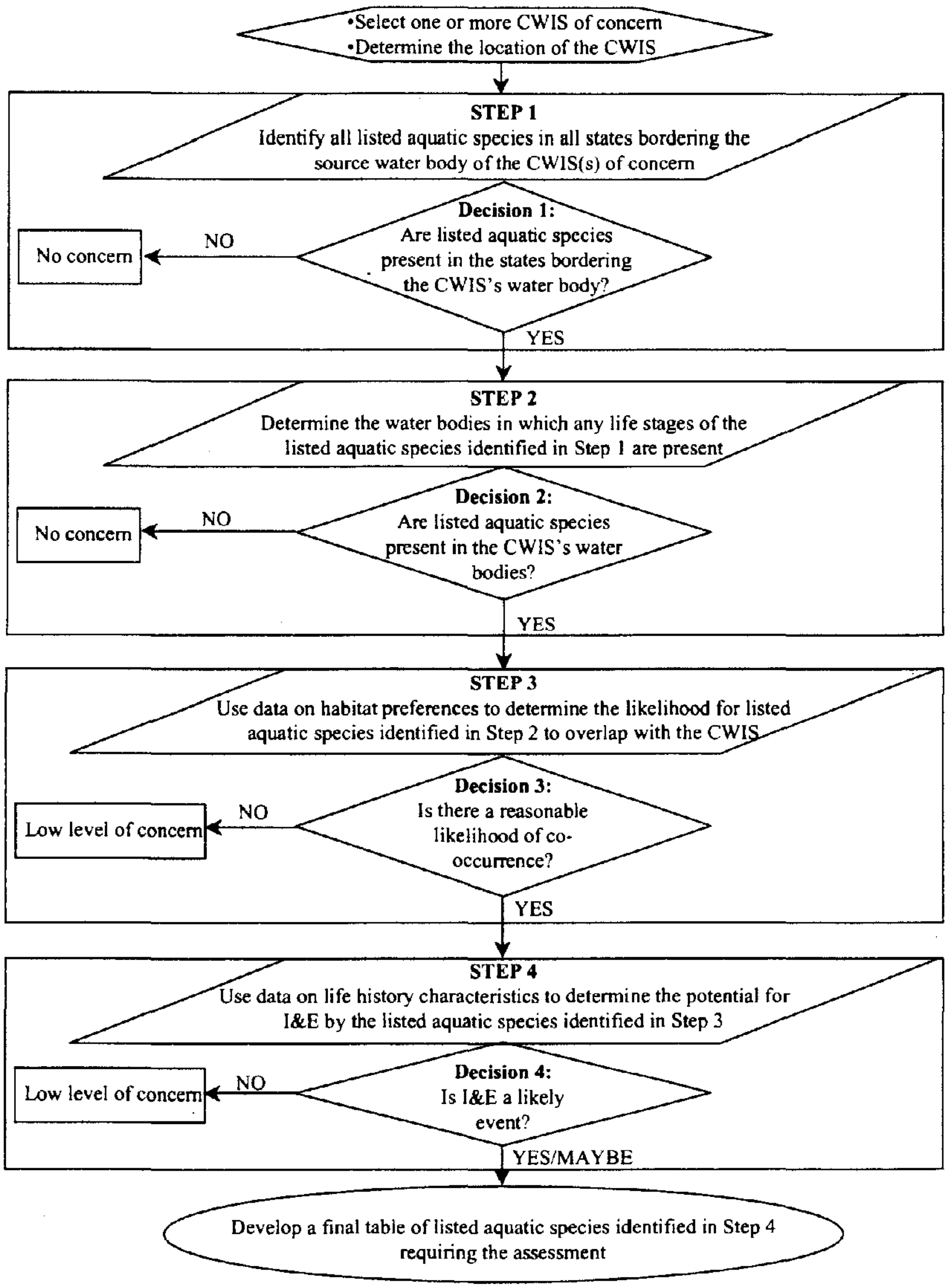
- Step 2 determines if a listed species from Step 1 is present in the vicinity of the CWIS. If a species distribution overlaps with the CWIS, the analysis proceeds to Step 3.

- Step 3 uses information on habitat preferences and site-specific intake structure characteristics to better define the degree of vulnerability of the listed species to the CWIS.

- Step 4, if necessary, further refines the potential for I&E based on the life history characteristics of the listed species.

[2] Mitigation can include preserving critical habitats, restoring degraded former habitat, creating new habitats, modifying land use practices to protect habitats, and establishing buffer areas around existing habitats.

Figure A12-1: Flowchart for Identifying T&E Aquatic Species with a Reasonable Potential for I&E by CWISs



The result of this four-step analysis is a table of listed species that are likely to experience I&E by a CWIS of concern based on their geographic distribution, habitat preferences, and life history characteristics.

A12-2.1 Step 1: Compile a Comprehensive Table of Potentially-Affected Listed Species

The first step in determining the potential for I&E by a CWIS is to identify all state and federally-listed aquatic species in the area of interest. Aquatic species may include fish; gastropods (such as snails, clams, or mussels); crustaceans (such as shrimp, crayfish, isopods, or amphipods); amphibians (such as salamanders, toads, or frogs); reptiles (such as turtles, alligators, or water snakes); and mammals (such as seals or sea lions). The U.S. FWS maintains a web site (http://endangered.fws.gov/endspp.html) on all federally-listed species organized by state or taxonomic group. Because the federal list represents only a small subset of the species listed by individual states, however, the analyst also needs to obtain state lists to develop a comprehensive table of aquatic species potentially affected by the CWISs of concern.[3] Individual state agencies, universities, or local organizations maintain web sites with data on state-listed species. A preliminary search in support of this chapter showed that various agencies have responsibilities for maintaining species lists in different states. The departments, agencies, or commissions with jurisdiction of T&E species include Fish and Game; Natural Resources; Fish and Wildlife Conservation; Fish, Wildlife and Parks; Game and Parks; Environmental Conservation; Conservation and Natural Resources; Parks and Wildlife; and several others. The states' Natural Heritage Programs can also be contacted to request listing information, species-specific data on geographic distributions, and other valuable data. Appendix A1 provides a recent compilation of aquatic T&E species by The Nature Conservancy (TNC). Information on Natural Heritage Programs in the U.S. can be obtained from The Natural Heritage Network at http://www.heritage.tnc.org. A thorough search of these and other relevant sources should be performed to get the data required to identify target species.

If a CWIS of concern is located on a water body confined to one state, then only federally-listed aquatic species found in that state and the aquatic species listed by the state itself need to be considered in the analysis. An example would be the Tampa Bay Estuary, which is entirely contained within the state of Florida. The search should expand if the CWIS is located on a water body that covers more than one state, which may be the case for large lakes, rivers, and estuaries. For example, the watersheds abutting the U.S. side of Lake Erie cover parts of New York, Pennsylvania, Ohio, Indiana, and Michigan. The Delaware River Basin covers parts of Delaware, Pennsylvania, New Jersey, and New York. At a minimum, a table of potentially affected T&E species should include species listed by the state in which the CWIS is located, together with any federally-listed aquatic species in all the states covered by the watershed. A more rigorous approach at this initial stage might be to include all state-listed aquatic species from every state covered by the water body of concern, even if the likelihood is small that a listed species moves beyond the boundaries of the CWIS's state.

The product of this initial step is a table of all the aquatic species listed by the U.S. FWS and the state(s) of interest. The information should be organized by species category — such as fish, amphibians, aquatic invertebrates, aquatic reptiles, and/or aquatic mammals. The information should also include:

- the common and scientific name of each listed species;
- the agency listing the species (state or U.S. FWS, or both); and
- the legal status of the species (threatened, endangered, or of special concern).

The analyst can assume that the CWIS does not have a direct impact on listed species only if no aquatic species are listed as threatened, endangered, or of special concern in the target state(s). The analyst must also determine if there is an indirect impact through the food chain. If not, then no further analysis is required for that CWIS.

A12-2.2 Step 2: Determine the Geographic Distribution of Listed Species

In the second step, the analyst determines if the listed species identified in Step 1 are present in the same water body as the CWIS of concern. This step represents a simple pass-fail decision: a species is retained if the distribution of one or more of its life stages coincides with the water body of interest; it is removed if it does not (see also Figure A12-1).

The analyst can obtain the information required for this step from several sources. Local agencies may have developed "species accounts" for certain federally-listed species. Recovery plans may also be available for some of the federally-listed species. These and other sources may provide information on species ranges, population levels, reproductive strategies, developmental characteristics, habitat requirements, reasons for current status, and/or management and protection needs. When compiling this information, the analyst should look not only at the distribution of adults but also of juveniles,

[3] As discussed earlier, both T&E species and species of special concern should be included.

particularly if the species is known to migrate between different locations over its life. This step is particularly important for anadromous fish species, but may also apply to other species that have seasonal or life cycle-dependent migrations (for example, adult frogs may live on land but spawn in rivers).

Most listed aquatic species are listed by individual states rather than on a federal level. Data on the federally-listed species are therefore unlikely to suffice for the analysis. States typically post their species list on the Internet. A few states have also developed short species accounts with information on distribution, life history characteristics, habitat requirements, and other useful details. Distribution or range data may consist of specific locations of sightings or catches (for example, particular river miles), general distributions within individual watersheds, or more generic and qualitative descriptions. Some states have also published hardcopy reports with species-specific information that may not be available on the Internet. Finally, the Natural Heritage Programs in numerous states have also developed species-specific data (see Appendix A1). All these materials should be obtained and reviewed during the data gathering process.

Distributional information for some of the T&E species may not be available. The analyst may need to consult secondary sources, such as species atlases (for example, see fish species distributions in the U.S.; or Smith, 1985, for fish distributions in New York State), field guides, published papers, or textbooks. Distributional data may be missing altogether for some of the more obscure species. The lack of such data should not by itself result in the removal an T&E species at this point in the selection process. The analyst should instead look at habitat requirements (Step 3) or life history characteristics (Step 4) before the species is no longer considered of concern to the CWIS under consideration.

The majority of species will be eliminated at this stage because most of the listed aquatic species, with some notable exceptions, tend to have rather fragmented and limited distributions due to extensive habitat loss or narrow habitat requirements. Step 2 produces a table of listed species whose geographic distributions generally overlap with the location of the CWIS.

A12-2.3 Step 3: Compare Habitat Preferences of Listed Species to the CWIS

Step 3 identifies listed species that could be affected by the CWIS of concern through a comparison of their habitat preferences and the location of the CWIS. The potential for I&E exists, and hence the listed species is retained, if the habitat preferences of one or more life stages match the location of the CWIS of concern. If the habitat preferences of no life stages of the listed species match the location of the CWIS, then the species can be removed from further consideration.
The analyst needs to obtain a general description of the location of the CWIS of concern in terms of (1) where the CWIS is found within the water body (e.g., inshore versus off-shore; deep versus shallow; etc.) and (2) the kinds of habitats associated with this general location. Such information may be available from site-specific field observations, permit applications by the facilities, natural resources maps, or other related sources.

a. Location

The presence of a listed species in the water body from which a CWIS withdraws water does not necessarily mean that the species will be impinged or entrained by the intake structure. Two additional variables need to be considered: the habitat preferences of the listed species and the characteristics of the CWIS (location, design, and capacity). The following example highlights the relationship between these two variables:

An endangered darter species is present in a river with a CWIS of concern. All life stages of this species are confined to swift-running, shallow (i.e., less than one foot deep) riffle zones, whereas the CWIS of concern is located many miles downstream in deep areas of the river that are unsuitable darter habitat. The likelihood of impact on the darter by the CWIS is minimal even though both are present within the same water body.

b. Other habitat information

Detailed information on the habitat requirements of the target species is also needed. This information should focus on *all* the life stages, including eggs, larvae, juveniles, and adults, because habitat requirements often vary by life stage. For example, adults of a listed fish species may inhabit deeper waters of large lakes and produce pelagic eggs, but juveniles may be found only in nearshore nursery areas. It would be insufficient to consider only the habitat requirements of adults of this species, particularly if a CWIS of concern was located nearshore.

The U.S. FWS T&E species web page, the web pages of individual states or other organizations, or general reference materials can provide data on the habitat preferences of the listed species. Such information may be qualitative, anecdotal, or missing altogether for obscure T&E species. Not all states have developed accounts for their listed species. T&E species web sites of neighboring states may offer additional information if the target species has a regional distribution and is listed throughout its range. The information base can also be augmented by looking at a closely-related species. The substitute species must share the same general habitat preferences as the target species for the comparison to be valid. The analyst should consult appropriate reference materials to ensure a proper match.

c. Assess whether the overlap between habitat requirements and CWIS location exists

The information on habitat preferences for the listed species is compared to location-specific data on the CWIS of concern. The decision step is a simple pass-fail test: a species is retained if the habitat requirements of one or more of its life stages is likely to coincide with the CWIS of concern; otherwise it is removed. The logic supporting this decision is that I&E is unlikely if all the habitat requirements of the target T&E species do not overlap with the habitat in which the CWIS of concern is located.

The exact habitat cutoff point for eliminating a species outright cannot be defined up front; it will depend not only on the target T&E species but also on site-specific factors tied to the CWIS of concern. Several aquatic habitats, however, can be dismissed out of hand because they are not suitable to support CWISs. These habitats include springs, caves, temporary pools, very small ponds and lakes, and shallow headwater streams and creeks. Target T&E species that spend their entire life cycle in these habitats are unlikely to encounter CWISs and can be removed from further consideration. Habitats that have enough volume to support CWISs, namely large rivers and lakes, large estuaries, and inshore marine areas, are likely to require more analysis.

A12-2.4 Step 4: Use Life History Characteristics to Refine Estimate of I&E Potential or Monitor for Actual I&E of the Listed Species

From this point on, the assessment can go in two different directions (see Figure A12-1): (1) the target species is added to the final table because the data indicate potential for I&E, or because more data are needed to refine the assessment; or (2) the species is excluded from the list because there is a low level of concern.

The data may not be as clear-cut for smaller or less mobile species. The overlap between habitat requirements and the location of a CWIS of concern may not suffice to justify adding a target species to the final table without first considering life history information. The decision to proceed beyond Step 3 will vary on a case-by-case basis: it will depend on the target species, access to additional biological information, and the CWIS of concern. The analyst should focus on finding information that will support the decision to add or eliminate a target species. Additional data may not exist for some of the more obscure listed species. Given the protected status of T&E species, however, EPA recommends using a conservative approach to ensure that species are not accidentally omitted when in fact they should be added to the final table. The species should be retained if doubts persist after Step 3: it can still be removed during more site-specific assessments.

Listed clams in big Midwestern rivers are an example of species which may require further assessment in Step 4. Certain clam species would likely pass Step 2 because their distribution overlaps with the locations of CWISs of concern on major rivers. These clam species may also pass Step 3 if their presence coincided with the general location of one or more CWIS of concern. Yet, it is unclear if they should be added to the final table: a closer look at the clams' life history is required to determine the potential for I&E.

The risk of I&E of adult clams is low because they are sedentary, benthic filter feeders or are firmly attached to the substrate. The risk may increase, however, during the reproductive season. During the reproductive season, males release their sperm into the water column. The sperm are carried downstream by the water current and are captured by feeding female clams. The sperm fertilize the female's eggs, which develop inside her body until they hatch. The larvae are released into the water column and must quickly find and attach themselves to a specific fish host to complete their development.[4] Larval clams die if they fail to find a host. After a period of days to weeks, the larval clams detach themselves from their hosts, drop to the bottom, and bury into the sediment or attach to a solid substrate where they remain for the rest of their lives. The only reasonable chance for clam I&E occurs when a fish host with larval life stages attached to it becomes impinged or entrained by a CWIS of concern. Adding a clam species to the final table would depend on whether or not the following occurs:

[4] Larvae of freshwater clams typically require a very specific fish species to complete their development. Scientists do not always know which fish hosts are required by the T&E river clams.

- the host fish is known to science,
- the host fish is present in the stretch of river containing the CWIS, and
- the habitat characteristics of the host fish match the general location of the CWIS of concern. These decisions can be made only on a case-by-case and species-by-species basis.

The information on life history characteristics for the target T&E species should be carefully reviewed to determine the potential for I&E. Several variables may raise concerns, including migratory behavior, pelagic eggs or larvae, foraging activity, and so on. This information is evaluated in comparison to the location of the CWIS of concern. The decision point in this step is a simple pass-fail test: a species is retained if one or more of its life history characteristics enhances the potential for contact with the CWIS of concern; it is removed if all of its life characteristics are unlikely to result in vulnerability to the CWIS of concern.

A12-3 IDENTIFICATION OF SPECIES OF CONCERN AT CASE STUDY SITES

The following sections illustrate the use of this procedure for identifying vulnerable special status species. The example is for fish species of the Delaware Estuary, the site of one of EPA's benefits case studies (see Part B of this document).

A12-3.1 The Delaware Estuary Transition Zone

a. Step 1: Identify all state- or federally-listed species for the states that border the water body on which the CWIS is located.

Table A12-1 summarizes information compiled by EPA for fish species in the Delaware Estuary.

Table A12-1: Fish Species Listed as Threatened, Endangered, or of Special Concern (Federal plus PA, NJ, DE, and NY)

Common Name (*Latin Name*)	Federally-Listed Species			State-Listed Species											
				Pennsylvania			New Jersey			Delaware			New York		
	E	T	O[a]	E	T	O[b]	E	T	O[b]	E	T	O[b]	E	T	O[b]
Burbot (*Lota lota*)					X										
Chub, Gravel (*Erimystax x-punctata*)				X										X	
Chub, Silver (*Macrhybopsis storeiana*)													X		
Chub, Streamline (*Erymystax dissimilis*)															X
Chubsucker, Lake (*Erimyzon sucetta*)														X	
Darter, Bluebreast (*Etheostoma Camurum*)					X								X		
Darter, Channel (*Percina copelandi*)					X										
Darter, Eastern Sand (*Ammocrypta pellucida*)					X									X	
Darter, Gilt (*Percina evides*)					X								X		
Darter, Longhead (*Percina macrocephala*)				X										X	
Darter, Spotted (*Etheostoma maculatum*)				X										X	
Darter, Swamp (*Etheostoma fusiforme*)														X	
Darter, Tippecanoe (*Etheostoma tippecanoe*)				X											
Lamprey, Mountain Brook (*Ichthyomyzon greeleyi*)					X										X
Lamprey, Northern Brook (*Ichthyomyzon fossor*)				X											
Lamprey, Ohio (*Ichthyomyzon bdellium*)					X										
Madtom, Mountain (*Noturus eleutherus*)					X										
Madtom, Northern (*notutus stigmotus*)					X										
Mooneye (*Hiodon tergisus*)														X	
Redhorse, Black (*Moxostoma duquesnei*)															X

Table A12-1: Fish Species Listed as Threatened, Endangered, or of Special Concern (Federal plus PA, NJ, DE, and NY) (cont.)

Common Name (*Latin Name*)	Federally-Listed Species			State-Listed Species											
				Pennsylvania			New Jersey			Delaware			New York		
	E	T	O[a]	E	T	O[b]	E	T	O[b]	E	T	O[b]	E	T	O[b]
Sculpin, Deepwater (*Myoxocephalus thompsoni*)													X		
Sculpin, Spoonhead (*Cottus ricei*)													X		
Shiner, Ironcolor (*Notropis chalybaeus*)															X
Shiner, Pugnose (*Notropis anogenus*)													X		
Shiner, Redfin (*Lythrurus umbratilis*)															X
Sturgeon, Atlantic (*Acipenser oxyrhynchus*)					X										
Sturgeon, Lake (*Acipenser fulvescens*)				X										X	
Sturgeon, Shortnose (*Acipenser brevirostrum*)	X			X			X			X			X		
Sucker, Longnose (*Catostomus catostomus*)				X											
Sunfish, Banded (*Enneacanthus obesus*)														X	
Sunfish, Longear (*lepomis megalotis*)														X	
Sunfish, Mud (*Acantharchus pomotis*)														X	
Whitefish, Round (*Prosopium cylindraceum*)													X		
TOTAL	**1**	**0**	**0**	**8**	**10**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**8**	**11**	**5**

[a] Other federally-listed species may include species of special interest or concern, monitored species, candidate species, etc.
[b] Other state-listed species may include rare species, species of special interest, species of concern, candidate species, etc.

Sources: New Jersey Division of Fish and Wildlife (2002); Pennsylvania Department of Conservation and Natural Resources (2002); State of New York, Department of Environmental Conservation (2001); U.S. Fish and Wildlife Service (2000).

b. Step 2: Determine if a species listed in Step 1 is present in the area of the CWIS

After identifying species of concern in the source water body, the next step is to determine if any of these species are present in the vicinity of the CWIS. This step involves consulting local biologists as well as literature sources such as species atlases, field guides, and scientific publications. Table A12-2 summarizes the results of EPA's analysis of the distribution of species of concern in the Delaware River Basin. Results indicate two there are two fish species potentially vulnerable to CWIS in the Delaware Estuary transition zone, Atlantic sturgeon and shortnose sturgeon (highlighted in bold in the table).

Table A12-2: Distribution of Listed Species Identified in Step 1

Species Name	Current Distribution	Found in Delaware River Basin?
Burbot	PA: Lake Erie and headwaters of Allegheny River	NO
Chub, gravel	NY: medium and large-sized streams in the Allegheny basin PA: Allegheny River and French Creek	NY: NO PA: NO
Chub, silver	NY: Lake Erie	NO
Chub, Streamline	NY: Allegheny River drainage	NO
Chubsucker, Lake	NY: the Lake Erie drainage basin and embayments along the southern shore of Lake Ontario	NO
Darter, bluebreast	NY: upper reaches of the Allegheny River drainage basin PA: upper Allegheny River and two of its tributaries, namely Little Brokenstraw Creek and French Creek	NY: NO PA NO
Darter, channel	PA: Lake Erie and large tributaries, and the upper part of the Allegheny River	NO
Darter, eastern sand	NY: Lake Erie, the Metawee and Poultney Rivers near Lake Champlain, the Saint Regis and Salmon Rivers near Quebec, and the Grasse River PA: Lake Erie and Allegheny basin	NY: NO PA: NO

Table A12-2: Distribution of Listed Species Identified in Step 1 (cont.)

Species Name	Current Distribution	Found in Delaware River Basin?
Darter, gilt	NY: found only in the Allegheny River PA: Upper Allegheny River	NY: NO PA: NO
Darter, longhead	NY: Allegheny River and a few of its large tributaries; French Creek PA: Scattered sites in the Allegheny River and French Creek headwaters	NY: NO PA: NO
Darter, spotted	NY: French Creek PA: upper Allegheny River and French Creek	NY: NO PA: NO
Darter, swamp	NY: eastern two-thirds of Long Island	NY: NO
Darter, tippecanoe	PA: upper Allegheny River and French Creek	PA: NO
Lamprey, mountain brook	NY: French Creek and Allegheny River tributaries PA: moderate to large streams of the upper Allegheny River system	NY: NO PA: NO
Lamprey, northern brook	PA: Conneaut Creek in Crawford County in north west PA	NO
Lamprey, Ohio	PA: moderate to large streams of the upper Allegheny River system	NO
Madtom, mountain	PA: French Creek in Mercer and Erie Counties in north west PA	NO
Madtom, northern	PA:French Creek	NO
Mooneye	NY: Lake Champlain, Black Lake, Oswegatchie River, Lake Erie, Saint Lawrence River, and the mouth of Cattaraugus Creek	NO
Redhorse, black	NY: Lake Ontario (likely extirpated) and Lake Erie drainage basins, and the Allegheny River	NO
Sculpin, deepwater	NY: Lakes Erie and Ontario	NO
Sculpin, spoonhead	NY: historically found in Lakes Erie and Ontario but believed to be extirpated	NO
Shiner, ironcolor	NY: Basher Kill and Hackensack River	NO
Shiner, pugnose	NY: Sodus Bay and Saint Lawrence River	NO
Shiner, redfin	NY: drainages of Lakes Erie and Ontario in western NY	NO
Sturgeon, Atlantic	PA: Delaware Estuary	**YES**
Sturgeon, Lake	NY: Saint Lawrence River, Niagara River, Oswegatchie River, Grasse River, Lakes Ontario & Erie, Lake Champlain, Cayuga Lake, Seneca & Cayuga canals PA: Lake Erie	NY: NO PA: NO
Sturgeon, shortnose	DE: Tidal Delaware River NJ: Tidal Delaware River NY: Lower portion of the Hudson River PA: Tidal Delaware River	**DE, NJ, PA: YES** NY: NO
Sucker, longnose	PA: Youghiogheny River headwater streams in south west PA	NO
Sunfish, landed	NY: Passaic River drainage and in eastern Long Island in the Peconic River drainage	NO
Sunfish, longear	NY: Tonawanda Creek	NO
Sunfish, mud	NY: Hackensack River	NO
Whitefish, round	NY: scattered lakes throughout the state	NO

Sources: New Jersey Division of Fish and Wildlife (2002); Pennsylvania Department of Conservation and Natural Resources (2002); Smith (1985); State of New York, Department of Environmental Conservation (2001).

c. Step 3: Use information on habitat preferences and intake location to better define the degree of overlap between listed species and the CWIS

Step 3 involves determining the habitat preferences and life history requirements of species identified in step 2. In Step 2 EPA determined that two fish species of concern are potentially vulnerable to CWIS in the Delaware Estuary transition zone, Atlantic sturgeon and shortnose sturgeon. The habitat preferences and life histories of these species are summarized in Table A12-3.

Table A12-3: Habitat Preferences and Life Histories of Listed Species Identified in Step 2

Species Name	Current Distribution	Habitat Preferences	Potential of overlap w/ CWIS?	Life History	Potential for I&E?	Life Stages Susceptible to I&E?
sturgeon, atlantic	Delaware estuary	estuarine and riverine bottom habitats of large river systems	YES	adults stay in the ocean but move into estuaries and large rivers to spawn in deep water (> 10m deep); eggs sink and stick to the bottom; juveniles make seasonal migrations between shallower areas (summer) and deeper areas (winter) of their birth rivers; juveniles move to the ocean at age 4-5 to mature	YES	larvae and juveniles
sturgeon, shortnose	tidal Delaware River (mostly in the upper and transitional estuary)	estuarine and riverine bottom habitats of large river systems	YES	adults stay in nearshore marine habitats but move in estuaries and large rivers to spawn; eggs sink and stick to the bottom; juveniles make seasonal migrations between shallower areas (summer) and deeper areas (winter) of their birth rivers; juveniles move out to the ocean at age 4-5 to mature	YES	larvae and juveniles

d. Step 4: Use of monitoring or life history characteristics to refine estimate of I&E

In some cases I&E or waterbody monitoring data may be available to estimate CWIS impacts on T&E species. However, in many cases, it will be necessary to estimate relative risk based on waterbody monitoring of the species distribution relative to CWIS and life history and facility characteristics that influence a species vulnerability to I&E.

For the Delaware Estuary example discussed here, there are only limited data available for shortnose sturgeon (Masnik and Wilson, 1980) and Atlantic sturgeon (Shirey et al., 1997) from monitoring in the vicinity of transition zone CWIS. In the case of shortnose sturgeon, 1980 monitoring results indicate that the species is not vulnerable to transition zone CWIS. However, because the data are over 20 years old, further information is needed to confirm that the potential for I&E of shortnose sturgeon remains low. An analysis of life history information indicates that spawning takes many miles upstream of transition zone CWIS, and therefore the risk of entrainment of eggs and larvae is minimal (Masnik and Wilson, 1980). Impingement is also unlikely because salinity and feeding conditions in the transition zone are unfavorable for impingeable-sized juveniles and adults (Masnik and Wilson, 1980).

In the case of Atlantic sturgeon, monitoring in the transition zone indicates that young Atlantic sturgeon occur in the vicinity of the Hope Creek and Salem facilities in the summer months. Data also suggest that Atlantic sturgeon move back downstream in fall, although use of the lower estuary (Delaware Bay) remains unknown (Shirey et al., 1997). This information suggests that Atlantic sturgeon are potentially at risk to transition zone CWIS and indicates the need for I&E monitoring to confirm the degree of harm.

A12-4 BENEFIT CATEGORIES APPLICABLE FOR IMPACTS ON T&E SPECIES

Once a T&E species has been identified as vulnerable to a CWIS, special considerations are necessary to fully capture the benefits of reducing I&E of the species. The benefits case study presented in Part E of this document illustrates some of the challenges in assigning economic value to T&E species and presents a valuation approach that may prove useful in other cases.

Estimating the economic benefits of helping to preserve T&E and other special status species, such as by reducing I&E impacts, is difficult due to a lack of knowledge of the ecological role of different T&E species and a relative paucity of economic studies focusing on the benefits of T&E preservation. Most of the wildlife economic literature focuses on recreational use benefits that may be irrelevant for valuation of T&E species because T&E species (e.g., the delta smelt in California) are not often targeted by recreational or commercial fishermen. The numbers of special status species that are recreationally or commercially fished (e.g., shortnose sturgeon in the Delaware Estuary) have been so depleted that any use estimates associated with angling participation or landings data for recent years (or decades) would not be indicative of the species' potential value for direct use if and when the population recovers. Nevertheless, there are some T&E species for which consumptive use-related benefits could be significant once the numbers of individuals are restored to levels that enable resumption of relevant uses.

Based on their potential uses, T&E species can be divided into three broad categories:

- *T&E species with high potential for consumptive uses.* The components of total value of such species are likely to include consumptive, non-consumptive, and indirect use values, as well as existence and option values. Pacific salmon, a highly prized game species, is a good example of such species. In addition to having a high consumptive use value, this species is likely to have a high non-consumptive use value. People who never go fishing may still watch salmon runs. The user value may actually dominate the total economic value of enhancing a T&E fish population for species like salmon. For example, Olsen et al. (1991) found that users contribute 65 percent to the total regional WTP value ($171 million in 1989$) for doubling the Columbia River salmon and steelhead runs. Nonusers with zero probability of participation in the sport fishery contribute 25 percent. Nonusers with some probability of future participation contribute the remaining ten percent.

- *T&E species that do not have consumptive uses, but are likely to have relatively large non-consumptive and indirect use values.* The total value of such species would include non-consumptive use and indirect values, and existence and option values. Loggerhead sea turtles can represent such species. The non-consumptive use of loggerhead sea turtles may include photography or observation of nesting or swimming reptiles. For example, a study by Whitehead and Blomquist (1992) reports that the average subjective probability that North Carolina residents will visit the North Carolina coast for non-consumptive use recreation is 0.498. Policies that protect loggerhead sea turtles may therefore enhance individual welfare for a large group of participants in turtle viewing and photography.

- *T&E species whose total value is a pure non-use value.* Some prominent T&E species with minimal or no use values may have high non-use values. The bald eagle and the gray whale are examples of such species. Conversely, many T&E species with little or no use value are not well known or of significant public interest and therefore their non-use values may be difficult to elicit.. Most obscure T&E species, which may have ecological, biological diversity and other non-use values, are likely to fall into this category.

Non-use motives are often the principal source of benefits estimates for T&E species because many T&E species fall into the "obscure species" group. As described in greater detail in Chapter A9, motives often associated with non-use values held for T&E species include bequest (i.e., inter-generational equity) and existence (i.e., preservation and stewardship) values. These non-use values are not necessarily limited to T&E species, but I&E-related adverse impacts to these unique species would be locally or globally irreversible, leading to extinction being a relevant concern. Irreversible adverse impacts on unique resources are not a necessary condition for the presence of significant non-use values, but these attributes (e.g., uniqueness; irreversibility; and regional, national, or international significance) would generally be expected to generate relatively high non-use values (Carson et al., 1999; Harpman et al., 1993).

A12-5 Methods Available for Estimating the Economic Value Associated with I&E of T&E Species

Estimating the value of increased protection of T&E species from reducing I&E impacts requires the following steps:

- Estimating I&E impacts on T&E species; and
- Attaching an economic value to changes in T&E status from reducing I&E impacts on species of concern (e.g., increasing species population, preventing species extinction, etc.)

A12-5.1 Estimating I&E Impacts on T&E Species

Several cases of I&E of federally-protected species by CWIS are documented, including the delta smelt in the Sacramento-San Joaquin River delta, sea turtles in the Delaware Estuary and elsewhere (NMFS, 2001e), and shortnose sturgeon eggs and larvae in the Hudson River (New York State Department of Environmental Conservation, 2000). Mortality rates vary by species and life stage: it is estimated to range from two to seven percent for impinged sea turtles (NMFS, 2001e), but mortality can be expected to be much higher for entrained eggs and larvae of the shortnose sturgeon and other special status fish species. The estimated yearly take of delta smelt by CWISs in the Sacramento-San Joaquin River Delta led to the development of a Habitat Conservation Plan as part of an incidental take permit application (Southern Energy Delta LLC, 2000).

A12-5.2 Economic Valuation Methods

Valuing impacts on special status species requires using nonmarket valuation methods to assign likely values to losses of these individuals. The fact that many of these species typically are not commercially or recreationally harvested (once they are listed) means no market value can be placed on their consumption. Benefits estimates are therefore often confined to non-use values for special status species. The total economic value of preserving species with potentially high use values (i.e., T&E salmon runs) should include both use and non-use values. Economic tools allowing estimates of both use and non-use values (e.g., stated preferences methods) may be suitable for calculating the benefits of preserving T&E species. The relevant methods are briefly summarized below.

It is necessary to note that the benefits of preserving T&E species estimated to date reflect a human-centered view; benefit cost analysis may not be appropriate when T&E species are involved because extinction is irreversible.

a. Stated preferences method

As described in Chapter A9, the only available way to directly estimate non-use values for special status species is through applying stated preference methods, such as the contingent valuation method (CVM). This method relies on statements of intended or hypothetical behavior elicited though surveys to value species. CVM has sometimes been criticized, especially in applications dating back a decade or more, because the analyst cannot verify whether the stated values are realistic and absent of various potential biases. CVM and other stated preference techniques (including conjoint analysis) have evolved and improved in recent years, however, and empirical evidence shows that the method can yield reliable (and perhaps even conservative) results where stated preference results are compared to those from revealed preference estimates (e.g., angling participation as observable behavior) (Carson et al., 1996).

Regardless of the debates over whether or not stated preference methods such as the CVM can generate reliable estimates of non-use values, EPA cannot apply this approach to the 316(b) rulemaking because the time and cost associated with conducting the necessary primary research is well beyond the budget and schedule available to the Agency. Such research also requires that the survey questionnaire and sampling design be reviewed and approved by OMB to comply with the Paperwork Reduction Act. The cost, time requirements, and administrative burdens associated with implementing a valuation survey in accordance with Paperwork Reduction Act create significant additional barriers to the potential for EPA implementing such relevant and useful research.

b. Benefits transfer approach

Using a benefit transfer approach may be a viable option in some cases. By definition, benefits transfer involves extrapolating the benefits findings estimated from one analytic situation to another situation(s). The initial analytic situation is defined in terms of an environmental resource (e.g., T&E species), the policy variable(s) (e.g.,changes in species status or population), and the benefitting populations being investigated. Only in ideal circumstances do the environmental resource and policy variables of the original study very closely match those of the analytic situation to which a policy or regulatory analyst may wish to extrapolate study results. Despite discrepancies, this approach may provide useful insights into benefits to society from reducing stress on T&E species.

The current approach to benefit transfers most often focuses on the meta analysis of point estimates of the Hicksian or Marshalian surplus reported from original studies. If, for example, the number of candidate studies is small and the variation of characteristics among the studies is substantial, then meta analysis is not feasible. This is likely to be the case when T&E species are involved, requiring a more careful consideration of analytic situations in the original and policy studies. If only one or a few studies are available, an analyst evaluates their transferability based on technical criteria developed by Desvouges (1992).

The analyst first identifies T&E species affected by I&E and the type of environmental change resulting from reducing I&E impacts on T&E species, and then selects from a pool of available studies the appropriate WTP values for protecting those species. EPA illustrated the value to society of protecting T&E species by conducting a review of the contingent valuation (CV) literature that estimates WTP to protect those species. This review focused on those studies valuing those aquatic species that may be at risk of I&E by CWISs. EPA also identified studies that provide WTP estimates for fish-eating species, i.e., the bald eagle and the whooping crane. These species may also be at risk because they rely to some degree on aquatic organisms as a food source. Table A12-4 lists the 13 relevant CV studies that EPA identified and provides corresponding WTP estimates and selected study characteristics.

The identified valuation studies vary in terms of the species valued and the specific environmental change valued. Twelve of these studies represent a total of 15 different species. In addition one study (Walsh et al., 1985) estimates WTP for a group of 26 species. Most of these studies value prominent species well known by the public, such as salmon. The studies valued one of the following general types of environmental changes:

- avoidance of species loss/extinction,
- species recovery/gain,
- acceleration of the recovery process,
- improvement of an area of a species' habitat, and
- increases in species population.

The value of preserving or improving populations of T&E species reported in T&E valuation studies has a wide range. Mean household WTP estimates of obscure aquatic species range from $7.20 for the striped shiner (Boyle & Bishop, 1987) to $10.03 for the squawfish (Cummings et al., 1994).

WTP values are low compared with estimates of other prominent fish species, which range from the relatively low estimate of $8.69 (Stevens et al., 1991), to $33.24 (Stevens et al., 1991); both values are mean non-user WTP for Atlantic salmon. WTP estimates for the two fish-eating species, the whooping crane and the bald eagle, both of which have high non-use values (i.e., existence value), range from $18.35 to $303.44 (Loomis and White, 1996). It may be possible to develop individual WTP ranges for a given species or species group based on the estimated changes in T&E status (e.g., species gain or recovery) from reducing I&E impacts and the applicable WTP values from existing studies.

Once individual's WTP for protecting T&E species or increasing their population is developed the next step is the estimation of total benefits from reducing I&E of the special status species. The analyst should apply the estimated WTP value to the relevant population groups to estimate the total value of improving protection of T&E species. The affected population may include both potential users and non-users, depending on species type. The relevant population may also include area residents, regional population, or, in exceptional cases (e.g., bald eagle), the U.S. population. The total value of improved protection of T&E species (e.g., preventing extinction or doubling the population size) should be then adjusted to reflect the percentage of cumulative environmental stress attributable to I&E.

Table A12-4: WTP ($2000) for Improving T&E Species Populations

Species Type	Reference	Publication Date	Survey Date	Species	Environ-mental Change	Size of Change	Annual Mean WTP ($2000)	CVM method	Survey Region	Sample Size	Response Rate	Payment Vehicle
Aquatic	Boyle & Bishop	1987	1984	Striped shiner	Avoid loss	100%	$7.20	DC	WI households	365	73%	Foundation
	Carson et al.	1994	1994	Kelp Bass White Croaker Bald Eagle	Speed recovery from 50 to 5 years		$75.36[a]	DC	CA households	2810	73%	One-time tax
	Cummings et al.	1994	1994	Squawfish	Avoid loss	100%	$10.03	OE	NM	921	42%	Increase state taxes
	Duffield & Patterson	1992	1992	Arctic grayling	Improve 1 of 3 rivers		$20.69[a]	PC	US visitors	157	27%	Trust fund
				Cutthroat Trout			$15.52[a]	PC	US visitors	170	77%	Trust fund
	Kotchen & Reiling	1999	1997	Shortnose Sturgeon	Recovery to self-sustaining population		$28.57[a]	DC	Maine residents (random)	635	63%	One-time tax
	Loomis & Larson	1994	1991	Gray Whale	Gain	50%	$20.44	OE	CA households	890	54%	Protection fund
					Gain	100%	$22.92	OE	CA households	890	54%	Protection fund
					Gain	50%	$31.58	OE	CA visitors	1003	72%	Protection fund

Table A12-4: WTP ($2000) for Improving T&E Species Populations (cont.)

Species Type	Reference	Publication Date	Survey Date	Species	Environ-mental Change	Size of Change	Annual Mean WTP ($2000)	CVM Method	Survey Region	Sample Size	Response Rate	Payment Vehicle
Aquatic (cont.)	Loomis & Larson (cont.)	1994	1991	Gray Whale	Gain	100%	$37.55	OE	CA visitors	1003	72%	Protection fund
	Olsen et al.	1991	1989	Pacific Salmon and Steelhead	Gain (existence value)	100%	$37.29	OE	Pac. NW household	695	72%	Electric bill
					Gain (user value)	100%	$105.35	OE	Pac. NW anglers	482	72%	Electric bill
	Stevens et al.	1991	1989	Atlantic salmon	Avoid loss	100%	$8.69[b]	DC	MA households	169	30%	Trust fund
				Atlantic salmon	Avoid loss	100%	$9.65[b]	OE	MA households	169	30%	Trust fund
	Stevens et al.	1994	1993	Atlantic salmon	Gain	50%	$23.15[b]	DCOE	College students	76	93%	Contri-bution
				Atlantic salmon	Gain	90%	$33.24[b]	DCOE	College students	76	93%	Contri-bution
	Walsh et al.	1985	1985	26 species in CO	Avoid loss	-100%	$69.12	OE	CO households	198	99%	Taxes
	Whitehead	1991, 1992	1991	Sea turtle	Avoid loss	100%	$15.48[a]	DC	NC households	207	35%	Preservation fund

Table A12-4: WTP ($2000) for Improving T&E Species Populations (cont.)

Species Type	Reference	Publication Date	Survey Date	Species	Environ-mental Change	Size of Change	Annual Mean WTP ($2000)	CVM Method	Survey Region	Sample Size	Response Rate	Payment Vehicle
Fish-eating Birds	Bowker & Stoll	1988	1983	Whooping crane	Avoid loss	100%	$37.91	DC	TX and US visitors	316	36%	Foundation
				Whooping crane	Avoid loss	100%	$59.49	DC	TX and US visitors	254	67%	Foundation
	Boyle & Bishop	1987	1984	Bald eagle	Avoid loss	100%	$18.35	DC	WI households	365	73%	Foundation
	Carson et al.	1994	1994	Bald eagle Kelp bass White Croaker	Speed recovery from 50 to 5 years		$75.36[a]	DC	CA households	2810	73%	One-time tax
	Stevens et al.	1991	1989	Bald eagle	Avoid loss	100%	$39.25	DCOE	NE households	339	37%	Trust fund
				Bald eagle	Avoid loss	100%	$27.65	DCOE	NE households	339	37%	Trust fund
	Swanson	1993	1991	Bald eagle	Increase in populations	300%	$303.44[a]	DC	WA visitors	747	57%	Membership fund
				Bald eagle	Increase in populations	300%	$212.55[a]	OE	WA visitors	747	57%	Membership fund

[a] Value is a lump sum.
[b] Annual payment in 5-year program.
Sources: Table adapted from Loomis & White, 1996; CPI: U.S. Bureau of Labor Statistics, Division of Consumer Prices and Price Indexes, 2001.

c. Revealed preference — Cost of T&E species restoration

For the case study analyses, EPA pursued an innovative alternative to infer societal WTP to preserve T&E species. This alternative approach relies on actual sums of money dedicated to restoring special status species as an indication of societal revealed preference to preserve and protect these species. Program costs devoted to habitat restoration in aquatic ecosystems with a comprehensive program to restore special status species fish populations can be used as an indicator of societal WTP for restoring those species. Restoration programs and/or use restrictions designed to help reduce losses of T&E species (or in other ways help to restore and preserve the species) indicate a societal revealed preference to incur costs in order to achieve this goal.

Each individual of a T&E species is important; the restoration costs can therefore be divided by the number of individuals the program is intended to protect or add to the baseline (depleted) population. This action yields a revealed preference value per individual fish. The analyst can then apply these values to the numbers of T&E individuals adversely impacted by I&E. The extent to which this method is a true indicator of societal WTP for species restoration depends on the extent to which the allocation of resources through the political process reflects the true needs for habitat restoration and the extent to which the political process allows for public input. To the extent that the program costs reflect true needs and allows for public input, this method may thus reflect non-use (and any applicable use) values for special status species. Costs incurred to protect and/or restore aquatic special status species reflect a revealed preference by society; the value of the effort is deemed to exceed the costs incurred.

A12-6 Issues in the Application of the T&E Valuation Approaches

Several technical and conceptual issues are associated with valuing I&E impacts on T&E species:

- issues associated with estimating I&E contribution to the cumulative impact from several stressors; and
- issues associated with implementing an economic valuation approach.

A12-6.1 Issues in Estimating Environmental Impacts from I&E on Special Status Fish

Difficulties in estimating the number of individuals or size of the population of special status fish present in a given location are often very difficult for numerous reasons including the following.

- the act of monitoring a T&E species is problematic in and of itself because monitoring generally results in some harm to the species so researchers and federal agencies are reluctant to do it;
- monitoring programs typically focus only on commercially harvested species;
- the number of individuals may be so low that they rarely/never show up in monitoring programs for other species;
- there is often a lack of complete knowledge of the life cycles of special status fish species contributes to an inability to accurately estimate population sizes for some species.

Deriving population estimates from existing monitoring programs often means extrapolating sampling catches to the population as a whole. The variance in estimates is likely to be very high. Several assumptions must be assessed when extrapolating sample catches to population estimates:

- fish are completely recruited and vulnerable to the gear (i.e., are large enough to be retained by the mesh and do not preferentially occupy habitats not sampled) or selectivity of the gear by size is known;
- sampling fixed locations for species approximates random sampling that approximates a stratified random sampling scheme;
- species are uniformly distributed through the water column;
- volume filtered by trawls can be accurately estimated; and
- volumes of water can be estimated for each embayment in the habitat range for the species.

a. Issues in using a benefits transfer approach

The following issues may arise in developing a benefit transfer approach:

- *Some studies estimated WTP for multiple species.* In this review of T&E species studies, values established by Carson et al. (1994), Olsen et al. (1991) and Walsh et al. (1985) value groups of T&E species and therefore transferring values from this studies may not be feasible unless the group of species affected by I&E is the same as the group of species valued in the original studies,.

- The type of *environmental change* valued in the study may not provide a good match to the changes resulting from reducing I&E impacts. As noted above, T&E valuation studies addressed one of the following qualitative changes in T&E status:

  - avoidance of species loss/extinction
  - species recovery/gain
  - acceleration of the recovery process
  - improvement of an area of a species' habitat
  - increases in species population

  The environmental change resulting from reduced I&E effects on T&E species may not match the scenarios considered in the original studies.

- The *size of the environmental change* that the hypothetical scenario defines is also vital for developing WTP estimates. Several studies describe programs that avoid the loss of a species. This outcome may be considered a 100 percent improvement with respect to the alternative, extinction, but the restoration of a species or the increase in population may be specified at any level (e.g. 50 percent, 300 percent, etc.). Swanson estimated a 300 percent *increase* in bald eagle populations and Boyle and Bishop estimated WTP to avoid the possibility of bald eagle *extinction* in Wisconsin (cited in Loomis and White, 1996). Although avoiding extinction may be considered a 100 percent improvement, this environmental change is not comparable with the 300 percent increase in existing populations; preventing regional extinction is quite different than realizing a nominal increase in species population (in which the alternative is not necessarily species loss).

- Although a considerable amount of CV literature has valued T&E species, such research is largely limited to species with high consumptive use or non-use values. They either have high recreational or industrial value, or are popularly valued as significant species for various reasons (e.g., national symbol, aesthetics). Many T&E species that are likely to be affected by I&E (either federal-or state-listed) are obscure and WTP for their preservation has not been estimated.

b. Cost of restoration approach

The issues associated with using habitat restoration costing as an indication of societal revealed preference to preserve T&E species are illustrated in the San Francisco Bay case study (Part E of this document), in which EPA applied this innovative approach. These issues are also discussed in Chapter A11 in Part A of this document, which details the habitat-based restoration cost (HRC) method, applied in the case studies of Brayton Point (Part F), Pilgrim (Part G), J.R. Whiting(Part H), and Monroe (Part I). Issues in the restoration costing approach can generally be divided into three groups:

- "Restoration" programs need not be relied upon exclusively to infer societal revealed WTP to preserve special status species. In many instances, other programs or restrictions are used in lieu of (or in conjunction with) restoration programs, and the costs associated with the non-restoration components also reveal a WTP. For example, efforts to preserve fish species in the San Francisco Estuary area also include water use restrictions that reduce the amount of fresh water diverted from the upstream portion of the Sacramento River to highly valued water uses in the central and southern parts of California. The foregone use values of these waters in agricultural and municipal applications are an important component of the cost society bears to protect and preserve special status species, such as the delta smelt.

- Costs directed at a special species must be isolated from program elements intended to address other species or problems. For example, in a multifaceted restoration or use restriction program, the percentage of costs used mainly to target restoration of special status species fish as opposed to other ecosystem benefits needs to be estimated.

- Estimates must be developed of the change in fish numbers associated with the program. A habitat restoration program may set population targets for restoration of special status fish species, but might not target a specific population size. Often targets are set to abundance levels that existed before a significant decline in populations. If the program has set a population target for restoration of the fish species involved, then the number of fish needed to reach the restoration target can be divided into the relevant portion of program costs to calculate a dollar per fish indicator of the value society places on restoring special status species fish. This per fish value can be used to assess damages for fish species that are not valued commercially or recreationally.

A12-7 CONCLUSIONS

T&E species may be adversely impacted by I&E. To the extent that the proposed rule reduces these adverse impacts, there may be appreciable benefits of reducing stresses on these species of special concern.

Estimating the benefits of reducing the adverse impacts of I&E on special status species often requires a focus on non-use benefits. Use-related benefits for these species may not be relevant (e.g., for fish not targeted by recreational or commercial anglers) or may be misconstrued as minimal based on recent data (e.g., because the reduced numbers of these species have led to long-standing fishing restrictions or such reduced catches that recent period use data are not informative).

Estimating non-use values for T&E species (or other species) is difficult for many reasons. WTP estimates can be derived only from stated preference methods; this line of primary research is not feasible for the Agency to pursue given the cost, time, and administrative requirements of a survey effort. Use of the benefits transfer approach is limited to only those species for which economic valuation studies exist. In some cases, existing restoration programs may serve as a basis for inferring benefits from reducing stresses on special status species if such a program exists. EPA pursued an approach for its case study analysis of T&E species that relies largely on restoration programs to infer revealed preferences by society to incur costs to preserve special status species (see Part E for a detailed example).

Appendix A1

This appendix contains information compiled by The Nature Conservancy on threatened, endangered, and special status species in 30 states (NatureServe, 2002). States included are AZ, CA, NM, ID, WY, ND, SD, NE, KS, MI, IN, KY, VA, NC, AR, LA, MS, AL, FL, WV, MD, DE, NJ, CT, RI, NH, IA, OK, IL, and PA. Table A1-1 lists the status of species and their location by hydrologic unit code (HUC). Table A1-2 provides definitions of abbreviations used for global status listings in Table A1-1. Table A1-3 provides definitions of the abbreviations used for federal status.

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	01080205
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	01080205
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	01100003
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	01100004
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	01100005
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	01100007
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02040105
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02040201
AFCQC02680	Freshwater Fishes	*Etheostoma Sellare*	Maryland Darter	GH	LE	02050306
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02050306
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	02050306
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02060001
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	02060001
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02060002
AFCQC02680	Freshwater Fishes	*Etheostoma Sellare*	Maryland Darter	GH	LE	02060003
AFCQC04240	Freshwater Fishes	*Percina Rex*	Roanoke Logperch	G1G2	LE	03010101
AFCQC04240	Freshwater Fishes	*Percina Rex*	Roanoke Logperch	G1G2	LE	03010103
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03010107
AFCQC04240	Freshwater Fishes	*Percina Rex*	Roanoke Logperch	G1G2	LE	03010201
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03010203
AFCQC04240	Freshwater Fishes	*Percina Rex*	Roanoke Logperch	G1G2	LE	03010204
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03010205
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03020105
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03020204
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03030001
AFCJB28660	Freshwater Fishes	*Notropis Mekistocholas*	Cape Fear Shiner	G1	LE	03030002
AFCJB28660	Freshwater Fishes	*Notropis Mekistocholas*	Cape Fear Shiner	G1	LE	03030003
AFCJB28660	Freshwater Fishes	*Notropis Mekistocholas*	Cape Fear Shiner	G1	LE	03030004
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03030005
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03030005
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03040201
AFCND02020	Freshwater Fishes	*Menidia Extensa*	Waccamaw Silverside	G1	LT	03040206
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03080103
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03080103
AFCAA01042	Freshwater Fishes	*Acipenser Oxyrinchus Oxyrinchus*	Atlantic Sturgeon	G3T3	C	03080103
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03080201

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy[a] (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCNG01020	Marine Fishes	*Rivulus Marmoratus*	Mangrove Rivulus	G3	(PS:C)	03080202
AFCAA01042	Freshwater Fishes	*Acipenser Oxyrinchus Oxyrinchus*	Atlantic Sturgeon	G3T3	C	03080202
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03080203
AFCNG01020	Marine Fishes	*Rivulus Marmoratus*	Mangrove Rivulus	G3	(PS:C)	03080203
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03090202
AFCNG01020	Marine Fishes	*Rivulus Marmoratus*	Mangrove Rivulus	G3	(PS:C)	03090202
AFCND02030	Marine Fishes	*Menidia Conchorum*	Key Silverside	G3Q	C	03090203
AFCNG01020	Marine Fishes	*Rivulus Marmoratus*	Mangrove Rivulus	G3	(PS:C)	03090203
AFCNG01020	Marine Fishes	*Rivulus Marmoratus*	Mangrove Rivulus	G3	(PS:C)	03090204
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03100101
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03100206
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03100207
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03110101
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03110205
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03120003
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03130011
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03140101
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03140102
AFCQC02520	Freshwater Fishes	*Etheostoma Okaloosae*	Okaloosa Darter	G1	LE	03140102
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03140103
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03140104
AFCNB04090	Marine Fishes	*Fundulus Jenkinsi*	Saltmarsh Topminnow	G2	C	03140105
AFCNB04090	Marine Fishes	*Fundulus Jenkinsi*	Saltmarsh Topminnow	G2	C	03140107
AFCNB04090	Marine Fishes	*Fundulus Jenkinsi*	Saltmarsh Topminnow	G2	C	03140305
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03140305
AFCAA02030	Freshwater Fishes	*Scaphirhynchus Suttkusi*	Alabama Sturgeon	G1	LE	03160103
AFCQC04360	Freshwater Fishes	*Percina Aurora*	Pearl Darter	G1	C	03170001
AFCQC04360	Freshwater Fishes	*Percina Aurora*	Pearl Darter	G1	C	03170004
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03170004
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03170006
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03170007
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03170008
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03170009
AFCNB04090	Marine Fishes	*Fundulus Jenkinsi*	Saltmarsh Topminnow	G2	C	03170009
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	03180001
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03180002
AFCQC04360	Freshwater Fishes	*Percina Aurora*	Pearl Darter	G1	C	03180002
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	03180002
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03180003
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	03180003
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	03180004
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03180004
AFCQC04360	Freshwater Fishes	*Percina Aurora*	Pearl Darter	G1	C	03180004
AFCQC04360	Freshwater Fishes	*Percina Aurora*	Pearl Darter	G1	C	03180005
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	03180005
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03180005
AFCJB31010	Freshwater Fishes	*Phoxinus Cumberlandensis*	Blackside Dace	G2	LT	05130101

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy° (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCJB31010	Freshwater Fishes	*Phoxinus Cumberlandensis*	Blackside Dace	G2	LT	05130101
AFCJB31010	Freshwater Fishes	*Phoxinus Cumberlandensis*	Blackside Dace	G2	LT	05130102
AFCJB31010	Freshwater Fishes	*Phoxinus Cumberlandensis*	Blackside Dace	G2	LT	05130103
AFCJB28A90	Freshwater Fishes	*Notropis Albizonatus*	Palezone Shiner	G2	LE	05130104
AFCQC02X30	Freshwater Fishes	*Etheostoma Percnurum*	Duskytail Darter	G1	LE	05130104
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	05140101
AFCKA02060	Freshwater Fishes'	*Noturus Flavipinnis*	Yellowfin Madtom	G1	(LT,XN)	06010101
AFCJB50010	Freshwater Fishes	*Erimystax Cahni*	Slender Chub	G1	LT	06010101
AFCJB15080	Freshwater Fishes	*Hybopsis Monacha*	Spotfin Chub	G2	LT	06010101
AFCJB15080	Freshwater Fishes	*Hybopsis Monacha*	Spotfin Chub	G2	LT	06010102
AFCJB15080	Freshwater Fishes	*Hybopsis Monacha*	Spotfin Chub	G2	LT	06010105
AFCJB15080	Freshwater Fishes	*Hybopsis Monacha*	Spotfin Chub	G2	LT	06010202
AFCJB15080	Freshwater Fishes	*Hybopsis Monacha*	Spotfin Chub	G2	LT	06010203
AFCJB50010	Freshwater Fishes	*Erimystax Cahni*	Slender Chub	G1	LT	06010205
AFCQC02X30	Freshwater Fishes	*Etheostoma Percnurum*	Duskytail Darter	G1	LE	06010205
AFCKA02060	Freshwater Fishes	*Noturus Flavipinnis*	Yellowfin Madtom	G1	(LT,XN)	06010205
AFCJB50010	Freshwater Fishes	*Erimystax Cahni*	Slender Chub	G1	LT	06010206
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	06040006
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08010100
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	08010100
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08010100
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	08010100
AFCQC02B00	Freshwater Fishes	*Etheostoma Chienense*	Relict Darter	G1	LE	08010201
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08020100
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08020203
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08030100
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08030207
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08060100
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	08060100
AFCQC02630	Freshwater Fishes	*Etheostoma Rubrum*	Bayou Darter	G1	LT	08060203
AFCQC02630	Freshwater Fishes	*Etheostoma Rubrum*	Bayou Darter	G1	LT	08060302
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08070100
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	08070205
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08080101
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08090100
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	08090201
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	08090202
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08090203
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	08090203
AFCHA07011	Freshwater Fishes	*Thymallus Arcticus Pop 2*	Arctic Grayling - Upper Missouri River Fluvial	G5T2Q	C	10020007
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10060005
AFCHA07011	Freshwater Fishes	*Thymallus Arcticus Pop 2*	Arctic Grayling - Upper Missouri River Fluvial	G5T2Q	C	10070001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10080007
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10080010
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10090202
AFCJB3705B	Freshwater Fishes	*Rhinichthys Osculus Thermalis*	Kendall Warm Springs Dace	G5T1	LE	10090202

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy© (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10090207
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10100004
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10100004
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110101
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10110101
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110201
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110202
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110203
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110204
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10110205
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110205
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10120109
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10120110
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10120111
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10120112
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10130102
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10130102
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10130102
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10130105
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10130202
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10140101
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10140101
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10140103
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10140201
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10140202
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10140203
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10140204
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10150007
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10160004
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10160006
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10160011
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10160011
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10170101
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10170101
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10170101
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10170101
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10170102
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10170103
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10170202
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10170203
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10180002
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10200101
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10200202
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10200202
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10200203
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10210006
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10210009

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy[a] (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10220002
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10220003
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10230001
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10230001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10230001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10230006
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10230006
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10230006
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10230006
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10240001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10240001
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10240001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10240005
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10240005
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10240005
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10240011
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10240011
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10240011
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10250004
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10250016
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10250017
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10260001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10260008
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10260008
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270101
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10270102
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270102
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10270104
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10270104
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270104
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270202
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270205
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270206
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10290101
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11010001
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030004
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030009
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030010
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11030010
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11030013
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030013
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030014
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030015
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11030015
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11030016
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030016
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	11030017

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ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11040006
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040006
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11040007
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040007
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11040008
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040008
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11060002
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11060002
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11060003
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11060003
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11060005
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	11070201
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070201
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	11070202
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070203
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	11070203
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070204
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070205
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11070207
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070207
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11070208
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11070209
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11110103
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11110103
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11110202
AFCQC04210	Freshwater Fishes	*Percina Pantherina*	Leopard Darter	G1	LT	11140108
AFCQC04210	Freshwater Fishes	*Percina Pantherina*	Leopard Darter	G1	LT	11140109
AFCJB16070	Freshwater Fishes	*Hybognathus Amarus*	Rio Grande Silvery Minnow	G1G2	LE	13020201
AFCJB16070	Freshwater Fishes	*Hybognathus Amarus*	Rio Grande Silvery Minnow	G1G2	LE	13020203
AFCJB13110	Freshwater Fishes	*Gila Nigrescens*	Chihuahua Chub	G1	LT	13030202
AFCHA02101	Freshwater Fishes	*Oncorhynchus Gilae Gilae*	Gila Trout	G3T1	LE	13030202
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	13060003
AFCJB28891	Freshwater Fishes	*Notropis Simus Pecosensis*	Pecos Bluntnose Shiner	G2T2	LT	13060003
AFCNC02070	Freshwater Fishes	*Gambusia Nobilis*	Pecos Gambusia	G2	LE	13060003
AFCNC02070	Freshwater Fishes	*Gambusia Nobilis*	Pecos Gambusia	G2	LE	13060005
AFCNC02070	Freshwater Fishes	*Gambusia Nobilis*	Pecos Gambusia	G2	LE	13060007
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	13060007
AFCJB28891	Freshwater Fishes	*Notropis Simus Pecosensis*	Pecos Bluntnose Shiner	G2T2	LT	13060007
AFCNC02070	Freshwater Fishes	*Gambusia Nobilis*	Pecos Gambusia	G2	LE	13060008
AFCJB28891	Freshwater Fishes	*Notropis Simus Pecosensis*	Pecos Bluntnose Shiner	G2T2	LT	13060011
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	13060011
AFCNC02070	Freshwater Fishes	*Gambusia Nobilis*	Pecos Gambusia	G2	LE	13060011
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	14040106
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	14040106
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	14040107
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	14070006
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	14070006

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ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCJB35020	Freshwater Fishes	*Ptychocheilus Lucius*	Colorado Pikeminnow	G1	(LE,XN)	14080101
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	15010001
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	15010002
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	15010003
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15010005
AFCJB33010	Freshwater Fishes	*Plagopterus Argentissimus*	Woundfin	G1	(LE,XN)	15010010
AFCJB13170	Freshwater Fishes	*Gila Seminuda*	Virgin River Chub	G1	(PS:LE)	15010010
AFCJB20040	Freshwater Fishes	*Lepidomeda Vittata*	Little Colorado Spinedace	G1G2	LT	15020001
AFCJB20040	Freshwater Fishes	*Lepidomeda Vittata*	Little Colorado Spinedace	G1G2	LT	15020002
AFCJB20040	Freshwater Fishes	*Lepidomeda Vittata*	Little Colorado Spinedace	G1G2	LT	15020005
AFCJB20040	Freshwater Fishes	*Lepidomeda Vittata*	Little Colorado Spinedace	G1G2	LT	15020008
AFCJB20040	Freshwater Fishes	*Lepidomeda Vittata*	Little Colorado Spinedace	G1G2	LT	15020010
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	15020016
AFCJB13100	Freshwater Fishes	*Gila Elegans*	Bonytail	G1	LE	15030101
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15030101
AFCJB13100	Freshwater Fishes	*Gila Elegans*	Bonytail	G1	LE	15030104
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15030104
AFCJB35020	Freshwater Fishes	*Ptychocheilus Lucius*	Colorado Pikeminnow	G1	(LE,XN)	15030107
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15030203
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15030204
AFCJB13100	Freshwater Fishes	*Gila Elegans*	Bonytail	G1	LE	15030204
AFCHA02101	Freshwater Fishes	*Oncorhynchus Gilae Gilae*	Gila Trout	G3T1	LE	15040001
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15040001
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15040001
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15040002
AFCHA02101	Freshwater Fishes	*Oncorhynchus Gilae Gilae*	Gila Trout	G3T1	LE	15040002
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15040002
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15040004
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15040004
AFCHA02101	Freshwater Fishes	*Oncorhynchus Gilae Gilae*	Gila Trout	G3T1	LE	15040004
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15040004
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15040005
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15040005
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15040005
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15040005
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15040005
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15040006
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15040007
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15050100
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15050100
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15050202
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15050203
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15050203
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15050203

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy[a] (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15050301
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15050301
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15050302
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15060101
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15060103
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15060105
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15060106
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15060106
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15060201
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15060202
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15060202
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15060202
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15060203
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15060203
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15070102
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15070102
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15070103
AFCJB13100	Freshwater Fishes	*Gila Elegans*	Bonytail	G1	LE	15070103
AFCNB02062	Freshwater Fishes	*Cyprinodon Macularius Eremus*	Quitobaquito Desert Pupfish	G1T1	(LE)	15080102
AFCJB13090	Freshwater Fishes	*Gila Ditaenia*	Sonora Chub	G2	LT	15080201
AFCJB13140	Freshwater Fishes	*Gila Purpurea*	Yaqui Chub	G1	LE	15080301
AFCJB13140	Freshwater Fishes	*Gila Purpurea*	Yaqui Chub	G1	LE	15080302
AFCJB49080	Freshwater Fishes	*Cyprinella Formosa*	Beautiful Shiner	G2	LT	15080302
AFCHA02089	Freshwater Fishes	*Oncorhynchus Clarki Seleniris*	Paiute Cutthroat Trout	G4T1T2	LT	16060010
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010101
AFCAA01051	Freshwater Fishes	*Acipenser Transmontanus Pop 1*	White Sturgeon - Kootenai River	G4T1Q	LE	17010104
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010104
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010105
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010213
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010214
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010215
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010216
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010301
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010303
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17040212

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy[a] (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17040217
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17050101
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050102
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17050103
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050111
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050112
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050113
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050120
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050121
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050122
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050124
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050201
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17050201
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060101
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060101
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060101
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060101
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060103
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060103
AFCHA02042	Freshwater Fishes	*Oncorhynchus Nerka Pop 1*	Sockeye Salmon - Snake River	G5T1Q	LE	17060103
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060103
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060103
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060108
AFCHA02042	Freshwater Fishes	*Oncorhynchus Nerka Pop 1*	Sockeye Salmon - Snake River	G5T1Q	LE	17060201
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060201
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060201
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060201
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060201
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060202
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060202
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060202
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060203
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060203
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060203
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060203
AFCHA02042	Freshwater Fishes	*Oncorhynchus Nerka Pop 1*	Sockeye Salmon - Snake River	G5T1Q	LE	17060203

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy[a] (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060204
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060204
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060204
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060205
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060205
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060205
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060206
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060206
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060206
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060207
AFCHA02042	Freshwater Fishes	*Oncorhynchus Nerka Pop 1*	Sockeye Salmon - Snake River	G5T1Q	LE	17060207
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060207
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060207
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060207
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060208
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060208
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060208
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060209
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060209
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060209
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060209
AFCHA02042	Freshwater Fishes	*Oncorhynchus Nerka Pop 1*	Sockeye Salmon - Snake River	G5T1Q	LE	17060209
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060210
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060210
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060210
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060301
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060301
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060301
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060302
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060302
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060302

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ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060303
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060303
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060303
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060304
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060305
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060305
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060305
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060306
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060306
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060306
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060307
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060308
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060308
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060308
AFCJB1303M	Freshwater Fishes	*Gila Bicolor Vaccaceps*	Cowhead Lake Tui Chub	G4T1	PE	17120007
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18010101
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18010102
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18010108
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18010111
AFCJC03010	Freshwater Fishes	*Chasmistes Brevirostris*	Shortnose Sucker	G1	LE	18010204
AFCJC12010	Freshwater Fishes	*Deltistes Luxatus*	Lost River Sucker	G1	LE	18010204
AFCJC12010	Freshwater Fishes	*Deltistes Luxatus*	Lost River Sucker	G1	LE	18010206
AFCJC03010	Freshwater Fishes	*Chasmistes Brevirostris*	Shortnose Sucker	G1	LE	18010206
AFCJC02140	Freshwater Fishes	*Catostomus Microps*	Modoc Sucker	G1	LE	18020002
AFCHA0205B	Freshwater Fishes	*Oncorhynchus Tshawytscha Pop 7*	Chinook Salmon - Sacramento River Winter Run	G5T1Q	LE	18020101
AFCHA0205B	Freshwater Fishes	*Oncorhynchus Tshawytscha Pop 7*	Chinook Salmon - Sacramento River Winter Run	G5T1Q	LE	18020102
AFCHA0205B	Freshwater Fishes	*Oncorhynchus Tshawytscha Pop 7*	Chinook Salmon - Sacramento River Winter Run	G5T1Q	LE	18020103
AFCJB34020	Freshwater Fishes	*Pogonichthys Macrolepidotus*	Splittail	G2	LT	18020104
AFCJB34020	Freshwater Fishes	*Pogonichthys Macrolepidotus*	Splittail	G2	LT	18020106
AFCJB34020	Freshwater Fishes	*Pogonichthys Macrolepidotus*	Splittail	G2	LT	18020109
AFCHA0205B	Freshwater Fishes	*Oncorhynchus Tshawytscha Pop 7*	Chinook Salmon - Sacramento River Winter Run	G5T1Q	LE	18020112

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy[a] (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCHA0209B	Freshwater Fishes	*Oncorhynchus Mykiss Whitei*	Little Kern Golden Trout	G5T2Q	LT	18030001
AFCHA0209B	Freshwater Fishes	*Oncorhynchus Mykiss Whitei*	Little Kern Golden Trout	G5T2Q	LT	18030006
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18050005
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18050006
AFCHA0209J	Freshwater Fishes	*Oncorhynchus Mykiss Pop 10*	Steelhead - Southern California	G5T1T2Q	LE	18050006
AFCHA0209J	Freshwater Fishes	*Oncorhynchus Mykiss Pop 10*	Steelhead - Southern California	G5T1T2Q	LE	18060001
AFCHA0209J	Freshwater Fishes	*Oncorhynchus Mykiss Pop 10*	Steelhead - Southern California	G5T1T2Q	LE	18060001
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060001
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060001
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060006
AFCHA0209J	Freshwater Fishes	*Oncorhynchus Mykiss Pop 10*	Steelhead - Southern California	G5T1T2Q	LE	18060006
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060008
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060009
AFCPA03011	Freshwater Fishes	*Gasterosteus Aculeatus Williamsoni*	Unarmored Threespine Stickleback	G5T1	LE	18060010
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060011
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060013
AFCPA03011	Freshwater Fishes	*Gasterosteus Aculeatus Williamsoni*	Unarmored Threespine Stickleback	G5T1	LE	18060013
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18070101
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18070102
AFCJC02190	Freshwater Fishes	*Catostomus Santaanae*	Santa Ana Sucker	G1	LT	18070102
AFCJC02190	Freshwater Fishes	*Catostomus Santaanae*	Santa Ana Sucker	G1	LT	18070203
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18070301
AFCNB02090	Freshwater Fishes	*Cyprinodon Radiosus*	Owens River Pupfish	G1	LE	18090102
AFCJB1303J	Freshwater Fishes	*Gila Bicolor Snyderi*	Owens Tui Chub	G4T1	LE	18090102
AFCHA02089	Freshwater Fishes	*Oncorhynchus Clarki Seleniris*	Paiute Cutthroat Trout	G4T1T2	LT	18090102
AFCNB02090	Freshwater Fishes	*Cyprinodon Radiosus*	Owens River Pupfish	G1	LE	18090103
AFCJB1303J	Freshwater Fishes	*Gila Bicolor Snyderi*	Owens Tui Chub	G4T1	LE	18090103
AFCJB1303H	Freshwater Fishes	*Gila Bicolor Mohavensis*	Mohave Tui Chub	G4T1	LE	18090207
AFCJB1303H	Freshwater Fishes	*Gila Bicolor Mohavensis*	Mohave Tui Chub	G4T1	LE	18090208
AFCPA03011	Freshwater Fishes	*Gasterosteus Aculeatus Williamsoni*	Unarmored Threespine Stickleback	G5T1	LE	18100200
AFCNB02060	Freshwater Fishes	*Cyprinodon Macularius*	Desert Pupfish	G1	LE	18100200
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	18100200
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	07110000
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10000000
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10000000
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040001
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040006
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040008
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11050001
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11050002
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11050003
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11060004

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy[a] (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11060006
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11070105
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070206
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11070206
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11070207
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11070209
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11090201
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11090202
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11090203
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11090204
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100101
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100102
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100103
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100104
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100201
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100203
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100301
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100302
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100303
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11110101
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11110103
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11110104
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11130210
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11130304
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11140107
AFCQC04210	Freshwater Fishes	*Percina Pantherina*	Leopard Darter	G1	LT	11140107
AFCQC04210	Freshwater Fishes	*Percina Pantherina*	Leopard Darter	G1	LT	11140108
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02040202
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	02040201

Source: NatureServe. 2002. Natural Heritage Central Databases. Arlington, VA.

Table A1-2: Definitions of Abbreviations for Global Status.

Abbreviation	Global Status
GX	Presumed Extinct (species)——Believed to be extinct throughout its range. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
GH	Possibly Extinct (species)——Known from only historical occurrences, but may nevertheless still be extant; further searching needed.
G1	Critically Imperiled——Critically imperiled globally because of extreme rarity or because of some factor(s)making it especially vulnerable to extinction. Typically 5 or fewer occurrences or very few remaining individuals (<1,000) or acres (<2,000) or linear miles (<10).
G2	Imperiled——Imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction or elimination. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000) or acres (2,000 to 10,000) or linear miles (10 to 50).
G3	Vulnerable——Vulnerable globally either because very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction or elimination. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
G4	Apparently Secure——Uncommon but not rare (although it may be rare in parts of its range, particularly on the periphery), and usually widespread. Apparently not vulnerable in most of its range, but possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals.
G5	Secure——Common, widespread, and abundant (although it may be rare in parts of its range, particularly on the periphery). Not vulnerable in most of its range. Typically with considerably more than 100 occurrences and more than 10,000 individuals.
G#G#	Range Rank——A numeric range rank (e.g., G2G3) is used to indicate uncertainty about the exact status of a taxon. Ranges cannot skip more than one rank (e.g., GU should be used rather than G1G4).
GU	Unrankable——Currently unrankable due to lack of information or due to substantially conflicting information about status or trends. NOTE: Whenever possible, the most likely rank is assigned and the question mark qualifier is added (e.g., G2?) to express uncertainty, or a range rank (e.g., G2G3) is used to delineate the limits (range) of uncertainty.
G?	Unranked——Global rank not yet assessed.
HYB	Hybrid——(species elements only) Element not ranked because it represents an interspecific hybrid and not a species. (Note, however, that hybrid-derived species are ranked as species, not as hybrids.)
?	Inexact Numeric Rank——Denotes inexact numeric rank
Q	Questionable taxonomy that may reduce conservation priority. Distinctiveness of this entity as a taxon at the current level is questionable; resolution of this uncertainty may result in change from a species to a subspecies or hybrid, or inclusion of this taxon in another taxon, with the resulting taxon having a lower-priority (numerically higher) conservation status rank.
C	Captive or Cultivated Only——Taxon at present is extant only in captivity or cultivation, or as a reintroduced population not yet established.
T_	Infraspecific Taxon (trinomial)——The status of infraspecific taxa (subspecies or varieties) are indicated by a "T-rank" following the species' global rank. Rules for assigning T ranks follow the same principles outlined above. For example, the global rank of a critically imperiled subspecies of an otherwise widespread and common species would be G5T1. A T subrank cannot imply the subspecies or variety is more abundant than the species (e.g., a G1T2 subrank should not occur). A vertebrate animal population (e.g., listed under the U.S. Endangered Species Act or assigned candidate status) may be tracked as an infraspecific taxon and given a T rank; in such cases a Q is used after the T rank to denote the taxon's informal taxonomic status.

Table A1-3: Definitions of Abbreviations for Federal Status Listing

Abbreviation	Federal Status
LE	Listed endangered
LT	Listed threatened
PE	Proposed endangered
PT	Proposed threatened
C	Candidate
PDL	Proposed for delisting
E(S/A) or T(S/A)	Listed endangered or threatened because of similarity of appearance
XE	Essential experimental population
XN	Experimental nonessential population
Combination values	The taxon has one status currently, but a more recent proposal has been made to change that status with no final action yet published. For example, LE-PDL indicates that the species is currently listed as endangered, but has been proposed for delisting.
Values in parentheses	The taxon itself is not named in the Federal Register as having federal status; however, it does have federal status as a result of its taxonomic relationship to a named entity. For example, if a species is federally listed with endangered status, then by default, all of its recognized subspecies also have endangered status. The subspecies in this example would have the value "(LE)" under U.S. Federal Status. Likewise, if all of a species' infraspecific taxa (worldwide) have the same federal status, then that status appears in the record for the "full" species as well. In this case, if the taxon at the species level is not mentioned in the Federal Register, the status appears in parentheses in that record.
Combination values in parentheses	The taxon itself is not named in the Federal Register as having official federal status; however, all of its infraspecific taxa (worldwide) do have official status. The statuses shown in parentheses indicate the statuses that apply to infraspecific taxa or populations within this taxon.
(PS)	Indicates "partial status" - status in only a portion of the species' range. Typically indicated in a "full" species record where an infraspecific taxon or population has federal status, but the entire species does not.
Null value	Usually indicates that the taxon does not have any federal status. However, because of potential lag time between publication in the Federal Register and entry in the NHCD, some taxa may have a status that does not yet appear.

Part B: The Delaware Estuary

Chapter B1: Background

This case study presents the results of an analysis performed by EPA to assess the potential benefits of reducing the cumulative impacts of impingement and entrainment (I&E) at cooling water intake structures (CWIS) within the transition zone of the Delaware Estuary that are in scope of the proposed § 316(b) Phase II (existing facilities) regulation. In-scope facilities include any steam electric power generating facility that (1) is a point source that uses or proposes to use a cooling water intake structure, (2) has a design intake flow equal to or greater than 50 MGD, and (3) withdraws water from waters of the United States or obtains cooling water by any sort of contract or arrangement with an independent supplier (or suppliers) that withdraws water from waters of the United States.

CHAPTER CONTENTS

EPA chose the transition zone of the estuary for a study of cumulative CWIS impacts because of its ecological, economic, and recreational importance and its susceptibility to harm from multiple CWIS. The Agency is limiting its analysis of the Delaware Estuary to the transition zone because the facilities within this zone impinge and entrain the same species. Section B1-1 of this chapter provides information on both in-scope and out-of-scope CWIS within the transition zone, Section B1-2 describes the aquatic environment of the case study area, Section B1-3 discusses cooling water use by transition zone CWIS, and Section B1-4 presents information on the region's social and economic characteristics.

B1-1 Overview of Transition Zone Case Study Facilities

Figure B1-1 indicates the locations of all in-scope and out-of-scope CWIS throughout the Delaware River Basin. Those in green are in scope of Phase II of the § 316(b) regulation. This case study focuses only on CWIS within the transition zone of the Delaware Estuary, including four in scope power plants (Salem Nuclear Generating Station, Hope Creek Nuclear Generating Station, Edge Moor Power Plant, and Deepwater Generating Station), three out-of-scope power plants (Hay Road, Logan Generating Company, and Chambers Cogen LP), and six out-of-scope manufacturing facilities (Delaware City Refinery, E.I. DuPont de Nemours and Company Chemicals and Pigments Department, General Chemical Corporation, SPI Polyols, Citisteel, and Sun Refining). The locations of these facilities are indicated in Figure B1-2. The in scope power plants of the transition zone are described briefly below, and Table B1-1 summarizes their technical characteristics.

Figure B1-1: The Delaware River Basin

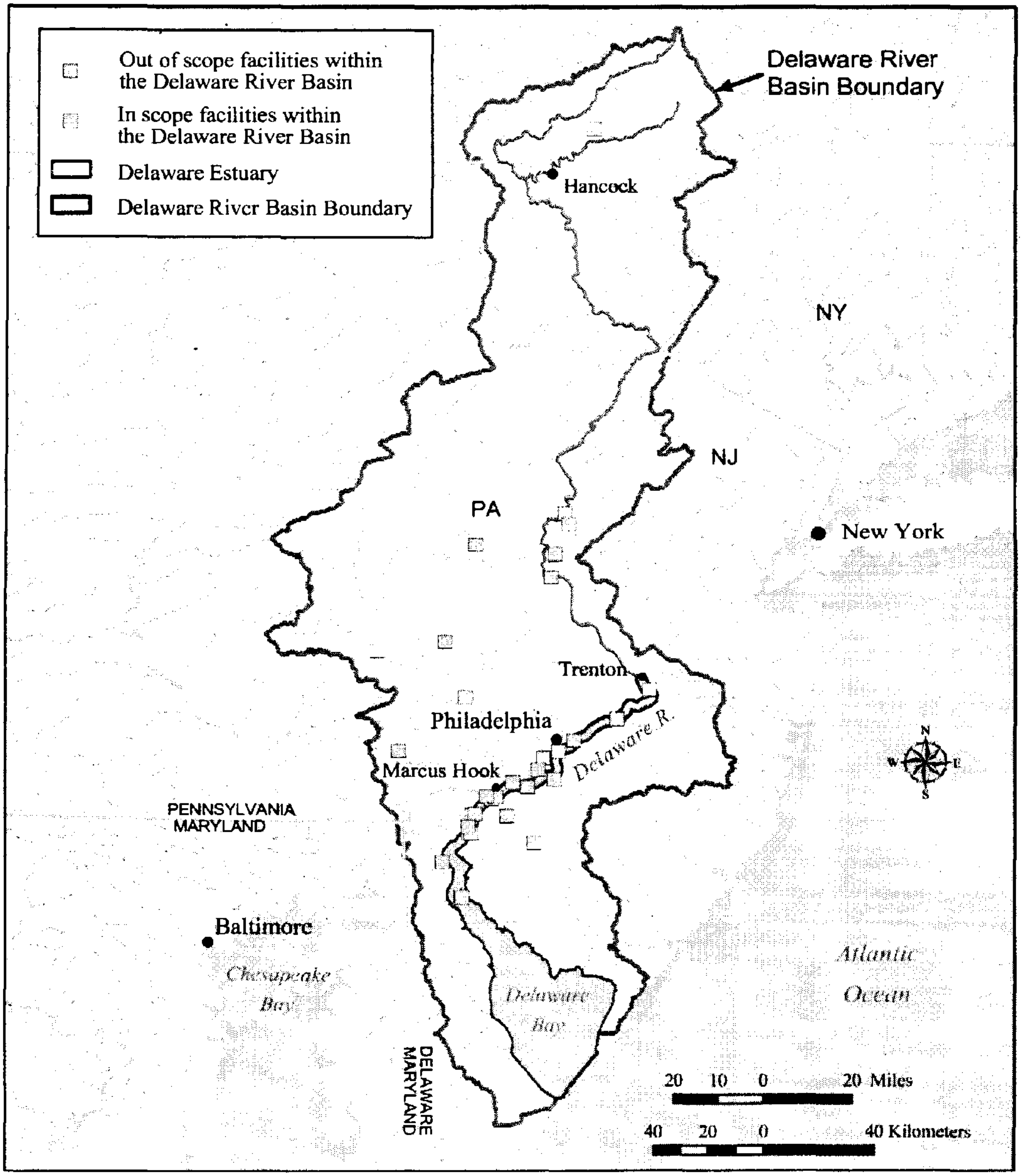


Figure B1-2: The Delaware Estuary and the Case Study Facilities of the Transition Zone

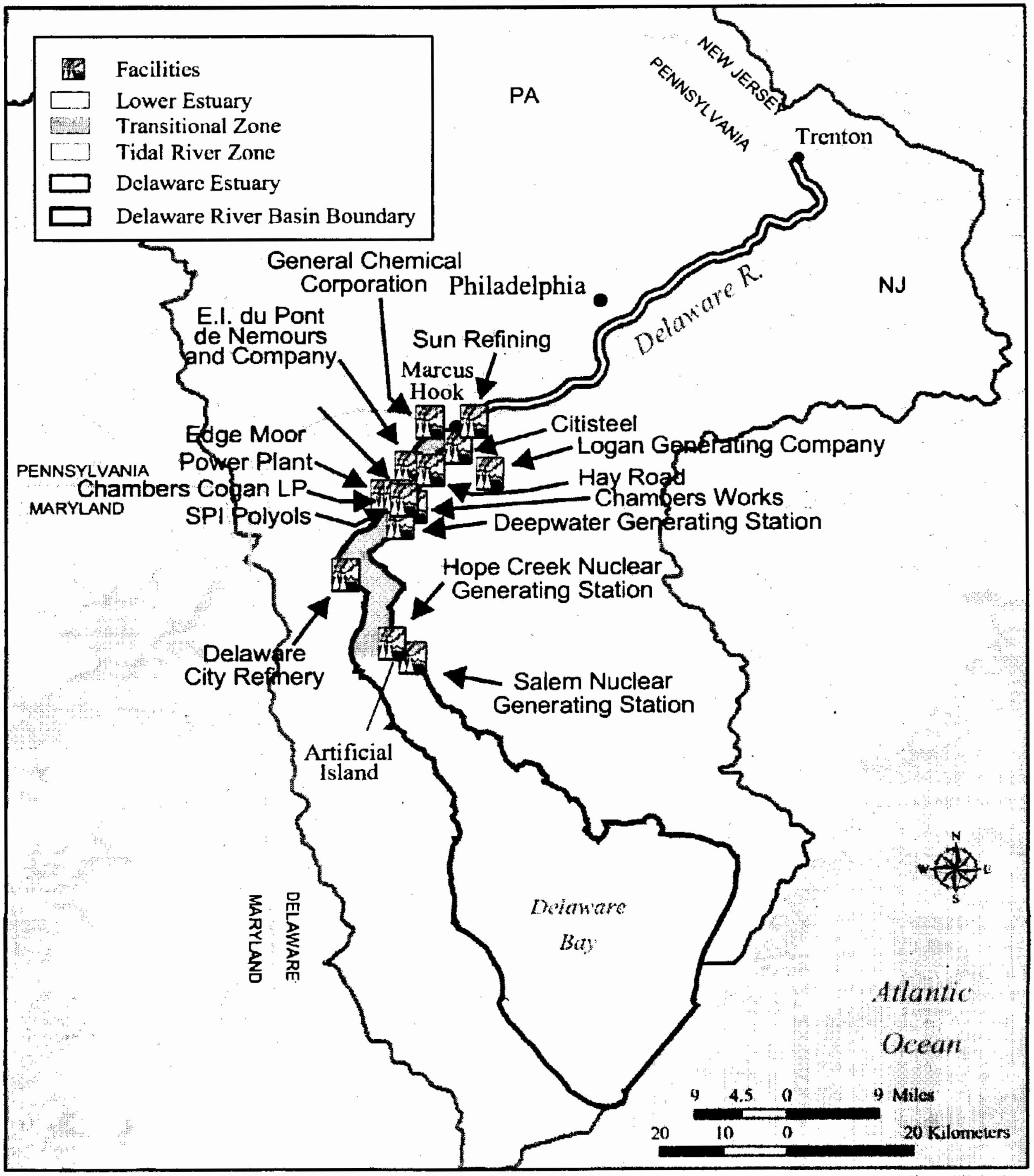


Table B1-1: Summary of Delaware Estuary Power Plants (1999)

	Salem	Hope Creek	Edge Moor	Deepwater
Plant EIA Code	2410	6118	593	2384
NERC Region	MAAC	MAAC	MAAC	MAAC
Total Capacity (MW)	2,382	1,170	710	259
Primary Fuel	Uranium	Uranium	Oil/Coal	Coal/Gas
Number of Employees	425	399	119	48
Net Generation (million MWh)	15.9	7.7	2.2	0.38
Estimated Revenues (million)	$1,373	$663	$141	$43
Total Production Expense (million)	$358	$174	$76	$18
Production Expense (¢/kWh)	2.256¢	2.268¢	3.405¢	4.908¢
Estimated Operating Income (million)	$1,015	$489	$65	$25

Notes: NERC = North American Electric Reliability Council
MAAC = Mid-Atlantic Area Council
Dollars are in $2001.
Source: Form EIA-860A (NERC Region, Total Capacity, Primary Fuel); FERC Form-1 (Number of Employees, Net Generation, Total Production Expense).

The **Salem Nuclear Generating Station** (Salem) is located on the Delaware Estuary in New Jersey, on an artificial peninsula known as Artificial Island. Artificial Island is the dividing line between the transitional and lower estuary. This section of the estuary is approximately 4 km (2.5 miles) wide, and is situated in the transition zone of the estuary. Tidal flow in this area is approximately 11,327 m^3/s (400,000 cfs; NJDEP, 2000). Salem operates two large nuclear units of 1,170 MW each.[1] Both units serve baseload demand. Unit 1 began operation in 1977, and is licensed to operate through June 30, 2017. Unit 2 began operation in 1981, and is licensed to operate through October 13, 2021. Each unit has a once-through cooling system with a design flow of 1,584 MGD. Estuary water is drawn in approximately 122 m (400 ft) north of the circulating water system, where it cools heat exchangers and other equipment before it is discharged back into the estuary (Correia et al., 1993). In addition to the two nuclear units, Salem operates one gas-fired generating unit, which does not require cooling water.

In 1999, Salem had 425 employees and generated 15.9 million MWh of electricity.[2] Estimated 1999 revenues for the Salem plant were approximately $1.4 billion, based on the plant's 1999 estimated electricity sales[3] of 14.7 million MWh and the 1999 company-level electricity revenues of $93.14 per MWh. Salem's 1999 production expenses totaled $358 million, or 2.256¢ per kWh, for an operating income of $1,015 million.

The **Hope Creek Nuclear Generating Station** (Hope Creek) is less than half a mile northwest of the Salem Nuclear Generating Station, and thus has the same estuary characteristics as the Salem facility. Commercial operation at Hope Creek began in 1986. The facility has one boiling water nuclear reactor capable of generating 1,170 MW. Like Salem's units, the Hope Creek reactor is operated as a baseload unit.

Salem and Hope Creek Ownership Information

Salem and Hope Creek both began operation as regulated utility plants and are both currently owned by PSEG Power. Salem and Hope Creek were purchased by PSEG Power from Public Service Electric & Gas Company (PSE&G), a regulated utility company, in August 2000.

PSEG Power is a wholly owned, nonregulated subsidiary of Public Service Enterprise Group (PSEG) Incorporated. PSEG Power was established in 1999 to purchase and operate the nonregulated generation assets of PSEG (Standard & Poor's, 2001a). PSEG Power is a domestic, competitive energy company with 3,100 employees. PSEG Power owns or controls more than 11,200 MW of electric generating capacity and intends to add an additional 6,100 MW. In 2000, PSEG Power posted revenues of $1.0 billion (PSEG, 2001a,d,e).

[1] The data on electric generating units in this chapter come from the 1999 Forms EIA-860A (U.S. Department of Energy 2001b) (Annual Electric Generator Report – Utility) and 860B (U.S. Department of Energy 2001c) (Annual Electric Generator Report – Nonutility).

[2] One MWh equals 1,000 kWh.

[3] Electricity sales are net generation adjusted for utility-specific energy losses, energy furnished without charge, and energy used by the utility's own electricity department. See *Chapter C2: Cost Impact Analysis* for details on the estimation of plant-level electricity sales.

The design flow for the facility is 115.2 MGD. The Hope Creek facility uses a closed-cycle circulating water system consisting of four circulating water pumps. The system holds 9 million gallons of water (PSEG, 1989).

In 1999, Hope Creek had 399 employees and generated 7.7 million MWh of electricity. Estimated 1999 revenues for the Hope Creek plant were approximately $663 million, based on the plant's 1999 estimated electricity sales of 7.1 million MWh and the 1999 company-level electricity revenues of $93.14 per MWh. Hope Creek's 1999 production expenses totaled $174 million, or 2.268¢ per kWh, for an operating income of $489 million.

The **Edge Moor Power Plant** is located at rivermile 72.3 of the Delaware Estuary, just upstream of Wilmington, Delaware. The facility began commercial service in 1951. Edge Moor currently has four active generating units: units 3 and 4 are coal-steam units of 75 and 177 MW, respectively; unit 5 is an oil-steam unit of 446 MW, and unit 10 is a small gas turbine. Edge Moor's units are located in three separate pumphouses. Pumphouse 1 houses units 1 and 2, and contains two traveling screens for each unit; both units retired in 1983. Pumphouse 2 houses units 3 and 4, and contains three traveling screens for unit 3 and two for unit 4. Pumphouse 3 houses unit 5, and contains eight traveling screens. Each unit has one circulating pump operating full time. The average intake flow at unit 5 is reported as 558 MGD, and units 3 and 4 have an average intake flow of 224.5 MGD. The approach velocity as water passes through the traveling screens at the intake structures is 0.5 to 0.85 fps. Organisms impinged on the traveling screens are washed off into a trough and returned to the Delaware River when the screens are rotated (Versar, 1990).

In 1999, Edge Moor had 119 employees and generated 2.24 million MWh of electricity. Estimated 1999 revenues were approximately $141 million, based on the plant's 1999 estimated electricity sales of 2.16 million MWh and the 1999 company-level electricity revenues of $65.20 per MWh. Edge Moor's 1999 production expenses totaled $76 million, or 3.405¢ per kWh, for an operating income of $65 million.

> Edge Moor and Deepwater Ownership Information
>
> Edge Moor and Deepwater both began operation as regulated utility plants and are both currently owned by Conectiv. Conectiv purchased Edge Moor from Delmarva Power & Light Company in July 2000. Conectiv merged with Atlantic Energy Inc. (previously the owner of Atlantic City Electric Company) in March 1998 and assumed ownership of Deepwater.
>
> Conectiv Corporation is a domestic, competitive energy company with 3,800 employees (Hoover's Online, 2001d). Conectiv owns or controls more than 4,000 MW of electric generating capacity (Conectiv, 2001). In 2000, Conectiv posted revenues of $5.0 billion (Hoover's Online, 2001d). During the first quarter of 2002, Conectiv is anticipated to merge with Potomac Electric Power Company (Pepco) in a $2.2 billion transaction that will create a single holding company which will serve more than 1.8 million customers in the mid-Atlantic region (PR Newswire, 2001).

The **Deepwater Generating Station** is located on the east side of the Delaware River in New Jersey, just north of the Delaware Memorial Bridge. The facility began commercial service in 1930. Deepwater currently has three steam electric units: unit 1 is a natural gas unit of 96 MW, unit 4 is an oil unit of 53 MW, and unit 6 is a coal unit of 92 MW. Each unit has a separate cooling water intake. All three intakes are located approximately 32 m (105 ft) offshore in the Delaware River (U.S. Department of Energy, 2001a). In the 2000 EPA questionnaire, the Deepwater Generating Station reported the design intake flow for units 1, 4, and 6 at 151 MGD; the average intake flow for these same units was 104.6 MGD. In addition to the steam electric unit, Deepwater operates one gas turbine which does not require cooling water.

In 1999, Deepwater had 48 employees and generated approximately 376,000 MWh of electricity. Estimated 1999 revenues were approximately $43 million, based on the plant's 1999 estimated electricity sales of 351,000 MWh and the 1999 company-level electricity revenues of $122.74 per MWh. Deepwater's 1999 production expenses totaled over $18 million, or 4.908¢ per kWh, for an operating income of $25 million.

B1-2 ENVIRONMENTAL SETTING

B1-2.1 The Delaware Estuary

The Delaware River Basin (Figure B1-1) encompasses some 35,066 km^2 (13,539 m^2), including parts of Pennsylvania, New Jersey, New York, and Delaware (DRBC, 2001). The main stem of the Delaware River is fed by 216 tributaries along its 531 km (330-mile) course from Hancock, New York, to the mouth of the Delaware Bay. Nearly three-quarters of the nontidal portion of the river is now included in the National Wild and Scenic Rivers Program (DRBC, 2001).

The Delaware Estuary is the tidally influenced portion of the Delaware River Basin, and is one of the largest estuaries of the U.S. Atlantic Coast (Santoro, 1998; DRBC, 2001). It extends 214 km (133 miles), from the falls at Trenton, New Jersey, to the mouth of Delaware Bay, and includes some 1,878 km^2 (725 mi^2) of open water. The C&D Canal at rivermile 59 provides a sea-level connection between the estuary and the upper Chesapeake Bay. A substantial exchange of water occurs through the canal, with average net flow from the Chesapeake Bay to the Delaware Estuary.

The annual mean freshwater inflow to the Delaware Estuary is about 574 m^3 (20,243 cfs), most of which is provided by the nontidal Delaware and Schuylkill rivers (PSEG, 1999c). Highest flows are in March and April and lowest flows are in August and September. Although there is a longitudinal change in salinity from 30 ppt at the mouth of the estuary to freshwater at Trenton, New Jersey, vigorous mixing results in little variation in salinity with depth (PSEG, 1999c). When freshwater inflow is low, higher salinity water moves up-estuary, and when freshwater inflow is high, saline waters move down-estuary.

For most of its length, the estuary is a broad, shallow body of water, with an average depth of 5.8 m (19 ft) and maximum depth of 45.1 m (148 ft). It is divided into three ecological zones based on salinity, turbidity, and biological productivity (PSEG, 1999c):

- The first section is the tidal river zone and consists of an 86.9 km (54 miles) long, heavily urbanized, tidal freshwater area of 64.7 km^2 (25 mi^2). This zone extends from Trenton, New Jersey, to Marcus Hook, Pennsylvania, just north of the Pennsylvania-Delaware state line. It is profoundly affected by urban, commercial, and industrial activities along its shores. It carries high nutrient levels from municipal discharges and also receives significant inputs of dissolved metals and organic pollutants.

- The second section is the transition zone and runs from Marcus Hook, Pennsylvania, to Artificial Island, New Jersey. The transition zone is the focus of this case study. It has a wide salinity range (from 0 to 15 ppt, depending on river flow and tidal currents), high levels of turbidity **and lower levels of biological productivity and diversity than the lower estuary. The transition zone is** brackish and influenced by salt water from the bay. It is also an area with a significant amount of sedimentation. Because of its brackish nature, it is the least biologically productive of the three zones. However, extensive shallow mudflats, sandbars, and tidal marshes in the nearshore areas of the transition zone provide important feeding and nursery areas for hundreds of fish, invertebrates, and bird species.

- The third section is the lower estuary, which is Delaware Bay itself, extending from the mouth of the bay to Artificial Island. It has the highest salinity levels, ranging from less than 5 ppt to more than 30 ppt depending on flow conditions, and is responsible for over 90 percent of the biological productivity of the entire estuary.

The map of the Delaware Estuary in Figure B1-2 shows the locations of these three ecological zones of the estuary and the locations of the CWIS within the transition zone that are evaluated in this case study.

B1-2.2 Aquatic Habitat and Biota

The major habitats of the Delaware Estuary include the open water (pelagic) zone, littoral zone, benthic zone, and tidal marsh zone (PSEG, 1999c; U.S. EPA/ORD, 1998). These habitats support a wide range of species and include important spawning and nursery areas for fish species (Weisberg and Burton, 1993) and nursery and staging areas for migratory birds (i.e., places where birds temporarily stay, feed, and rest during their migrations). These habitat types are described briefly below.

The open water zone includes all areas with water deeper than 2 m (6.6 ft) at low tide. Herring (*Clupeidae*) and anchovies (*Engraulidae*) are common in the open waters of the transition zone (PSEG, 1999c). Use of this extensive habitat varies depending on the species considered. Some species such as the white perch *(Morone americana)* are year-round residents and have adapted to the different conditions found throughout the estuary. Others such as striped bass *(Morone saxatilis)* enter the estuary to spawn only for relatively short periods of time and then return to the ocean. However, the young of many resident and transient species spend at least some part of their early life history in the estuary. For example, striped bass hatch in the transition zone and move downstream in search of nursery habitat, whereas the planktonic life stages of weakfish *(Cynoscion regalis)* use tidal fluctuations to migrate upstream. This aquatic environment also supports a rich diversity of waterfowl and shorebirds that use adjacent terrestrial or semiterrestrial habitat for nesting and resting but rely on the productivity of the estuary for food and sustenance.

The littoral zone includes the intertidal zone as well as nearshore areas less than 2 m (6.6 ft) deep at low tide. The fish communities of littoral areas vary with salinity and substrate type. Among the most common littoral zone fish species are bay anchovy (*Anchoa mitchilli*), Atlantic menhaden (*Brevoortia tyrannus*), Atlantic croaker (*Micropogonias undulatus*), mummichog (*Fundulus heteroclitus heteroclitus*), weakfish, bluefish (*Pomatomus saltator)*, striped bass, white perch, and

Atlantic silverside *(Menidia menidia)* (PSEG, 1999c; U.S. EPA/ORD, 1998). Although less common, American shad (*Alosa sapidissima*) is also found in littoral areas of the transition zone.

The littoral zone is also important for geese, ducks, loons, herons, egrets, gulls, terns, and shorebirds such as plovers and sandpipers; in May and June the estuary's beaches and mudflats host the second largest population of migrating shorebirds in North America (PSEG, 1999c; Delaware Estuary Program, 1996). These birds are attracted to the eggs of spawning horseshoe crabs and other food resources, and feast on them on their journey north. The Pea Patch heronry, located on the upper bay, is the largest heronry in the northeastern United States (Delaware Estuary Program, 1996).

The benthic zone consists of substrate in the deeper parts of the estuary. Many important commercial and recreational fish species are found at least seasonally in the benthic zone, including weakfish, bluefish, striped bass, and white perch (PSEG, 1999c).

The tidal marsh zone includes freshwater emergent marshes of the tidal river, tidal scrub/shrub and forested wetlands along shorelines of tidal tributaries, and the coastal marshes of Delaware Bay (PSEG, 1999c). The most abundant salt marsh fish include mummichog, spot (*Leiostomus xanthurus*), white perch, Atlantic menhaden, bay anchovy, and Atlantic silverside.

B1-2.3 Major Environmental Stressors

In the 1940's, the lower Delaware was essentially an open sewer, with some reaches so polluted that the water was devoid of the oxygen needed to support aquatic life (DRBC, 1998). Beginning in the 1960's, comprehensive efforts were undertaken to address the severe pollution problems, and today the river supports healthy, year-round fish populations of many highly valued species such as striped bass, herring, and shad.

The Delaware Estuary still faces significant environmental challenges despite the recent improvements in water quality. The region still experiences habitat and water quality degradation due to industrial and municipal effluent discharges, untreated storm sewer overflow, nutrient enrichment, agricultural runoff, habitat degradation, and land use changes. As a result, sections of the estuary contain contaminated sediments, toxic contaminants in surface water, and suboptimal levels of dissolved oxygen resulting from high nutrient levels. Fish consumption advisories have been issued for several fish species because of high levels of PCBs and chlorinated pesticides in their tissue. Physical habitat alterations in selected parts of the bay have resulted in losses of hundreds of thousands of adult horseshoe crabs. Even though numerous fish populations increased over the last two decades, other species, e.g., the Atlantic sturgeon, are experiencing inadequate population growth or are still declining (Delaware Estuary Program, 1996; DRBC, 1998; Santoro, 1998).

While these stressors will not be directly affected by the § 316(b) regulation, they do affect the health of the ecosystem and influence the abundance and variety of aquatic organisms present. A solid understanding of factors currently limiting the waterbody's health is important because the ecosystem surrounding a CWIS is one of the primary determinants of a facility's potential for adverse environmental impact. In addition, some of the facilities that operate CWIS also contribute to these other stressors, as discussed below.

a. Habitat destruction, degradation, or modification

It has been estimated that between the mid-1950's and early 1980's, Delaware, New Jersey, and Pennsylvania lost over 50 percent of their wetlands (Jenkins and Gelvin-Innvaer, 1995). Others have put the loss at closer to 25 percent (Delaware Estuary Program, 1996). Irrespective of the precise extent of wetland losses, nontidal freshwater and forested wetlands have been more affected than the tidal marshes. Existing federal and state regulations limit further wetland loss from human encroachment. However, in the past, tidal wetlands have been lost, degraded, or modified by spoil disposal practices, residential developments, parallel-grid ditching for mosquito control programs, impoundments, diking to support salt-hay farming, and agricultural uses. The non-native common reed (*Phragmites australis*) has overrun large areas of tidal marsh habitat and outcompeted the diverse native plant species. This has reduced the overall biological value of this type of habitat by eliminating feeding and nesting areas for waterfowl and wading birds.

Dredging activities to support shipping in the estuary over the last 100 years have had both positive and negative consequences for estuarine habitats (Delaware Estuary Program, 1996). In many cases, dredge spoils were simply deposited on adjacent marshlands, which were subsequently lost to industrial development. Other dredged material was deposited on dredge-disposal islands within the estuary. Trees grew on the dredge-disposal islands and provided habitat for a large number of nesting colonies of wading birds (Jenkins and Gelvin-Innvaer, 1995).

The dredged ship channel increased the tidal range in the upper estuary because the dense marine water can now push further upstream. However, other factors involved in this process include general sea level rise and a decrease in the river debit due to upstream removal of freshwater for drinking water. The intensified ship traffic within the estuary has also resulted in increased shoreline erosion due to ship wakes. A combination of these two factors has been blamed for a decrease in intertidal vegetation in the upper and transitional estuary (Delaware Estuary Program, 1996).

Rising sea levels over the next century in response to global warming are also seen as a significant threat to the well-being of the tidal wetlands around the estuary (Delaware Estuary Program, 1996). Any further loss can directly affect anadromous and indigenous fish species by eliminating nursery habitat or resident and migratory bird species by removing nesting, feeding, or staging areas.

b. Introduction of non-native species

Under the right environmental conditions, non-native species can upset entire ecosystems. For example, the introduction of the sea lamprey into the Great Lakes in the 20th century was in part responsible for the decline of big game fish. The more recent introduction of zebra mussels has had dramatic negative effects on the Great Lakes food chain. Such "exotic" species can cause tremendous harm by displacing native species or radically changing native habitats.

A number of non-native species such as largemouth and smallmouth bass, grass carp (*Ctenopharyngodon idella*), hydrilla (*Hydrilla verticillata*, a prolific aquatic weed), and purple loosestrife (*Lythrum salicaria*) have become established in and around the estuary. The zebra mussel, though not yet present in the Delaware River system, could be introduced via ship ballast water. Nutria, a non-native and destructive rodent introduced elsewhere in the country for its fur, is present along Chesapeake Bay and has the potential of reaching the Delaware. Proposals have also been made to introduce non-native species such as the Japanese oyster and Pacific salmon for commercial and recreational reasons (Delaware Estuary Program, 1996).

The common reed *(Phragmites australis)* exemplifies how a non-native species can have far-ranging effects on an ecosystem. *Phragmites* is a highly competitive plant that has overpowered and replaced native marsh plants in thousands of acres of emergent tidal wetlands along the Delaware Estuary. This has led to a significant drop in available food resources, habitat diversity, and open water space and affects a number of species, including ducks, which are excluded from these infested areas. An aggressive eradication program has been proposed to reduce the amount of *Phragmites* cover in wetlands by 40 percent over the next decade and allow natural revegetation by pre-*Phragmites* marsh plants[4] (Delaware Estuary Program, 1996). In addition, recommendations have been made for developing and implementing an estuary-wide program to assess the potential effects of intentional introductions of non-native species and prevent unintentional future introductions (Delaware Estuary Program, 1996).

c. Overfishing

The long-term decline of the Delaware fisheries in the 20th century was due primarily to low dissolved oxygen (DO) concentrations and high levels of pollution. Since the early 1980's, when these two problems were brought under control, many of the original fish stocks have experienced a comeback. The commercial and recreational fisheries resources within the Delaware Estuary, however, are all strictly regulated to avoid overfishing and protect the stocks. A number of species-specific fishery management plans have also been developed and implemented throughout the estuary and across jurisdictional lines to provide coordinated protection. For example:

- The recovery of the striped bass population in the estuary in the 1970's and early 1980's may have been impeded by overfishing due to lack of regulatory controls at the time. In fact, Delaware completely closed down the fishery between 1985 and 1989 to help the stock recover. New Jersey and Pennsylvania ban commercial fishing for this species. Delaware allows a small gill net fishery. Recreational fishing is permitted in the three states, but the daily bag limit is one legal-size fish. In addition, the spawning grounds are closed to striped bass fishing during April and May (Miller, R.W. 1995).

- The Atlantic menhaden is a strictly regulated species and has become an important recreational fishery within the estuary and nontidal river. For example, purse seining for this species is prohibited in most of the bay. In 1992, a new fishery management plan was adopted by the Atlantic Menhaden Board of the Atlantic States Marine Fishery

[4] *Phragmites* eradication measures often consist of a combination of herbicide and burn treatments, which in themselves may have negative environmental side effects.

Commission. This plan relies on biological "triggers" to tell the fisheries managers when to close the fishery to protect the species (Hall, 1995).

- The American shad fishery in the estuary is being managed under a 1982 fishery management plan. The plan sets forth four specific goals: (1) achieving a predetermined annual spawning population size, (2) supporting a recreational sport fishery in the nontidal river, (3) maintaining a basic commercial harvesting rate, and (4) restoring shad spawning areas that have been closed to migration because of dams (Miller, J.P., 1995).

d. Pollution

The Delaware Estuary is an ecosystem on the rebound from severe water quality impairment (Delaware Estuary Program, 1996). The upper estuary (i.e., the tidal, freshwater portion of the tidal zone) was once considered one of the most polluted rivers in the United States. From the early 1990's until the 1970's, high biological oxygen demand (BOD) rendered the region around Philadelphia/Camden almost anoxic during several months of the year. The lack of DO served as a "pollution block," preventing the spawning migration of anadromous fish upstream into the nontidal, freshwater reaches of the Delaware River. As a result, several species, including striped bass and American shad, showed severe population-related declines. A combination of industrial effluent controls and improvements in municipal sewage treatment, completed in the late 1980's, has since reversed this problem and has resulted in one of the most successful estuarine water quality improvements in the world (Santoro, 1998). Indeed, the numbers of juvenile striped bass and American shad have increased more than a thousandfold since the early 1980's (Weisberg et al., 1996).

The kind of separation between freshwater- and salt water layers observed in other bays and estuaries, which can lead to severe DO depletions during the summer months (notably in the Chesapeake Bay), does not typically occur in the Delaware Estuary. This is because there is little stratification between fresh and salt water due to the unique shape of the estuary, its relatively shallow depth, and the strong tidal currents within it, all of which promote mixing. Consequently, even though the Delaware River is highly enriched with nutrients, the combination of high turbidity and hydrologic mixing limits the amount of DO depletion during the summer months. Occasional DO deficits still reflect inputs of high BOD compounds from the major urban areas surrounding the upper estuary.

A number of facilities of concern to § 316(b) add to the estuary's pollution load through effluent releases. These include pulp and paper plants, refineries, chemical facilities, and primary metal facilities. In addition, electric utilities can release chemicals to the receiving water in the form of antifouling agents or anticorrosives that are added to cooling water to protect pipes and other structures.

Ongoing sources of pollution in the estuary include contaminated sediments, point and nonpoint sources of aquatic toxicants, and thermal discharges.

❖ *Contaminated sediments*

Sediments act as long-term reservoirs for contaminants, which can be released back into the water column or passed up into the food chain. Several chemicals present in Delaware Estuary sediments (in particular mercury, DDT and its metabolites, other pesticides, and PCBs) can bioaccumulate and are difficult to eliminate once they are ingested by aquatic organisms. As a result, the concentrations of these compounds increase as they move up the food chain. This becomes a long-term problem for predators, in particular piscivores (predators that consume fish), because high levels of these chemicals are present in their prey. Fish consumption advisories are posted throughout the estuary and a section of the nontidal river because of unacceptable levels of PCBs in several recreational fish species (DRBC, 1998; Santoro, 1998). In addition, reproductive success in fish-eating raptors is believed to be impaired by the presence of these chemicals in their food source, because they lead to egg shell thinning (Clark, 1995; Niles, 1995).

❖ *Aquatic toxicants from point and nonpoint sources*

Although water quality has improved markedly since new water quality regulations were implemented in the 1970's, the presence of bioaccumulative compounds (DDE, chlordane, PCBs) within the aquatic food chain is still a concern (DRBC, 1998). Fish and shellfish in the Delaware Estuary contain some of the nation's highest levels of chemical contaminants (U.S. EPA/ORD, 1998). The presence of these chemicals has resulted in fish consumption advisories for channel catfish and white perch, to limit the potential effects on human health (DRBC, 1998). A 1990 study to assess the chronic toxicity of ambient waters indicated significant growth reductions of fathead minnow larvae in 8 of 12 surface water samples collected throughout the upper estuary. These results suggested that large stretches of the upper estuary may be chronically toxic to sensitive life stages of aquatic organisms under specific hydrological and effluent loading conditions. The most toxic water samples were collected in areas impacted by industrial and municipal effluent outfalls. It is unclear from the available information if more recent bioassay data exist or if additional studies have been conducted to clarify the effects of tides, currents, seasons, and effluent loadings on the observed toxicity (DRBC, 1998; Santoro, 1998).

❖ *Thermal discharges*

In the Delaware River Basin, numerous steam-electric and industrial facilities release heated water to the estuary, which can increase water temperatures above levels that are tolerated by aquatic life. Thermal discharge is a byproduct of the cooling cycle of power plants and other industrial facilities. Production processes that generate heat generally use cool water to remove excess heat from the production process and transfer it to the cooling water. The heated water can either be cooled and reused within the facility (as in closed-cycle or recirculating systems), or it can be directly released to the environment (as in once-through systems). The environmental impacts of thermal discharges are site specific and depend on factors such as the size and/or flow of the receiving water, temperature differences between the discharge and the receiving water, the time of year, and the biological characteristics of the affected aquatic community.

B1-3 Water Withdrawals and Uses

Nearly 10 percent of Americans rely on the waters of the Delaware River Basin for drinking and industrial use (DRBC, 1998). The waters of the Delaware River and its tributaries provide drinking water, irrigation water, and water for industrial manufacturing processes, electricity generation, mining, and livestock. Water use can be classified as either "instream" or "offstream." As its name implies, instream use does not require removal of water from its source and therefore does not involve intake structures. The primary instream use of water is for hydroelectric power generation. Offstream water use, on the other hand, does involve water withdrawals through intake structures and is therefore of interest to the § 316(b) regulation. This subsection discusses water withdrawals and uses in the Delaware River Basin.

Total water withdrawals from the Delaware River Basin averaged 6,801 MGD in 1995. Of this total, 91 percent were surface water withdrawals from rivers, streams, lakes, and estuaries and 9 percent came from groundwater. The term "water withdrawal" refers to water removed from the ground or diverted from a surface water source (USGS, 1995).

Large withdrawals of water can lead to a number of water management and ecological problems. Of greatest concern to this regulation is the I&E of aquatic organisms that inhabit the waterbodies from which facilities withdraw water through intake structures. In addition, overwithdrawal and overconsumption of water can increase salt water intrusion into aquifers that supply drinking water. An excessive level of salt in drinking water presents a known risk to human health. To date, there is no evidence that withdrawals from the Delaware River and its tributaries pose salinity or turbidity problems or that withdrawals are increasing enough to make such problems likely in the future. Because of reduced power generation cooling and public supply water management programs, water withdrawals for the Delaware Basin have actually decreased since in the late 1980's (Delaware Estuary Program, 1996).

B1-3.1 Cooling Water Use

In 1995, steam electric power generation[5] accounted for the single largest intake of water from the Delaware River Basin, at 72 percent of all surface water withdrawals. While this number has decreased in recent years because more power plants have moved to closed-cycle cooling systems rather than once-through systems (DRBC, 1996), the total withdrawal of this group is still substantial.

Table B1-2 summarizes cooling water intake flows of all utility-owned power plants, nonutilities, and manufacturing facilities in the transition zone of the Delaware River Basin, including facilities subject to § 316(b) regulation and those that are not yet affected. Both design and average annual intake flow rates are presented.

[5] Steam power generation is defined by the United States Geological Survey (USGS) as thermoelectric generation, which includes the generation of electric power with fossil fuel, nuclear, or geothermal energy.

Table B1-2: Characteristics of § 316(b) Facilities Operating CWIS in the Transitional Zone of the Delaware Estuary, 1999

EIA Plant Code	Plant Name	CWIS Information				HUC Watershed Code
		EIA CWIS Code	CWIS Type[a]	Design Intake Flow Rate (ft³/sec)	Average Annual Intake Flow Rate (ft³/sec)	
		Electric Power Plants				
593	Edge Moor	3	OF & OS	100	60	2040204
		4	OF & OS	148	107	
		5	OF & OS	581	303	
2384	Deepwater	1	OS	101	83	2040204
		4	OS	102	60	
		6	OS	97	76	
2410	Salem	SA1	OS	1,678	1,359	2040204
		SA2	OS	1,678	1,284	
6118	Hope Creek	HC1	RN	95	52	2040204
7153	Hay Road[b,c]	n/a	n/a	n/a	1.6	2040204
10043	Logan Generating Co.[c,d]	n/a	n/a	n/a	1.4	2040204
10566	Chambers Cogen LP[b,c,e]	n/a	n/a	n/a	37	2040204
		Total Electric Power Plant Intake		4,580	3,424	
		Manufacturing Facilities[b]				
Delaware City Refinery[c]		n/a			339	2040204
DuPont[c]		n/a			7	2040204
General Chemical Corporation[c]		n/a			24	2040204
SPI Polyols[c,d]		n/a	n/a	n/a	5	2040204
Citisteel[c,d]		n/a	n/a	n/a	0	2040204
Sun Refining[c,d]		n/a	n/a	n/a	6	2040204
		Total Manufacturing Facility Intake			382	

[a] U.S. Department of Energy, 2001a. Form EIA-767 codes for relevant CWIS types: OF - once through, freshwater; OS - once through, saline water; RN - recirculating with natural draft cooling tower.
[b] Based on EPA's Section 316(b) Industry Survey, these facilities are not in scope of the proposed section 316(b) Phase II rule: Hay Road because it does not hold an NPDES permit; Chambers Cogen LP because it does not directly withdraw cooling water from a surface water source. Manufacturing facilities are subject to Phase III of the section 316(b) regulations.
[c] Intake flow information from the Delaware River Basin Commission (DRBC, 1996).
[d] These facilities are not analyzed for this proposed rule because they were not part of the second phase of EPA's industry survey effort. However, all facilities withdraw from the Delaware River and are therefore presented in this table.
[e] Listed in DRBC (1996) as an industrial facility ("DuPont Chambers").
Sources: CWIS information: U.S. Department of Energy, 2001a (except where noted); HUC codes: Reach File 1, U.S. EPA, 1982b.

B1-4 Socioeconomic Characteristics

The Delaware River Basin is a highly valuable economic resource, providing the physical environment and biological resources for numerous commercial and recreational activities. It also supplies water for many different purposes, among others drinking water for 20 million people (Delaware Estuary Program, 1996). The region supports over 6.5 million people (Delaware Estuary Program, 1996; Santoro, 1998), and includes the city of Philadelphia, the fifth largest metropolitan area in the country. Between 1970 and 1990, 10 of the 22 counties in the region experienced population growth of more than 20 percent, resulting in rapid suburban development and more than 300,000 new housing units. The regional population is expected to grow by an additional 14 percent by 2020. The projected growth, however, will not be evenly distributed across the region. Indeed, the historical urban centers will continue to experience a net population loss, whereas the surrounding regions will show a net gain. Philadelphia, for example, is projected to lose 76,000 people (5 percent of its current population) by 2020 (Delaware Estuary Program, 1996; Santoro, 1998).

Not unexpectedly, the suburban sprawl associated with these demographic changes has profoundly affected land use patterns: large tracts of forest and agricultural lands have been converted into roads or housing and commercial developments. This activity consumes land, reduces terrestrial habitats, and directly affects the quality of the water in the estuary (Delaware Estuary Program, 1996). As an example, the Delaware Valley Regional Planning Commission (DVRPC) analyzed the 1990 land use patterns in its nine-county region and extrapolated these results to project future land use consumption through 2020. In 1990, the DVRPC estimated that 37 percent of the land area was developed. By 2020, the DVRPC projects that 51 percent of the land area will be developed, leaving less than half as agricultural, wooded, or vacant land or water (Delaware Estuary Program, 1996).

This subsection highlights the most important economic uses of the Delaware River Basin. Many of these uses may benefit from § 316(b) regulations and are therefore of particular interest to this study.

B1-4.1 Major Industrial Activities

a. Shipping

Commercial and recreational shipping activities take place throughout the Delaware Estuary, providing substantial support to the regional economy. The Port of Philadelphia, for example, generated $335 million in business revenue in 1997 (DRBC, 1998). The Philadelphia Regional Port Authority estimated that state and local taxes from port activities that year totaled $13 million and supported 3,622 jobs (DRBC, 1998).

Dredging operations have been ongoing in the Delaware Estuary for more than 100 years to support shipping and accommodate ever larger ships. Currently, the ship channel is 12-14 m (40 to 45 ft) deep and is maintained by annual dredging that removes and disposes of over 6 million cubic yards of sediments. In 1996, the cost was $15 to $18 million (Delaware Estuary Program, 1996).

b. Heavy industry

The Delaware River Basin has one of the largest concentrations of industrial facilities, oil refineries, and petrochemical plants in the world (DRBC, 1998). Discharges from 162 industries and municipalities and approximately 300 combined sewer overflows go into the estuary alone.

- The combined ports of Philadelphia, Camden, Gloucester City, Salem, and Wilmington receive over 70 percent of the oil, over 1 billion barrels, reaching the east coast of the United States every year. The port complex is the world's largest freshwater port and ranks second in the nation in total waterborne commerce, generating an income of over $3 billion and providing 180,000 jobs (Delaware Estuary Program, 1996).

- The Delaware Estuary supports the second largest refining-petrochemical center in the United States (Delaware Estuary Program, 1996).

B1-4.2 Commercial Fisheries

The Delaware Estuary is home to over 200 species of resident and migratory fish. Many of these species are an invaluable resource for both commercial and recreational fishing.

- At least 31 fish species are commercially harvested in the Delaware Estuary. The value of the estuary's commercial fin fishery was about $1.4 million in 1990 (Delaware Estuary Program, 1996).

- The first recorded oyster landings in the Delaware Bay, in 1880, totaled an estimated 2.4 million harvested oyster bushels. This number decreased to about 1 to 2 million bushels until the mid-1950's. Over the past 40 years, the oyster industry was depressed because of two diseases, MSX and Dermo, which ultimately resulted in the closure of the natural oyster beds in the Delaware Bay. When these beds reopened in 1996, fishermen harvested an estimated 75,000 bushels with a dockside value of approximately $1.6 million (Santoro, 1998).

- Shad has been an important fishery in the Delaware River since colonial times (Delaware Estuary Program, 2001). Between 1896 and 1901, the catch of shad in the Delaware River exceeded that of any other river system on the Atlantic Coast and accounted for up to 30 percent of the entire coastal catch. On average, fishermen landed 5,445 to 6,350 metric tons (12 to 14 million pounds) annually. Shad landings began to decline rapidly in the early 1900s, mainly due to pollution and overfishing. Although improved water quality and development of a fishery management plan led to some recovery after 1975, shad remain well below pre-1900 levels. High numbers of shad returned from the ocean to spawn in freshwater portions of the Delaware River in 1998 and again in 2000, but 1999 records show a very low number of returns, raising concerns about the extent to which the shad population has actually recovered. A recent study placed the current annual value of the shad fishery at $3.2 million (DRBC, 1998).

B1-4.3 Recreational Activities

a. Recreational fishing

The Delaware River Basin provides ample opportunity for recreational fishing ranging from marine fishing to freshwater and flyfishing. To characterize recreational fishing in the Delaware River Estuary, EPA relied mainly on the Marine Recreational Fisheries Statistics Survey (MRFSS) (NMFS, 2001b).

The MRFSS is a comprehensive coast-wide survey of marine recreational anglers operated by the National Marine Fishery Service (NMFS). The MRFSS is a long-term monitoring program that provides estimates of effort, participation, and finfish catch by recreational anglers. The MRFSS survey consists of two independent, but complementary, surveys: an intercept survey of anglers at fishing access sites and a random digit-dial telephone survey of households.

The basic intercept survey collects information about anglers' home ZIP code, the length of their fishing trip, the species they targeted on that trip, and the number of times anglers have fished in the past two and 12 months. Trained interviewers record the species and numbers of fish caught that are available for inspection and then weigh and measure the fish.

NMFS used the random telephone survey to estimate recreational fishing effort (i.e., trips) on a two-month basis (as opposed to annual participation) for coastal households. NMFS adjusted effort estimates for coastal households by the ratio of intercept data of coastal to non-coastal and out-of-state residents to calculate total effort. The survey asked households with individuals who had fished within two months of the phone call about the mode of fishing, the gear used, and the type of waterbody where the trip took place for every trip taken within that period. The telephone survey also collected data on the socioeconomic characteristics of recreational anglers.

The MRFSS found that, on average, participants spend approximately 28 days fishing at Delaware Bay and Atlantic coastal sites of Delaware and New Jersey each year. The Delaware Bay fishermen tend to travel relatively short distances, on average 40 miles for single-day trips and 107 miles for multiple-day trips. Fishermen taking single- and multiple-day trips spend an average of $62.43 and $100.24, respectively, in pursuit of their target species.[6]

From 1994 to 1998, recreational anglers in Delaware and New Jersey caught an annual average of:

- 18.03 metric tons (395,744 pounds) of striped bass;
- 1,265.63 metric tons (2,790,234 pounds) of weakfish;
- 2,527.29 metric tons (5,571,710 pounds) of flounder;
- 443.07 metric tons (976,795 pounds) of bluefish; and
- 1,385.37 metric tons (3,054,216 pounds) of bottom fish (including Atlantic croaker, tautog, spot, and white perch).

Table B1-3 shows the results of the MRFSS analysis of fishing participation at the lower Delaware Bay Estuary and adjacent coastal sites in Delaware and New Jersey. The table presents the five-year average of total fishing days by state and by fishing mode (1994 through 1998); this total number of fishing days includes both single- and multiple-day trips.

Table B1-3 shows that anglers spent an estimated 5.4 million days fishing at the lower Delaware Bay Estuary and adjacent Atlantic coastal sites. The NMFS data show that recreational fishing in the estuary and adjacent coastal sites is largely limited to residents living close to the case study area, such as residents of Delaware, New Jersey, Pennsylvania, and Maryland.

In addition to species reported by the NMFS, a 1986 creel census found that anglers made 65,690 trips and spent 299,597 hours fishing for shad in the Delaware River. This survey also estimated the economic value of recreational shad fishing in the Delaware River in 1986 to be $3.2 million (Miller, J.P., 1995).[7]

[6] Includes travel and boat expenditures for single-day trips and travel, lodging, and boat expenditures for multiple-day trips.

[7] This number reflects a $50/day replacement value.

Table B1-3: Recreational Fishing Participation in the Lower Delaware Bay Estuary and Atlantic Coastal Sites in Delaware and New Jersey

Visited State	Fishing Mode	Total Number of Fishing Days at the Delaware and New Jersey NMFS Sites
DE	Private or Rental Boat	390,578
DE	Shore	367,402
DE	Charter Boat	43,339
NJ	Private or Rental Boat	2,596,380
NJ	Shore	1,596,531
NJ	Charter Boat	403,523
Total		**5,397,753**

Source: NMFS, 2001b.

b. Bird watching

Bird Watching in the Delaware Bay

"The marshy convergence of water and land along the Delaware Bay shoreline, long resistant to human encroachment, encompasses some of the Atlantic coast's finest birding sites. Waterbirds of one sort or another, from loons to terns, are present throughout the year. This is one of the country's best places to find Curlew Sandpiper, a rare wanderer from breeding grounds in Siberia, and Ruff, another sandpiper that nests in Scandinavia and northern Asia."

White, 1999

Hundreds of thousands of migrating birds use the estuary's high biological productivity on their way to and from their overwintering and breeding grounds. In fact, the estuary is one of the most important feeding sites for shore birds in North America, with an estimated 425,000 to 1 million shorebirds arriving during their spring migrations. The arrival of migratory birds, together with numerous year-round avian residents, has promoted a burgeoning bird watching industry. In 1988, an estimated $5.5 million was spent by more than 90,000 bird watchers in the Cape May area alone. Much of this activity occurred in the "off-season" and provided a significant economic boost to the region (Delaware Estuary Program, 1996).

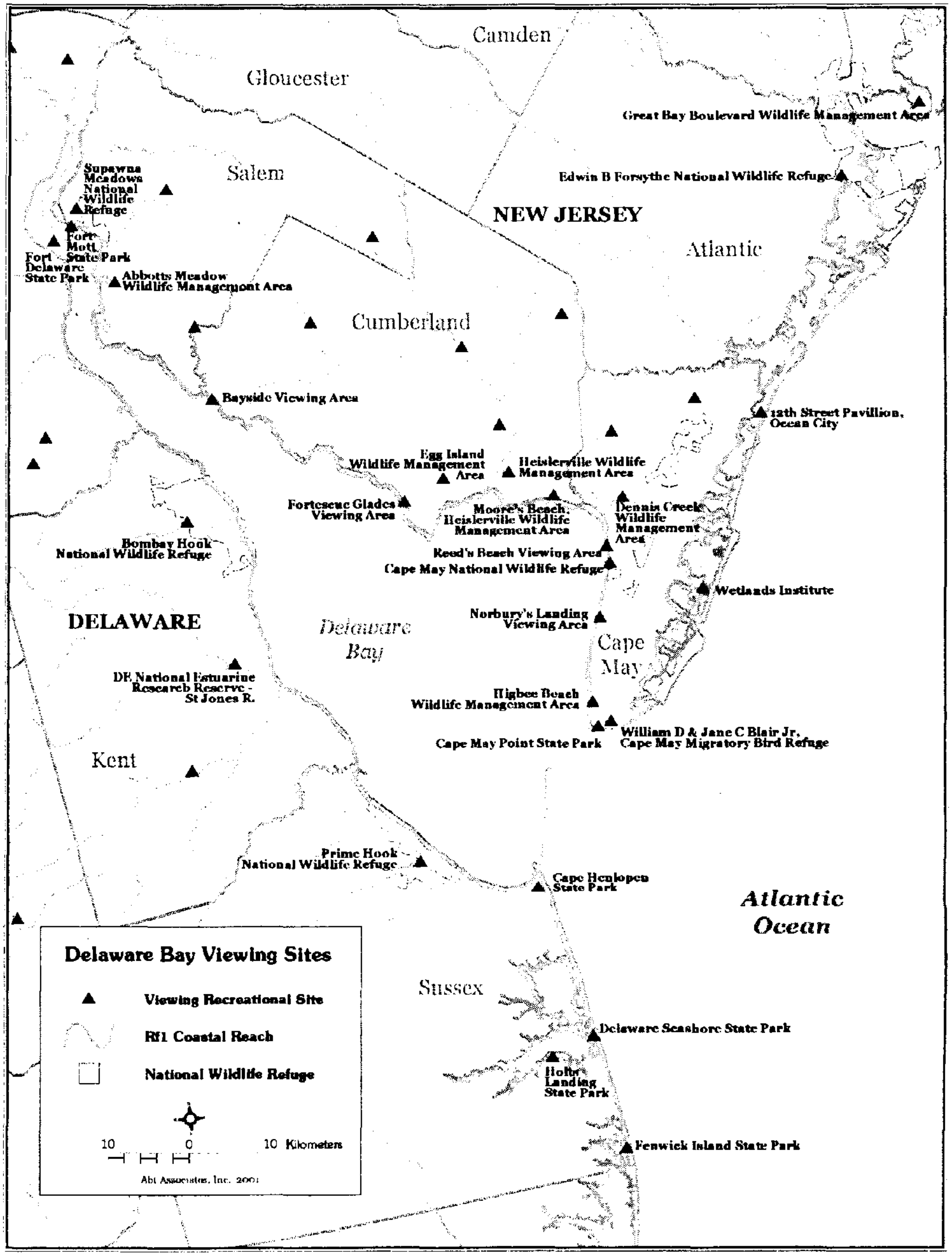
Figure B1-3 shows the most important bird watching areas along the Delaware River Basin. The following text highlights some of these areas.

❖ *Bombay Hook National Wildlife Refuge*

The Bombay Hook National Wildlife Refuge extends for approximately 6,070 hectares (15,000 acres) along the Atlantic Coastal Plain on the western shore of Delaware. The refuge provides a wide diversity of habitat types (including artificial bays and marshes, upland woods, swamps, brushy thickets, grassy fields, and croplands) and attracts numerous species of birds. Bombay Hook was originally established in 1937 as a link in the chain of waterfowl refuges that extends from Canada to the Gulf of Mexico. It is mainly a refuge for migrating and wintering ducks and geese but also hosts numerous other species of migratory birds (Great Outdoor Recreation Pages, 1999). The importance of Bombay Hook as a recreational area has increased greatly in the past 25 years, mainly because of the loss of extensive surrounding marshland to urban and industrial development. Approximately 128,500 visitors explored the refuge in 1998 (Personal Communication, Marion Pohlman, Bombay Hook National Wildlife Refuge, September 21, 1999).

Wildlife can be seen year round at Bombay Hook. In October and November, waterfowl populations are at their peaks, when over 100,000 ducks and geese use the refuge. March is the second peak for waterfowl that travel through on their return to northern breeding grounds. April brings early shorebird migrants. Shorebirds are at their highest concentrations during May and June, mainly because of the arrival of horseshoe crabs laying eggs along the bay shore and mud flats. These eggs provide the shorebirds with needed energy to complete their northward migration. Wading birds such as herons, egrets, and glossy ibis reach their peak numbers during the summer months (Great Outdoor Recreation Pages, 1999). Bombay Hook also hosts the greatest concentration of snow geese in North America and has a long history of nesting eagles. The refuge includes a 12-mile auto tour loop and five trails from which visitors can view the wildlife.

Figure B1-3: Bird Watching Areas of the Delaware River Basin



Source: Delorme, 1993, 1999; USGS, 2000.

❖ *Cape May Peninsula*

The Cape May peninsula is world renowned for its importance to migratory birds. Cape May is situated at the end of a peninsula separating Delaware Bay from the Atlantic Ocean. The peninsula acts as a funnel for songbirds, shorebirds, waterfowl, butterflies, and hawks migrating along the Atlantic Flyway. Cape May provides critical staging areas that provide important resting and feeding opportunities for migrating birds. The Cape May natural and recreational areas include:

- **Cape May Point State Park:** A large portion of the park is a designated Natural Area and has more than 3 miles of trails and boardwalks for nature study and hiking. The "Hawk Watch" observation platform provides an excellent view of one of the nation's most extraordinary autumn hawk migrations. Beginning in September and extending through December, tens of thousands of raptors, including bald eagles, peregrine falcons, ospreys, goshawks, Cooper's hawks, and various species of owl pass the platform (Pettigrew, 1998). From July 1, 1998, through June 30, 1999, over 800,000 people visited the park (Personal Communication, Cape May Point State Park, September 21, 1999).

- **Higbee Beach Wildlife Management Area:** Higbee Beach is a 2.4 km (1.5 mile) stretch of beach containing the last remnant of coastal dune forest on the bay shore, where visitors can admire hundreds of species of migrating songbirds and hawks. Higbee Beach is managed specifically to provide habitat for migratory wildlife. In addition to millions of songbirds, nearly 50,000 raptors migrate over the peninsula every year, and many stop here to rest and feed (Pettigrew, 1998).

- **William D. and Jane C. Blair Cape May Migratory Bird Refuge:** This area is recognized as one of the East Coast's premier birding spots. Thousands of raptors, shorebirds, songbirds, and waterfowl pass through the refuge on their way south. The refuge provides a haven for two state-listed endangered species: the least tern and the piping plover. New Jersey's beaches comprise a significant portion of the entire breeding population's nesting habitat.

❖ *Recreational viewing reported in the Survey of National Demand for Water Based Recreation*

The Agency used EPA's 1994 *Survey of National Demand for Water-Based Recreation* (National Demand Survey, NDS) to characterize recreational wildlife viewing at the Delaware River Basin. EPA cooperated with the National Forest Service and several other federal agencies and interested groups to collect data on the outdoor recreation activities of Americans. EPA's goal was to quantify the number of people who participate in water-based recreation and their total number of recreation trips. In addition, the survey was intended to explain how water quality conditions and other characteristics of water resources affect these numbers. Table B1-4 shows the results of the survey for the Delaware River Basin. The table presents two key results (shaded columns): (1) the extrapolated national number of people who visited the Delaware River Basin during 1994, and (2) the extrapolated national number of wildlife viewing trips to the Basin.[8]

To determine the total number of wildlife viewing participants from each state, EPA used the percentage of survey respondents from each state that reported having visited the basin and the total number of state residents 18 and older.[9] In addition, the survey collected information on the number of times the respondents visited the site of their last viewing trip. EPA used this number to derive an average number of trips per visitor to the Delaware River Basin and the total number of wildlife viewing trips by state.

Table B1-4 uses a 1994 recreation participation survey to estimate wildlife viewing in 2000. Approximately 1.4 million people used the Delaware River Basin for wildlife viewing.[10] These visitors accounted for about 5.1 million recreational trips to the area. Residents of Pennsylvania, New Jersey, and Delaware were the most frequent visitors.

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[8] Notably, the NDS collected information only on the *last* site visited. These numbers do not reflect people whose last visit was to a different area but who may have also visited the Delaware River Basin on a previous trip during the year. For the remainder of the NDS results discussion, the reported numbers of respondents and their trips refer only to respondents whose last trip was to the Delaware River Basin.

[9] The survey collected information only on respondents 18 or older.

[10] Note that given the small sample size, estimates of the total number of trips to the Delaware River Basing have a larger than desirable degree of uncertainty.

Table B1-4: National Number of Participants in Wildlife Viewing in the Delaware River Basin (DRB) in 2000

Home State	2000 State Population (18 & over)	Number of Survey Respondents	Number of Respondents with Last Recreational Viewing Trip to the DRB: Total	Number of Respondents with Last Recreational Viewing Trip to the DRB: % of Survey Respondents	Extrapolated Number of Participants in Recreational Viewing in the DRB	Number of Recreational Viewing Trips to the DRB by Last Trip Participants	Average Number of Recreational Viewing Trips per Respondent	Extrapolated Number of Recreational Viewing Trips in the DRB
CT	2,563,877	159	1	0.6%	N/A	1	1.0	N/A
DC	457,067	35	2	5.7%	N/A	3	1.5	N/A
DE	589,013	51	14	27.5%	161,690	112	8.0	1,293,519
FL	12,336,038	662	2	0.3%	N/A	2	1.0	N/A
IN	4,506,089	300	1	0.3%	N/A	2	2.0	N/A
MD	3,940,314	257	12	4.7%	183,984	21	1.8	321,971
NC	6,085,266	407	1	0.2%	N/A	1	1.0	N/A
NJ	6,326,792	346	15	4.3%	274,283	75	5.0	1,371,414
NY	14,286,350	774	4	0.5%	73,831	5	1.3	92,289
OH	8,464,801	650	1	0.2%	N/A	1	1.0	N/A
PA	9,358,833	742	52	7.0%	655,875	151	2.9	1,904,560
VA	5,340,253	389	5	1.3%	68,641	9	1.8	123,553
WI	3,994,919	299	1	0.3%	N/A	1	1.0	N/A
Total		**5,071**	**111**		**1,418,303**	**384**	**3**	**5,107,307**

Source: Survey of National Demand for Water-Based Recreation (U.S. EPA 1994b)
N/A: EPA did not extrapolate sample-based results due to insufficient number of observations.

Chapter B2: Technical and Economic Descriptions of In Scope Facilities of the Delaware Estuary Transition Zone

This chapter presents additional information related to in scope facilities within the Delaware Estuary transition zone. Section B2-1 presents detailed EIA data on the generating units (Salem, Hope Creek, Edge Moor, and Deepwater) addressed by this case study and within the scope of the Phase II rulemaking (i.e., in-scope facilities). Section B2-2 describes the configuration of the intake structure(s) at the in-scope facilities and out-of-scope electric generating and industrial facilities. For the in-scope power facilities, Section B2-3 presents an evaluation of the specific impacts of the proposed Phase II rule, i.e., defines the baseline for calculating benefits.

CHAPTER CONTENTS

B2-1 OPERATIONAL PROFILE

a. Salem

During 1999, the Salem power plant operated three active units.[1] Two of these are large nuclear units that use cooling water withdrawn from the Delaware River (Units 1 and 2). The third unit is a small gas turbine (GT3). The nuclear units began operation in June 1977 and October 1981, respectively.

Salem's total net generation in 1999 was 16.0 million MWh. Unit 1 accounted for 8.0 million MWh, or 50.2 percent of the plant's total, while Unit 2 accounted for 7.9 million MWh or 49.8 percent. The capacity utilization of these two nuclear units was 78.1 percent and 77.6 percent, respectively.

Table B2-1 presents details for Salem's three units.

Table B2-1: Salem Generator Characteristics (1999).

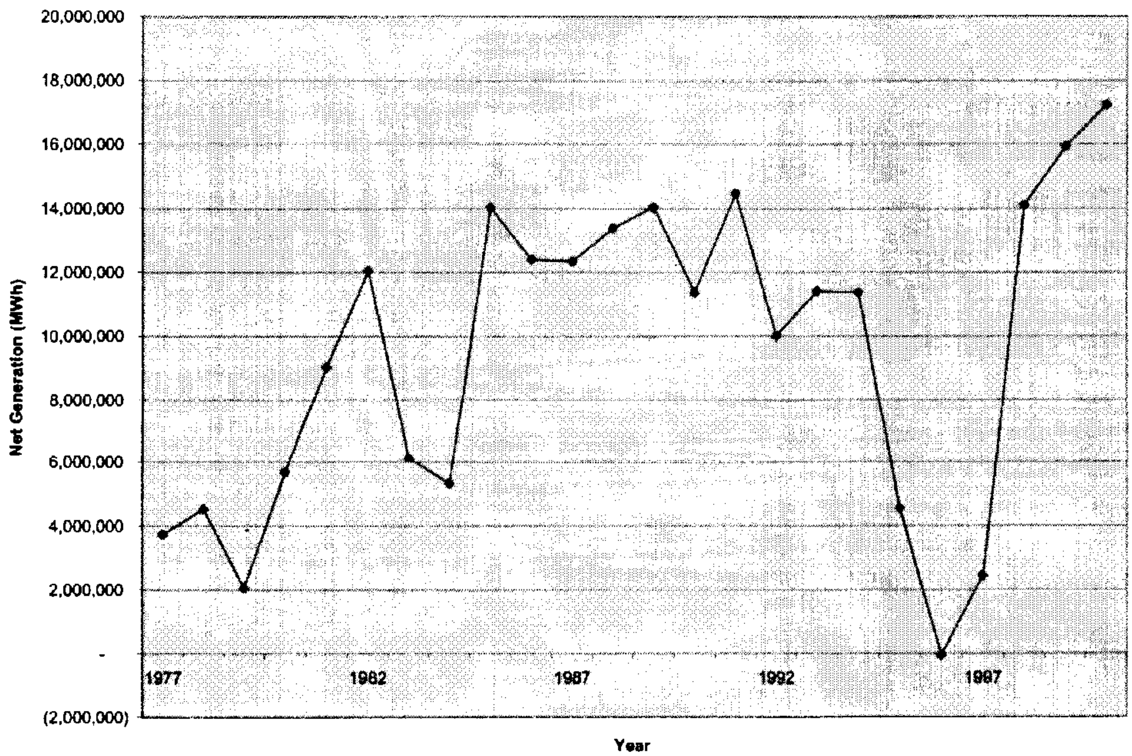
Unit ID	Capacity (MW)	Prime Mover[a]	Energy Source[b]	In-Service Date	Operating Status	Net Generation (MWh)	Capacity Utilization[c]	ID of Associated CWIS
1	1,170	NP	UR	Jun. 1977	Operating	8,009,172	78.1%	SA1
2	1,170	NP	UR	Oct. 1981	Operating	7,949,387	77.6%	SA2
GT3	42	GT	FO2	Jun. 1971	Operating	2,752	0.8%	Not applicable
Total	**2,382**					**15,961,311**	**76.5%**	

[a] Prime mover categories: NP = nuclear power; GT = gas turbine.
[b] Energy source categories: UR = Uranium; FO2 = No. 2 Fuel Oil.
[c] Capacity utilization was calculated by dividing the unit's actual net generation by the potential net generation if the unit ran at full capacity all the time (i.e., capacity * 24 hours * 365 days).
Source: U.S. Department of Energy, 2001a, 2001b, 2001d.

[1] For the purposes of this analysis, "active" units include generating units that are operating, on standby, on cold standby, on test, on maintenance/repairs, or out of service (all year). Active units do not include units that are on indefinite shutdown or retired.

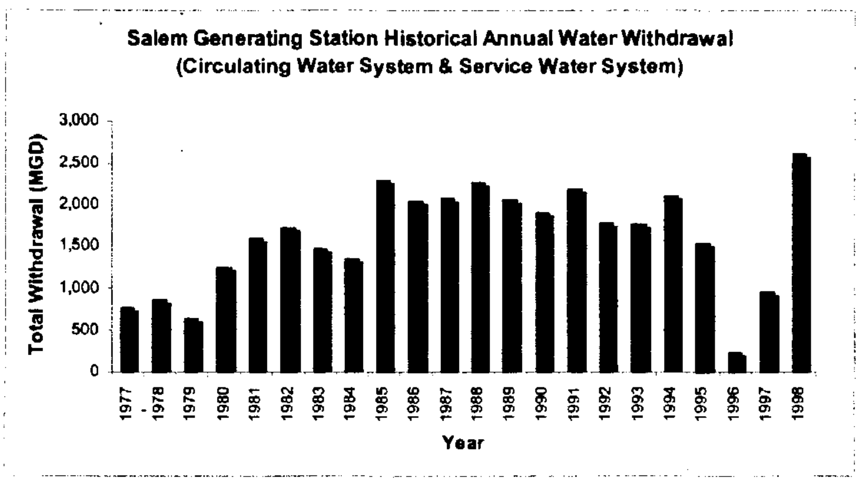
Figure B2-1 below presents Salem's electricity generation history between 1977 and 2000 and Figure B2-2 presents Salem's operational intake flows. Figure B2-1 shows that since 1982, when both of Salem's nuclear units were fully operational, Salem's generation has ranged between 10 and 18 million MW. During two periods, however, 1983-1984 and 1995-1996, Salem's generation was considerably lower. During 1995, Unit 1 was operating at only 26.0 percent while Unit 2 was operating at 20.8 percent. Both nuclear units were shut down during 1996, and during 1997, Unit 2 resumed generation at 25.5 percent of capacity while Unit 1 remained shut down (U.S. Department of Energy, 2002).

Figure B2-1: Salem Net Electricity Generation 1977 - 2000 (in MWh)



Source: U.S. Department of Energy, 2001d.

Figure B2-2: Salem Operational Intake Flows 1977 - 1998 (in MGD)



Year	Total Withdrawal (MGD)
1977	758
1978	858
1979	644
1980	1,254
1981	1,598
1982	1,713
1983	1,462
1984	1,336
1985	2,298
1986	2,040
1987	2,082
1988	2,267
1989	2,056
1990	1,903
1991	2,184
1992	1,778
1993	1,763
1994	2,109
1995	1,529
1996	227
1997	949
1998	2,612

Source: PSEG, 2001f.

b. Hope Creek

Hope Creek operates one active nuclear unit. The unit began operation in November 1986 and uses cooling water withdrawn from the Delaware River. Hope Creek's total net generation in 1999 was 7.7 million MWh with a capacity utilization of 75.1 percent.

Table B2-2 presents details for Hope Creek's unit.

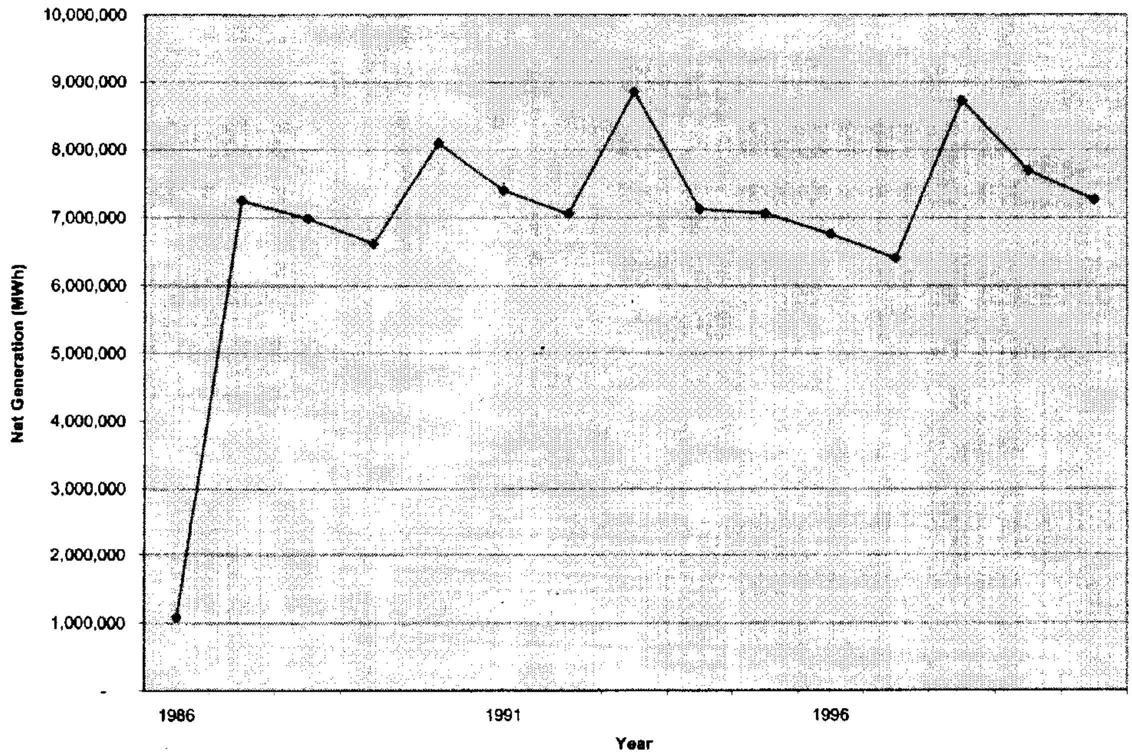
Table B2-2: Hope Creek Generator Characteristics (1999)

Unit ID	Capacity (MW)	Prime Mover[a]	Energy Source[b]	In-Service Date	Operating Status	Net Generation (MWh)	Capacity Utilization[c]	ID of Associated CWIS
1	1,170	NB	UR	Nov. 1986	Operating	7,701,078	75.1%	HC1
Total	**1,170**					**7,701,078**	**75.1%**	

[a] Prime mover categories: NB = nuclear.
[b] Energy source categories: UR = uranium.
[c] Capacity utilization was calculated by dividing the unit's actual net generation by the potential net generation if the unit ran at full capacity all the time (i.e., capacity * 24 hours * 365 days).
Source: U.S. Department of Energy, 2001a, 2001b.

Figure B2-3 below presents Hope Creek's electricity generation history between 1986 and 2000. The graph shows that Hope Creek's generation has been relatively stable since its first full year of operation in 1987, ranging between 6.5 and 9 million MW, with a capacity utilization of between 64 and 86 percent.

Figure B2-3: Hope Creek Net Electricity Generation 1986 - 2000 (in MWh)



Source: U.S. Department of Energy, 2001d.

c. Edge Moor

During 1999, the Edge Moor power plant operated four active units. Three of these units employ a steam-electric prime mover (Units 3 and 4 are coal-fired, Unit 5 is oil-fired) and use cooling water withdrawn from the Delaware River while Unit 10 is a gas turbine. All active units were built between December 1954 and August 1973. Two additional steam-electric units, Units 1 and 2, were retired during July 1983.

Edge Moor's total net electricity generation in 1999 was 2.2 million MWh. The oil-fired steam-electric unit accounted for 1.2 million, or 54 percent, of this total. The two coal-fired steam-electric units accounted for a combined 1.0 million, or 45 percent. The capacity utilization of Edge Moor's steam-electric units ranged from 30.7 percent to 49.3 percent.

Table B2-3 presents details for Edge Moor's four active and two retired units.

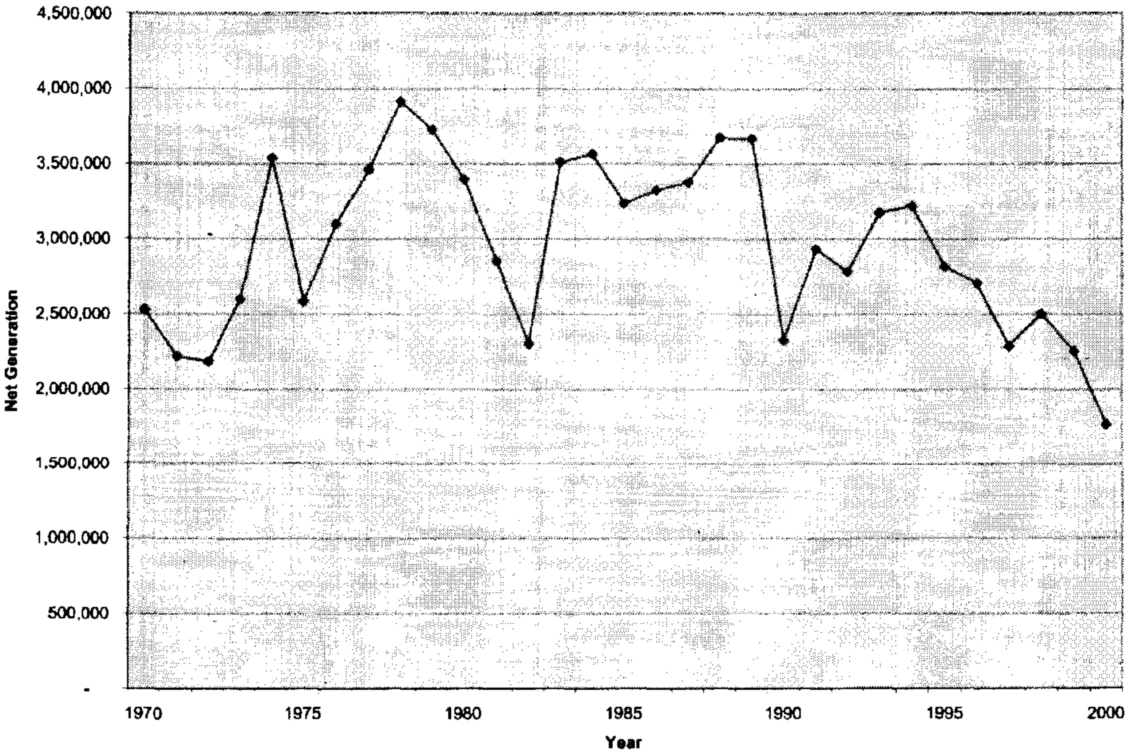
Table B2-3: Edge Moor Generator Characteristics (1999).

Unit ID	Capacity (MW)	Prime Mover[a]	Energy Source[b]	In-Service Date	Operating Status	Net Generation (MWh)	Capacity Utilization[c]	ID of Associated CWIS
1	69	ST	FO6	Jun. 1951	Retired - Jul. 1983			
2	69	ST	FO6	Jul. 1951	Retired - Jul. 1983			
3	75	ST	BIT	Dec. 1954	Operating	278,410	42.4%	3
4	177	ST	BIT	Apr. 1966	Operating	763,383	49.3%	4
5	446	ST	FO6	Aug. 1973	Operating	1,201,164	30.7%	5
10	13	GT	FO2	Jun. 1963	Operating	662	0.6%	Not applicable
Total[d]	**710**					**2,243,619**	**36.1%**	

[a] Prime mover categories: ST = steam turbine, GT = gas turbine.
[b] Energy source categories: FO6 = No. 6 Fuel Oil, BIT = Bituminous Coal, FO2 =No. 2 Fuel Oil.
[c] Capacity utilization was calculated by dividing the unit's actual net generation by the potential net generation if the unit ran at full capacity all the time (i.e., capacity * 24 hours * 365 days).
[d] Total only includes units that are operating.
Source: U.S. Department of Energy, 2001a, 2001b, 2001d.

Figure B2-4 below presents Edge Moor's electricity generation history between 1970 and 2000. Edge Moor's generation has varied considerably during this time period, ranging from a high of almost 4 million MWh to a low of less than 1.8 million. The closure of Units 1 and 2 in 1983 does not seem to have affected Edge Moor's electricity generation profile between 1970 and 2000.

Figure B2-4: Edge Moor Net Electricity Generation 1970 - 2000 (in MWh)



Source: U.S. Department of Energy, 2001d.

d. Deepwater

During 1999, the Deepwater power plant operated four active units: Units 1, 4, 6, and GTA. Each unit has a steam-electric prime mover and uses cooling water withdrawn from the Delaware River; while Unit GTA is a gas turbine. All active units were built between May 1930 and April 1967. In addition, three steam-electric units were retired between June 1991 and July 1994 (Units 3, 5, and 7).

Deepwater's total net generation in 1999 was approximately 0.36 million MWh. Unit 6 accounted for 0.32 million MWh, or 87 percent, of this total. Unit 1 was shut down for five months during 1999 but accounted for most of the remaining 10.5 percent of total net generation. The capacity utilization of Deepwater's active operating units ranged from 4.6 percent (Unit 1) to 39.2 percent (Unit 6). Unit 4 was on cold standby during 1999 and had a capacity utilization rate of 0.1 percent.

Table B2-4 presents details for Deepwater's four active and three retired units.

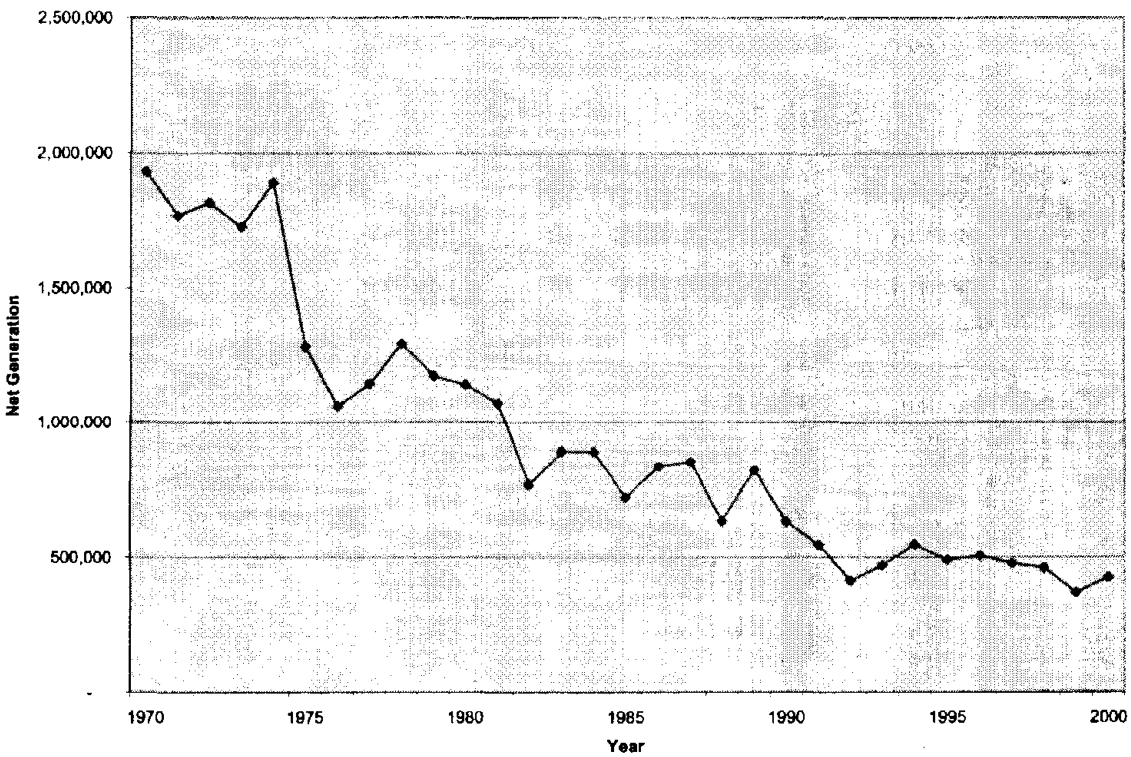
Table B2-4: Deepwater Generator Characteristics (1999).

Unit ID	Capacity (MW)	Prime Mover[a]	Energy Source[b]	In-Service Date	Operating Status	Net Generation (MWh)	Capacity Utilization[c]	ID of Associated CWIS
3	53	ST	FO6	Mar. 1930	Retired - Jun. 1991			
5	20	ST	BIT	Mar. 1942	Retired - Jul. 1994			
7	27	ST	BIT	May 1957	Retired - Jul. 1994			
4	53	ST	FO6	May 1930	Cold Standby	664	0.1%	4
6	92	ST	BIT	Dec. 1954	Operating	315,683	39.2%	4
1	96	ST	NG	Dec. 1958	Operating	38,262	4.6%	1
GTA	19	GT	NG	Apr. 1967	Operating	9,787	5.9%	Not applicable
Total[d]	**260**					**364,396**	**16.0%**	

[a] Prime mover categories: ST = steam turbine, GT = gas turbine.
[b] Energy source categories: FO6 = No. 6 Fuel Oil, BIT = Bituminous Coal, NG = natural gas.
[c] Capacity utilization was calculated by dividing the unit's actual net generation by the potential net generation if the unit ran at full capacity all the time (i.e., capacity * 24 hours * 365 days).
[d] Total only includes units that are operating.
Source: U.S. Department of Energy, 2001a, 2001b, 2001d.

Figure B2-5 below presents Deepwater's electricity generation history between 1970 and 2000. The graph shows that Deepwater's electricity generation has steadily declined throughout the 30-year time period. The considerable decline in the mid-1970s may partly be explained by the construction of two new large nuclear facilities in the region. *Three Mile Island* began operation of an 872 MW unit in 1974. A second unit of 961 MW began operation in December of 1978. In addition, *Calvert Cliffs* began operation of a 918 MW unit in 1975 and of a second, 911 MW, unit in 1977. These modern baseload plants may have displaced some of the generation of older, less efficient plants like Deepwater.

Figure B2-5: Deepwater Net Electricity Generation 1970 - 2000 (in MWh)



Source: U.S. Department of Energy, 2001d.

B2-2 CWIS Configuration and Water Withdrawal

This section describes clean water intake structure technologies at power generating and industrial facilities in the Delaware River Transition Zone. In addition to the 4 in-scope power generating facilities, PSE&G's Logan Generating Station and Conectiv's Hay Road Generating Station are located in the Transition Zone. The Logan Generating Station withdraws only 2 million gallons per day (MGD) from the Delaware River and has fine mesh wedgewire screens on the intake structure. The Hay Road Station withdraws only 1.6 MGD and has a wet, closed cycle cooling system. EPA does not have information on the design of the intake structure at Hay Road or three industrial facilities, SPI Polyols, Citisteel, and Sun Refining, also in the Transition Zone. Each of the industrial facilities has intake flows of less than 10 MGD. The combined intake flows for the three industrial facilities (about 12 MGD) represented only about 0.4 percent of the total cooling water intake flow. For purposes of estimating damages, EPA has assumed that Hay Road and three industrial facilities have conventional traveling screens.

a. Salem

PSE&G's Salem Generating Station has twelve separate intake bays in the Delaware River, six bays each for Generating Units 1 and 2. Prior to 1979, Salem Unit 1 had conventional (linkbelt) traveling screens designed for intermittent operation and debris handling. In 1979, Ristoph traveling screens with 3/8 inch mesh were installed on the Unit 1 intakes. The screens were designed for continuous rotation with fish handling and return systems. When Unit 2 came on-line in 1981, its intakes were designed with the same Ristoph screen system as Unit 1. Salem's screen and fish handling and return systems were most recently modified in 1994-95 to enhance fish survival. Both the screens and the fish baskets are now constructed of smooth materials with curved lips on the 10-foot long fish baskets. A low pressure spray is used to remove organisms followed by a high pressure spray to remove remaining debris. Fish and debris washed from the screens are returned to the river through bi-directional troughs on the north or south side of the intake structure depending upon the direction of tidal flow.

Under the conditions of the facility's 1994 NPDES permit reissuance, the operator has been required to restore a minimum of 10,000 acres of formerly diked wetlands and/or wetlands dominated by *Phragmites Australis*. Upland buffer can also count towards the 10,000 acre total at a 3:1 ratio. This has been ongoing since 1995. In addition, the permit requires the facility to construct a minimum of five fish ladders on the Delaware River tributaries to restore spawning runs of two species of river herring, namely alewife and blueback herring (steeppass ladder design). The permit also requires the operator to pursue the study of sound deterrents.

b. Hope Creek

PSE&G's Hope Creek Nuclear Generating station has a natural draft cooling tower system. Water is withdrawn from the Delaware River at Artificial Island just north of Salem, 20 feet from the shore. The cooling water intake structure consists of: (1) trash racks and trash rake, (2) curtain wall, and (3) four conventional traveling screens. Each screen is continuously rotated and baskets have troughs on the lower lips. A 20 pound per square inch (psi) low pressure wash is used to remove organisms followed by a 90 psi high pressure wash for debris removal. The average intake flow at the facility is 62 MGD to replace losses from evaporation and drift and the discharge of cooling tower blowdown.

c. Edge Moor

Conectiv's Edge Moor Power Plant withdraws water from the Delaware River. Since 1983, the cooling water intake structure has consisted of trash racks followed by traveling screens. Units 3 and 4 have a total of five 9.5 mm, dual flow traveling screens rotated intermittently. Unit 5 has 7 conventional traveling screens and one dual flow screen that are rotated intermittently once every 8 hours. Organisms and debris are washed off the screens with 80-120 psi sprays into a trough and then returned to the River. The total design capacity of the cooling water intake structures is about 782 MGD, which is also the approximate volume of water withdrawn from the river.

d. Deepwater

Conectiv's Deepwater Generating Station obtains cooling water make-up from three intake bays in the Delaware River at the Delaware Memorial Bridge. The average intake flow at the facility is 104.6 MGD from the river. The 3 intake bays supply water to Generating Units 1, 4, and 6. As noted above, Unit 4 was on cold standby as of 1999 with only minimal generation and intake requirements. Water is withdrawn through an intake structure (or intake crib) which is located approximately 75 feet off shore. Each intake is equipped with a single bay and trash racks. The intake water passes through submerged pipes that are located eight feet (bottom elevation) below mean low water on the shoreline bulkhead opposite the intake crib. The space between the face of the bulkhead and the back of the intake crib forms a discharge canal that is parallel to the river and open at both ends. The intake water then passes through on-shore conventional traveling screens where there are two screens for each unit. The screens are not rotated on a continuous basis. The screens are equipped with a debris removal system and return sluice.

e. Chambers Works

Dupont's Chambers Works facility has a dedicated intake structure co-located with the Deepwater Generating Station's offshore intakes in Delaware River at the Delaware Memorial Bridge. The intake consists of angled bar screens and two modified traveling screens. The screens are stainless steel wire mesh with 6.4 mm openings and lip troughs. Organisms removed by the low pressure spray are collected and returned to the river through a fiberglass fish sluice that is not submerged. Therefore, any surviving organisms returned to the surface waterbody via the return system would experience a drop in gravity prior to reaching the water surface. The operator can provide flow augmentation, as needed, to the fish sluice. The screens are rotated and cleaned once every 8 hours. The average intake flow is 37 MGD from the River.

f. Delaware City Refinery

Motiva's Delaware City Refinery withdraws water from the Delaware River via Cedar Creek. Cedar Creek is essentially an intake canal, used primarily for non-contact cooling. The facility's cooling water intake structure is located at the terminus of Cedar Creek approximately one mile from the river. The cooling water intake structure consists of a trash rack followed by 9 vertical traveling screens located in front of the circulating water pumps. Six screens have 3/8 inch mesh and the other three are 3/16 inch mesh. During summer, each screen is rotated once every 8 hours for 30 minutes. During winter, screen rotation occurs once per day. Organisms and fish are washed off the screen with a 70 psi spray into 6 inch deep trough. The trough flows back into Cedar Creek about 1,000 feet downstream from the intake. The facility has a small cooling tower on-site. However, the recirculating flow is minimal compared to the overall intake flow. The average intake flow is 364 MGD from Cedar Creek.

g. Dupont Chemical and Pigment

The Dupont Chemical and Pigment Department facility has one cooling water intake structure that provides make-up for two non-contact, once through cooling systems as well as process water for facility operations. The intake is located 180 feet offshore in the Delaware River. The intake has vertical, conventional single entry/exit traveling screen and fish/debris conveyance trough. The design capacity of the intake is 33.8 MGD. The average intake flow is 7 MGD from the river.

h. General Chemical Corporation

General Chemical Corporation's Delaware Valley facility has an intake structure located along the Delaware River shoreline. The structure is dedicated to facility cooling operations and consists of trash racks and conventional vertical traveling screens. The average intake flow is 33.9 MGD from the river.

Chapter B3: Evaluation of I&E Data

Although 20 years of I&E data are available for the Salem facility, I&E data for other CWIS of the transition zone are limited. Thus, to evaluate the potential cumulative impacts of all transition zone CWIS, EPA extrapolated Salem's I&E rates to other transition zone facilities, as described in this chapter. Section B3-1 lists fish and shellfish species that are impinged and entrained by CWIS of the transition zone, Section B3-2 summarizes the life histories of the primary species impinged and entrained, Section B3-3 describes the methods PSEG used to estimate I&E at Salem, Section B3-4 presents estimates of annual impingement at Salem, and Section B3-5 presents estimates of annual entrainment at Salem. Section B3-6 outlines the methods used by EPA to extrapolate Salem's I&E rates to other transition zone CWIS, Section B3-7 presents impingement extrapolations, Section B3-8 presents entrainment extrapolations, and Section B3-9 summarizes the cumulative I&E impacts of CWIS of the transition zone.

CHAPTER CONTENTS

B3-1 Transition Zone Species Vulnerable to I&E

EPA evaluated all fishery species known to be impinged or entrained by the Salem facility and other CWIS of the transition zone, including commercial, recreational, and forage species. Table B3-1 lists these species and the categories used by the Salem facility in their assessment of these species for their 1999 Permit Renewal Application (see F-4 Table 1 of Appendix F). Species names in bold indicate those fishery species considered by Salem to be "representative important species" (RIS) for assessment purposes. All other species were classified by Salem as non-RIS species.

Several federally listed T&E species are occasionally impinged at these facilities, including shortnose sturgeon (*Acipenser brevirostrum*), green sea turtle (*Chelonia mydas*), Kemp's ridley turtle (*Lepidochelys kempii*), and loggerhead sea turtle (*Caretta caretta*). However, biological assessments conducted by the U.S. Nuclear Regulatory Commission and the National Marine Fisheries Service indicated that populations of these T&E species are not being jeopardized, and therefore potential losses of these species were not considered by PSEG in Salem's 1999 Application (PSEG, 1999c). Because of the lack of I&E data on these species, EPA was unable to evaluate potential CWIS impacts on them.

Table B3-1: Aquatic Species Vulnerable to I&E by CWIS in the Transition Zone. Names in Bold Are Species Designated as RIS by the Salem Facility (see F-4 Table 1 of Appendix F of the 1999 Salem Permit Renewal Application).

Common Name	Scientific Name	Commercial	Recreational	Forage
Alewife	***Alosa pseudoharengus***	X		
American eel	*Anguilla rostrata*	X	X	
American shad	***Alosa sapidissima***	X	X	
Atlantic cod	*Gadus morhua*		X	

Table B3-1: Aquatic Species Vulnerable to I&E by CWIS in the Transition Zone (cont.). Names in Bold Are Species Designated as RIS by the Salem Facility (see F-4 Table 1 of Appendix F of the 1999 Salem Permit Renewal Application).

Common Name	Scientific Name	Commercial	Recreational	Forage
Atlantic croaker	***Micropogonias undulatus***	X	X	
Atlantic herring	*Clupea harengus*		X	
Atlantic menhaden	*Brevoortia tyrannus*	X		
Atlantic silverside	*Menidia menidia*	X		
Atlantic sturgeon	*Acipenser oxyrinchus oxyrinchus*			X
Banded killifish	*Fundulus diaphanus diaphanus*			X
Bay anchovy	***Anchoa mitchilli***			X
Black crappie	*Pomoxis nigromaculatus*			X
Black drum	*Pogonias cromis*	X	X	
Black sea bass	*Centropristis striata*	X	X	
Blackcheek tonguefish	*Symphurus plagiusa*			X
Blue crab	***Callinectes sapidus***	X	X	
Blue runner	*Caranx crysos*			X
Blueback herring	***Alosa aestivalis***		X[a]	X
Bluefish	*Pomatomus saltator*	X	X	
Bluegill	*Lepomis macrochirus*			X
Bluespotted sunfish	*Enneacanthus gloriosus*			X
Brown bullhead	*Ameiurus nebulosus*		X	
Butterfish	*Peprilus triacanthus*	X		
Channel catfish	*Ictalurus punctatus*		X[a]	
Common carp	*Cyprinus carpio carpio*	X		
Conger eel	*Conger oceanicus*		X	
Crevalle jack	*Caranx hippos*			X
Cusk-eel	*Lepophidium spp.*			X
Eastern silvery minnow	*Hybognathus regius*			X
Feather blenny	*Hypsoblennius hentzi*			X
Florida pompano	*Trachinotus carolinus*		X	
Fourspine stickleback	*Apeltes quadracus*			X
Fringed flounder	*Etropus crossotus*			X
Gizzard shad	*Dorosoma cepedianum*	X		
Goosefish	*Lophius americanus*	X		
Hake	*Urophycis spp.*	X	X	
Harvestfish	*Peprilus alepidotus*			X
Herring	*Alosa spp.*		X	
Hogchoker	*Trinectes maculatus*			X
Inland silverside	*Menidia beryllina*			X
Jack	*Caranx hippos*		X	
King mackerel	*Scomberomorus cavalla*		X	
Largemouth bass	*Micropterus salmoides*			X
Lined seahorse	*Hippocampus erectus*			X
Minnows	*Fundulus spp.*			X
Mud sunfish	*Acantharchus pomotis*			X

Table B3-1: Aquatic Species Vulnerable to I&E by CWIS in the Transition Zone (cont.).
Names in Bold Are Species Designated as RIS by the Salem Facility
(see F-4 Table 1 of Appendix F of the 1999 Salem Permit Renewal Application).

Common Name	Scientific Name	Commercial	Recreational	Forage
Mummichog	*Fundulus heteroclitus heteroclitus*			X
Naked goby	*Gobiosoma bosci*			X
Northern kingfish	*Menticirrhus saxatilis*		X	
Northern pipefish	*Syngnathus fuscus*			X
Northern puffer	*Sphoeroides maculatus*		X	
Northern searobin	*Prionotus carolinus*		X	
Orange filefish	*Aluterus schoepfii*		X	
Oyster toadfish	*Opsanus tau*	X	X	
Permit	*Trachinotus falcatus*			X
Pigfish	*Orthopristis chrysoptera*		X	
Pipefish	*Syngnathus spp.*			X
Planehead	*Stephanolepis hispidu*			X
Pollock	*Pollachius pollachius*		X	
Pumpkinseed	*Lepomis gibbosus*			X
Rainbow smelt	*Osmerus mordax mordax*			X
Red hake	*Urophycis chuss*	X	X	
Redfin pickerel	*Esox americanus americanus*			X
Rough silverside	*Membras martinica*			X
Sandbar shark	*Carcharhinus plumbeus*		X[a]	X
Scup	*Stenotomus chrysops*		X	
Sea lamprey	*Petromyzon marinus*			X
Searobins	*Triglidae*		X	
Sheepshead minnow	*Cyprinodon variegatus varieg*		X	
Shrimp	*Gammarus spp.*			X
Shrimp	*Neomysis spp.*			X
Silver perch	*Bairdiella chrysoura*		X	
Silversides	*Membras/Menidia spp.*	X		
Skilletfish	*Gobiesox strumosus*			X
Smallmouth bass	*Micropterus dolomieui*			X
Smooth dogfish	*Mustelus canis*			X
Spanish mackerel	*Scomberomorus maculatus*		X	
Spot	***Leiostomus xanthurus***	X	X	
Spotted hake	*Urophycis regia*		X	
Spotted seatrout	*Cynoscion nebulosus*		X	
Striped anchovy	*Anchoa hepsetus*			X
Striped bass	***Morone saxatilis***	X	X	
Striped cusk-eel	*Ophidion marginatum*			X
Striped killifish	*Fundulus majalis*			X
Striped mullet	*Mugil cephalus*		X	
Striped searobin	*Prionotus evolans*		X	
Summer flounder	*Paralichthys dentatus*	X	X	
Tautog	*Tautoga onitis*	X	X	

Table B3-1: Aquatic Species Vulnerable to I&E by CWIS in the Transition Zone (cont.).
Names in Bold Are Species Designated as RIS by the Salem Facility
(see F-4 Table 1 of Appendix F of the 1999 Salem Permit Renewal Application).

Common Name	Scientific Name	Commercial	Recreational	Forage
Tessellated darter	*Etheostoma olmstedi*			X
Threespine stickleback	*Gasterosteus aculeatus aculeatus*			X
Warmouth	*Lepomis gulosus*			X
Weakfish	***Cynoscion regalis***	X	X	
White catfish	*Ictalurus catus*		X[a]	
White crappie	*Pomoxis annularis*			X
White mullet	*Mugil curema*			X
White perch	***Morone americana***	X	X	
White sucker	*Catostomus commersoni*			X
Windowpane	*Scophthalmus aquosus*	X	X[a]	
Winter flounder	*Pleuronectes americanus*		X	
Yellow bullhead	*Ictalurus natalis*		X	
Yellow perch	*Perca flavescens*			X

[a] Designated as being in the recreational fishery at family level only.
Sources: PSEG, 1999c, Attachment 4, Table 1, NMFS, 2001a, NMFS, 2001b.

B3-2 Life Histories of Primary Species Impinged and Entrained

Life history characteristics of the primary species impinged or entrained at the Salem facility are summarized in the following sections. The species described are those with the highest I&E rates at Salem (presented below in Sections 3.4 and 3.5).

Alewife *(Alosa pseudoharengus)*

Alewife is a member of the herring family, Clupeidae, and ranges along the Atlantic coast from Newfoundland to North Carolina (Scott and Crossman, 1998). Alewife tend to be more abundant in the mid-Atlantic and along the northeastern coast. They are anadromous, migrating inland from coastal waters in the spring to spawn. Adult alewife overwinter along the northern continental shelf, settling at the bottom in depths of 56 to 110 m (184 ft to 361 ft) (Able and Fahay, 1998). Adults feed on a wide variety of food items, while juveniles feed mainly on plankton (Waterfield, 1995).

Alewife has been introduced to a number of lakes to provide forage for sport fish (Jude et al., 1987b). Ecologically, alewife is an important prey item for many fish, and commercial landings of river herring along the Atlantic coast have ranged from a high of 33,974 metric tons (74.9 million pounds) in 1958 to a low of less than 2,268 metric tons (5 million pounds) in recent years (Atlantic States Marine Fisheries Commission, 2000b).

Spawning is temperature-driven, beginning in the spring as water temperatures reach 13 to 15 °C, and ending when they exceed 27 °C (Able and Fahay, 1998). Spawning takes place in the upper reaches of coastal rivers, in slow-flowing sections of slightly brackish or freshwater.

Females lay demersal eggs in shallow water less than 2 m (6.6 ft) deep (Wang and Kernehan, 1979). They may lay from 60,000 to 300,000 eggs at a time (Kocik, 2000). The demersal eggs are 0.8 to 1.27 mm (0.03 to 0.05 in) in diameter. Larvae hatch at a size of approximately 2.5 to 5.0 mm (0.1 to 0.2 in) total length (Able and Fahay, 1998). Larvae remain in the upstream spawning area for some time before drifting downstream to natal estuarine waters. Juveniles exhibit a diurnal vertical migration in the water column, remaining near the bottom during the day and rising to the surface at night (Fay et al., 1983c). In the fall, juveniles move offshore to nursery areas (Able and Fahay, 1998).

Maturity is reached at an age of 3 to 4 years for males, and 4 to 5 years for females (Able and Fahay, 1998). The average size at maturity is 265 to 278 mm (10.4 to 10.9 in) for males and 284 to 308 mm (11.2 to 12.1 in) for females (Able and Fahay, 1998). Alewife can live up to 8 years, but the average age of the spawning population tends to be 4 to 5 years (Waterfield, 1995; PSEG, 1999c).

ALEWIFE
(Alosa pseudoharengus)

Family: Clupeidae (herrings).

Common names: River herring, sawbelly, kyak, branch herring, freshwater herring, bigeye herring, gray herring, grayback, white herring.

Similar species: Blueback herring.

Geographic range: Along the western Atlantic coast from Newfoundland to North Carolina.[a]

Habitat: Wide-ranging, tolerates fresh to saline waters, travels in schools.

Lifespan: May live up to 8 years.[b,c]

Fecundity: Females may lay from 60,000 to 300,000 eggs at a time.[d]

Food source: Small fish, zooplankton, fish eggs, amphipods, mysids.[e]

Prey for: Striped bass, weakfish, rainbow trout.

Life stage information:

Eggs: demersal
- Found in waters less than 2 m (6.6 ft) deep.[d]
- Are 0.8 to 1.27 mm (0.03 to 0.05 in) in diameter.[f]

Larvae:
- Approximately 2.5 to 5.0 mm (0.1 to 0.2 in) at hatching.[f]
- Remain in upstream spawning area for some time before drifting downstream to natal estuarine waters.

Juveniles:
- Stay on the bottom during the day and rise to the surface at night.[g]
- Emigrate to ocean in summer and fall.[f]

Adults: anadromous
- Reach maturity at 3-4 years for males and 4-5 years for females.[f]
- Average size at maturity is 265-278 mm (10.4-10.9 in) for males and 284-308 mm (11.2-12.1 in) for females.[f]
- Overwinter along the northern continental shelf.[f]

Location:
- Range along the western Atlantic coast from Newfoundland to North Carolina.
- Some landlocked populations exist in the Great Lakes and smaller lakes.

[a] Scott and Crossman, 1998.
[b] PSEG, 1999c.
[c] Waterfield, 1995.
[d] Kocik, 2000.
[e] Wang and Kernehan, 1979.
[f] Able and Fahay, 1998.
[g] Fay et al., 1983c.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

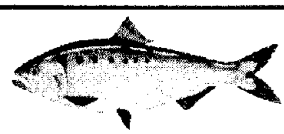
American shad (*Alosa sapidissima*)

American shad is a member of the herring family, Clupeidae. American shad ranges from the Gulf of St. Lawrence, Canada, south to Florida, and are most abundant from Connecticut to North Carolina (Able and Fahay, 1998). An anadromous species, American shad migrate inland to spawn in natal rivers. Suitable American shad spawning habitat has declined over the years because of degradation in water quality and the construction of dams blocking natal spawning grounds (Atlantic States Marine Fisheries Commission, 2000b). Though still commercially and recreationally an important species, the economic importance of American shad has declined in the last century with its decreased abundance (Wang and Kernehan, 1979).

Spawning generally takes place from mid-April through early June, when water temperatures reach 12 °C (Able and Fahay, 1998). The slightly demersal eggs may hatch in 12 to 15 days at 12 °C (54 °F) and in 6 to 8 days at 17 °C (63 °F) (Wang and Kernehan, 1979; Able and Fahay, 1998). Larvae hatch at 5 to 10 mm (0.2 to 0.4 in) , and are pelagic for 2 to 3 weeks. At 25 to 28 mm, shad become juveniles (Able and Fahay, 1998), and will remain in riverine habitats through the first summer, gradually dispersing downstream (Able and Fahay, 1998). Emigration from estuarine habitats to marine waters occurs in the fall, and is triggered by decreasing water temperatures. Young-of-year are approximately 75 to 125 mm (3.0 to 4.9 in) at this point (Able and Fahay, 1998).

At 1 year, juveniles reach approximately 120 mm (4.7 in). Males tend to mature at 3 to 5 years, while females mature at 4 to 6 years (Able and Fahay, 1998). Mortality rates vary according to spawning grounds. Over half of the American shad that spawn in the Hudson River survive spawning migration and return to spawn again the following year (Wang and Kernehan, 1979), compared to less than 5 percent in the Delaware River (Wang and Kernehan, 1979).

American shad have a potential lifespan of up to 11 years (Carlander, 1969), but generally do not live longer than 8 years (PSEG, 1999c).



AMERICAN SHAD
(Alosa sapidissima)

Family: Clupeidae (herrings).

Common names: Shad, Atlantic shad, white shad.

Similar species: Atlantic herring, alewife, blueback herring, Atlantic menhaden.

Geographic range: Atlantic coast from the St. Lawrence River to Florida.[a] May migrate more than 12,000 miles during their average lifespan.

Habitat: Marine waters, returning to inland tributaries and streams to spawn.

Lifespan: Generally up to 8 years.[b]

Fecundity: Females can lay over 600,000 eggs, as several hovering males fertilize them.[c]

Food source: Primarily plankton feeders, while at sea they feed on plankton, small crustaceans, and small fishes.

Prey for: Sea lamprey, striped bass, bluefish.

Life stage information:

***Eggs:** slightly demersal*
- Shad move far enough upstream for the eggs to drift downstream and hatch before reaching saltwater.
- The eggs mature rapidly and transform into young fish in 3 to 4 weeks.

***Larvae:** pelagic*
- Larvae hatch out at 5 to 10 mm (0.2 to 0.4 in) and are pelagic for 2 to 3 weeks.[d]

Juveniles:
- The young-of-year remain in fresh to brackish water until early fall before entering the sea. Some juveniles do not enter the sea and instead overwinter in deep holes near the mouth of the bay.

***Adults:** anadromous*
- American shad are anadromous and do not feed during their return migration.

Location:
- Inshore and offshore. Atlantic coast from the St. Lawrence River to Florida. Spends most of its life at sea in large schools. It only enters the freshwater river in which it was born to spawn.
- American shad may migrate more than 1,000 miles during their average life span of five years at sea. They enter the bay from January to June between the ages of 4 and 6 to spawn in the freshwater and low-salinity tributaries.

[a] Able and Fahay, 1998.
[b] PSEG, 1999c.
[c] Walburg, 1960.
[d] Able and Fahay, 1998.
Fish graphic from State of Maine Department of Marine Resources, 2001a.

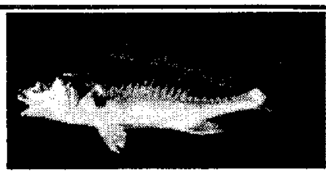
Atlantic croaker (*Micropogonias undulatus*)

The Atlantic croaker is a member of the drum family Sciaenidae. Its distribution ranges from Massachusetts to the Gulf of Mexico along the Atlantic coast, with the greatest abundance from Chesapeake Bay to Florida (Able and Fahay, 1998; Desfosse et al., 1999). Populations of Atlantic croaker fluctuated over the last century, showing high levels in the 1940's, then declining sharply in the 1950's and 1960's (Joseph, 1972). Numbers remained low until the mid-1970's and steadily increased since then (Wang and Kernehan, 1979). Commercial landings in Delaware were reported as low as 0.1 metric tons (220 lb) in 1988, increasing to 6.7 metric tons (14,770 lb) in 1999 (Personal Communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, Maryland, March 26, 2001).

As a bottom-feeding fish, the Atlantic croaker feeds mainly on worms, crustaceans, and fish (Atlantic States Marine Fisheries Commission, 2000a). It can tolerate a wide range of salinities ranging from freshwater to 70 ppt (Able and Fahay, 1998). Spawning occurs offshore from September through December along the continental shelf between Delaware Bay and Cape Hatteras (Morse, 1980a; Able and Fahay, 1998).

Female fecundity along the mid-Atlantic coast ranges from 100,800 to 1,742,000 eggs in females from 196 to 390 mm (7.7 to 15.4 in) in total length (Morse, 1980a). Atlantic croaker larvae enter Delaware Bay in fall and spend the winter over the continental shelf. Young croaker use the estuary as a nursery area in late winter, spring, and summer. Larvae are most abundant in September-October and juveniles are most abundant in October-January. Young-of-year leave the offshore shelf waters for inshore estuaries beginning in October, at lengths of 8 to 20 mm (0.3 to 0.8 in) (Able and Fahay, 1998). Young-of-year are often found over soft mud bottoms at water temperatures between 9.5 and 23.2 °C (49.1 and 73.8 °F), and tend to overwinter in deeper areas of the same habitats (Cowan and Birdsong, 1995). By age 1, individuals in the Delaware Bay have reached lengths of 135 to 140 mm (Able and Fahay, 1998). In the fall, age 1 individuals leave their overwintering estuaries to migrate offshore and south for their second winter (Able and Fahay, 1998).

Maturity begins at lengths of 140 to 170 mm (5.5 to 6.7 in), as Atlantic croaker approach 2 years (White and Chittenden, 1977). Atlantic croaker is a relatively short-lived species, living to a maximum age of 2 to 4 years in the Mid-Atlantic Bight (White and Chittenden, 1977). Adults tend to be less than 200 mm (7.9 in) long south of Cape Hatteras (North Carolina), although they can reach more than 350 mm (13.8 in). Individuals north of Cape Hatteras are generally larger (White and Chittenden, 1977).



ATLANTIC CROAKER
(Micropogonias undulatus)

Family: Sciaenidae (drums).

Common names: Corvina, hardhead, king billy, roncadina, and grumbler.

Similar species: Red drum, weakfish, spotted seatrout, spot.

Geographic range: From Massachusetts to the Gulf of Mexico along the western Atlantic coast, with the greatest abundance from Chesapeake Bay to Florida.[a,b]

Habitat: Usually found over mud and sandy mud bottoms in coastal waters and estuaries.[b]

Lifespan: Croaker generally live for 2-4 years.[c]

Fecundity: Females may lay between 100,800 to 1.74 million eggs.[d]

Food source: Croaker are opportunistic bottom-feeders that consume a variety of invertebrates (mysid shrimp, copepods, marine worms) and occasionally fish.

Prey for: Striped bass, flounder, shark, spotted seatrout, other croaker, bluefish, and weakfish.

Life stage information:

Eggs: *weakly demersal*
- Develop offshore.

Larvae:
- Larvae are most abundant in September-October.[e]

Juveniles:
- Young-of-year migrate to inshore estuaries in the fall, and tend to overwinter in relatively deep areas with soft mud bottoms.
- Juvenile croaker leave estuaries in the fall to spend their second winter offshore.

Adults:
- Maturity begins at approximately 140-170 mm (5.5 to 6.7 in).[c]
- May reach over 350 mm (13.8 in).[c]

Location:
- New Jersey to the Gulf of Mexico and the Western Atlantic Coast. Most abundant between the Chesapeake Bay and Florida.
- Adult croaker generally spend the spring and summer in estuaries and move offshore and south along the Atlantic coast in the fall.
- Prefer muddy bottoms and depths less than 120 m.
- Euryhaline species — able to tolerate a wide range of salinities.

[a] Desfosse et al., 1999.
[b] Froese and Pauly, 2001.
[c] White and Chittenden, 1977.
[d] Morse, 1980a.
[e] Able and Fahay, 1998.
Fish graphic from South Carolina Department of Natural Resources, 2001.

Atlantic menhaden (*Brevoortia tyrannus*)

The Atlantic menhaden, a member of the Clupeidae (herring) family, is a euryhaline species, occupying coastal and estuarine habitats. It is found along the Atlantic coast of North America, from Maine to northern Florida (Hall, 1995). Adults congregate in large schools in coastal areas; these schools are especially abundant in and near major estuaries and bays. They consume plankton, primarily diatoms and dinoflagellates, which they filter from the water through elaborate gill rakers. In turn, menhaden are consumed by almost all commercially and recreationally important piscivorous fish, as well as by dolphins and birds (Hall, 1995).

The menhaden fishery, one of the most important and productive fisheries on the Atlantic coast, is a multimillion-dollar enterprise (Hall, 1995). Menhaden are considered an "industrial fish" and are used to produce products such as paints, cosmetics, margarine (in Europe and Canada), and feed, as well as bait for other fisheries. Landings in New England declined to their lowest level of approximately 2.7 metric tons (5,952 lb) in the 1960s because of overfishing. Since then, landings have varied, ranging from approximately 240 metric tons (529,100 lb) in 1989 to 1,069 metric tons in 1998 (Personal Communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, Maryland, March 19, 2001).

Atlantic menhaden spawn year round at sea and in larger bays (Scott and Scott, 1988). Spawning peaks during the southward fall migration and continues throughout the winter off the North Carolina coast. There is limited spawning during the northward migration and during summer months (Hall, 1995). The majority of spawning occurs over the inner continental shelf, with less activity in bays and estuaries (Able and Fahay, 1998).

Females mature just before age 3, and release buoyant, planktonic eggs during spawning (Hall, 1995). Atlantic menhaden annual egg production ranges from approximately 100,000 to 600,000 eggs for fish age 1 to age 5 (Dietrich, 1979). Eggs are spherical and between 1.3 to 1.9 mm (0.05 to 0.07 in) in diameter (Scott and Scott, 1988).

Larvae hatch after approximately 24 hours and remain in the plankton. Larvae hatched in offshore waters enter the Delaware Estuary 1 to 2 months later to mature (Hall, 1995). Juveniles then migrate south in the fall, joining adults off North Carolina in January (Hall, 1995). Water temperatures below 3 °C (37 °F) kill the larvae, and therefore larvae that fail to reach estuaries before the fall are more likely to die than those arriving in early spring (Able and Fahay, 1998). Larvae hatchout at 2.4 to 4.5 mm (0.09 to 0.18 in). The transition to the juvenile stage occurs between 30 and 38 mm (1.2 and 1.5 in) (Able and Fahay, 1998). The juvenile growth rate in some areas is estimated to be 1 mm (0.04 in) per day (Able and Fahay, 1998).

During the fall and early winter, most menhaden migrate south off of the North Carolina coast, where they remain until March and early April. They avoid waters below 3 °C, but can tolerate a wide range of salinities from less than 1 percent up to 33-37 percent (Hall, 1995). Sexual maturity begins at age 2, and all individuals are mature by age 3 (Scott and Scott, 1988).

Adult fish are commonly between 30 and 35 cm (11.8 and 13.8 in) in length. The maximum age of a menhaden is approximately 7 to 8 years (Hall, 1995), although individuals of 8-10 years have been recorded (Scott and Scott, 1988).

ATLANTIC MENHADEN
(Brevoortia tyrannus)

Family: Clupeidae (herrings).

Common names: menhaden, bunker, fatback, bugfish.

Similar species: Gulf menhaden, yellowfin menhaden.

Geographic range: From Maine to northern Florida along the Atlantic coast.[a]

Habitat: Open-sea, marine waters. Travels in schools.[b]

Lifespan:
- Approximately 7 to 8 years.[a]

Fecundity:
- Females may produce between 100,000 to 600,000 eggs.[c]

Food Source: Phytoplankton, zooplankton, annelid worms, detritus[b]

Prey for: Sharks, cod, pollock, hakes, bluefish, tuna, swordfish, seabirds, whales, porpoises.[b]

Life Stage Information

Eggs: *pelagic*
- Spawning takes place along the inner continental shelf, in open marine waters.[d]
- Eggs hatch after approximately 24 hours.

Larvae: *pelagic*
- Larvae hatch out at sea, and enter estuarine waters 1 to 2 months later.[a]
- Remain in estuaries through the summer, emigrating to ocean waters as juveniles in September or October.[d]

Adults
- Congregate in large schools in coastal areas.
- Spawn year round.[b]

[a] Hall, 1995.
[b] Scott and Scott, 1988.
[c] Dietrich, 1979.
[d] Able and Fahay, 1998.
Fish graphic from South Carolina Department of Natural Resources, 2001.

Atlantic silverside (*Menidia menidia*)

The Atlantic silverside is a member of the silverside family, Atherinidae. Its geographic range extends from coastal waters of New Brunswick to northern Florida (Fay et al., 1983c), but it is most abundant between Cape Cod and South Carolina (Able and Fahay, 1998). Atlantic silversides inhabit sandy seashores and the mouths of inlets (Froese and Pauly, 2001). Silversides are an important species of forage fish, eaten by valuable fishery species such as striped bass (*Morone saxatilis*), bluefish (*Pomatomus salatrix*), weakfish (*Cynoscion regalis*), and Atlantic mackerel (*Scomber scombrus*) (Fay et al., 1983c; McBride, 1995).

Atlantic silversides spawn in the upper intertidal zone during spring and summer. Spawning appears to be stimulated by new and full moons, in association with spring tides. On average, females produce 4,500 to 5,000 demersal eggs per spawning season, which may include four to five separate spawning bouts (Fay et al., 1983c). The eggs are 0.9 to 1.2 mm (0.04 to 0.05 in) in diameter. Larvae range in size from 5.5 to 15.0 mm (0.2 to 0.6 in) (Fay et al., 1983c). The sex of Atlantic silversides is determined during the larval stage, at approximately 32 to 46 days after hatching. Water temperatures between 11 and 19 °C (52 and 66 °F) produce significantly more females, whereas temperatures between 17 and 25 °C (63 and 77 °F) produce significantly more males (Fay et al., 1983c).

Juveniles occur in estuaries during the summer months, occupying intertidal creeks, marshes, and shore zones of bays and estuaries. Silversides typically migrate offshore in the winter (McBride, 1995). In studies of seasonal distribution in Massachusetts, all individuals left inshore waters during winter months (Able and Fahay, 1998).

The diet of juveniles and adults consists of copepods, mysids, amphipods, cladocerans, fish eggs, squid, worms, molluscs, insects, algae, and detritus (Fay et al., 1983c). Atlantic silversides feed in large schools, preferring gravel and sand bars, open beaches, tidal creeks, river mouths, and marshes (Fay et al., 1983c).

Silversides live for only 1 or 2 years, usually dying after completing their first spawning (Fay et al., 1983c). Adults can reach sizes of up to 15 cm (5.9 in) in total length (Froese and Pauly, 2001).

ATLANTIC SILVERSIDE
(Menidia menidia)

Family: Atherinidae (silversides).

Common names: Spearing, sperling, green smelt, sand smelt, white bait, capelin, shiner.[a]

Similar species: Inland silverside (*Menidia beryllina*).[a]

Geographic range: New Brunswick to northern Florida[a]

Habitat: Sandy seashores and the mouths of inlets.[b]

Lifespan: One or 2 years. Often die after their first spawning.[a]

Fecundity: Females produce an average of 4,500 to 5,000 eggs per spawning season.[a]

Food Source: Zooplankton, fish eggs, squid, worms, molluscs, insects, algae, and detritus.[a]

Prey for: Striped bass, bluefish, weakfish, and Atlantic mackerel.[a,c]

Life Stage Information

Eggs: *demersal*
- Found in shallow waters of estuarine intertidal zones.[a]
- Can be found adhering to submerged vegetation.[a]

Larvae:
- Range from 5.5 to 15.0 mm (0.2 to 0.6 in) in size.[a]
- Sex is determined during the larval stage by the temperature regime. Colder temperatures tend to produce more females, and warmer temperatures produce more males.[a]

Adults:
- Overwinter in offshore marine waters.[d]
- Can reach sizes of up to 15 cm (5.9 in) total length.[d]

[a] Fay et al., 1983c.
[b] Froese and Pauly, 2001.
[c] McBride, 1995.
[d] Able and Fahay, 1998.
Fish graphic from Government of Canada, 2001.

Bay anchovy *(Anchoa mitchilli)*

Bay anchovy is a member of the anchovy family, Engraulidae, and is one of the most abundant species in estuaries along the Atlantic and Gulf coasts of the United States (Vouglitois et al., 1987). In Delaware Bay, bay anchovy shares the status of most abundant species with the Atlantic silverside (de Sylva et al., 1962). Because of its widespread distribution and overall abundance, bay anchovy are an important component of the food chain for recreational and commercial fish, and as such have indirect economic importance (Morton, 1989).

Bay anchovy is commonly found in shallow tidal areas, feeding mainly on copepods and other zooplankton. It tends to appear in higher densities in vegetated areas such as eelgrass beds (Castro and Cowen, 1991).

The spawning period of bay anchovy is long, with records ranging from April to November (Vouglitois et al., 1987). In the Delaware Estuary, the spawning season usually occurs from early April through mid-June (Wang and Kernehan, 1979). Spawning within the Delaware Estuary primarily occurs in the western part of the C & D Canal, and in the Elk River (Wang and Kernehan, 1979) (see Figure B1-1), and has been correlated with areas of high zooplankton abundance (Dorsey et al., 1996). In Chesapeake Bay, a minimum of 50 spawning events per female was estimated, with spawning events occurring every 4 days in June and every 1.3 days in July. Spawning generally occurs nocturnally, and during peak spawning periods females may spawn nightly. Fecundity estimates for bay anchovy in mid-Chesapeake Bay were reported at 643 eggs in July 1986 and 731 eggs in July 1987 (Zastrow et al., 1991). The pelagic eggs are 0.8 to 1.3 mm (0.03 to 0.05 in) in diameter (Able and Fahay, 1998). Size of the eggs varies with increased water salinity.

Eggs hatch in approximately 24 hours at average summer temperatures (Monteleone, 1992). The yolk sac larvae are 1.8 to 2.0 mm (0.07 to 0.08 in) long, with nonfunctioning eyes and mouth parts (Able and Fahay, 1998). Mortality during these stages is high. In a study conducted in the Chesapeake Bay, 73 percent of the eggs died before hatching, and mortality for surviving larvae was 72 percent within the first 24 hours of hatching (Dorsey et al., 1996).

Growth estimates for larval bay anchovy have been estimated at 0.53 to 0.56 mm (0.021 to 0.022 in) per day in Great South Bay, New York (Castro and Cowen, 1991), and young-of-year growth rates averaged 0.47 mm (0.02 in) per day in Chesapeake Bay (Zastrow et al., 1991). Sexual maturity occurs at a length of 40 to 45 mm (1.6 to 1.8 in) in Chesapeake Bay

(Zastrow et al., 1991). Individuals hatched early in the season may become sexually mature by their first summer (Morton, 1989).

Most young-of-year migrate out of the estuaries at the end of the summer in schools, and can be found in large numbers on the inner continental shelf in the fall (Vouglitois et al., 1987). The average size for adults is 75 mm (2.95 in) (Morton, 1989). Bay anchovy live for only 1 or 2 years (Zastrow et al., 1991).

Near the Salem station, bay anchovy eggs are present from May to November and are most abundant from May to August. Larvae are present from May to October, with greatest abundance from June to August. Juveniles are present throughout the year but are most abundant from July to October. Adults are also present year-round and are most abundant from April to November.

BAY ANCHOVY
(Anchoa mitchilli)

Family: Engraulidae (anchovies).

Common names: Anchovy.

Similar species: Atlantic silverside.

Geographic range: From Maine, south to the Gulf of Mexico.[a]

Habitat: Commonly found in shallow tidal areas with muddy bottoms and brackish waters; often appears in higher densities in vegetated areas such as eelgrass beds.[b]

Lifespan: 1-2 years.[c]

Fecundity: Females spawn a minimum of 50 times over the spawning season in the Chesapeake Bay. Fecundity per spawning event is about 700 eggs.[c]

Food source: Primarily feed on copepods and other zooplankton, as well as small fishes and gastropods.[b]

Prey for: Striped bass, weakfish, jellyfish.

Life stage information:

***Eggs:** pelagic*
- Eggs are 0.8-1.3 mm (0.03 to 0.05 in) in diameter.[a]
- Eggs experience an average mortality of 73 percent.[d]

Larvae:
- Yolk-sac larvae are 1.8 to 2.0 mm (0.7 to 0.8 in) on hatching.[a]
- Daily mortality for yolk-sac larvae is as high as 88 percent.[b]
- Daily mortality for 3-15 day old larvae is approximately 28 percent.[b]

Juveniles:
- Young-of-year migrate out of estuaries at the end of summer, and can be found in large numbers on the inner continental shelf in fall.[e]

Adults:
- Adults reach sexual maturity at 40 to 45 mm (1.6 to 1.8 in) in Chesapeake Bay.[c]
- The average adult is 75 mm (2.95 in) long.[f]

Location:
- Ranges from Cape Cod, Massachusetts, south to the Gulf of Mexico. Spawns in the Delaware Estuary in the Elk River and C&D Canal.[g]
- Most commonly found in shallow tidal areas with muddy bottoms and brackish waters, but can be found in a wide range of habitats.
- Tolerates a wide range of salinities.

[a] Able and Fahay, 1998.
[b] Castro and Cowen, 1991.
[c] Zastrow et al., 1991.
[d] Dorsey et al., 1996.
[e] Vouglitois et al., 1987.
[f] Morton, 1989.
[g] Wang and Kernehan, 1979.
Fish graphic from NOAA, 2001a.

Blue crab (*Callinectes sapidus*)

The Atlantic blue crab can be found in Atlantic coastal waters from Long Island to the Gulf of Mexico. Blue crab supports the most economically important inshore commercial fishery in the mid-Atlantic (Epifanio, 1995); Chesapeake Bay provides over 50 percent of the commercial landings of Atlantic blue crab nationwide (Epifanio, 1995).

Females typically mate only once within their lifetime. Spawning in the Delaware Bay peaks from late July to early August. After an elaborate courtship ritual, females lay two to three broods of eggs, each containing over 1 million eggs. Mating occurs in areas of low salinity. The eggs hatch near high tide and the larvae are carried out to sea by the current (Epifanio, 1995). This stage of the lifecycle is called the zoeal stage. The zoea go through seven molts before entering the next stage, the megalops stage, and are carried back to estuarine waters (Epifanio, 1995). The zoea stages last approximately 35 days, and the megalops stage may vary from several days to a few weeks (Epifanio, 1995).

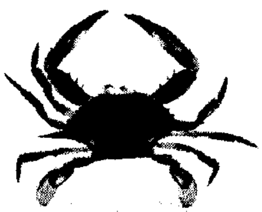
While in the zoeal stage along the continental shelf, larvae are vulnerable to predators, starvation, and transport to unsuitable habitats. Larvae are especially vulnerable to predators while molting. Dispersal of young Atlantic blue crabs is primarily controlled by wind patterns, and they do not necessarily return to their parent estuaries (Epifanio, 1995). In the Delaware Estuary, maturity is reached at approximately 18 months (Epifanio, 1995).

Atlantic blue crabs inhabit all regions of the Delaware Estuary. Males prefer areas of low salinity, while females prefer the mouth of the estuary. In the warmer months, crabs occupy shallower areas in depths of less than 4.0 m (13 ft). They can tolerate water temperatures exceeding 35 °C (95 °F), but do not fare as well in cold water (Epifanio, 1995). In winter months, adults burrow into the bottom of deep channels and remain inactive (Epifanio, 1995). Extremely cold weather has resulted in high mortality of overwintering crabs (Epifanio, 1995).

Atlantic blue crabs are omnivorous, foraging on molluscs, mysid shrimp, small crabs, worms, and plant material (Epifanio, 1995). Adults prey heavily on juvenile Atlantic blue crab (Epifanio, 1995).

Atlantic blue crab can live up to 3 years (Epifanio, 1995).

Impingeable sizes of blue crab are present throughout the year near Salem, but are most abundant from April to November.



ATLANTIC BLUE CRAB
(*Callinectes sapidus*)

Family: Portunidae (swimming crabs).

Common names: Blue crab.

Similar species: Lesser blue crab (*Callinectes similis*).

Lifespan: Up to 3 years. Maturity is reached at 18 months.[a]

Geographic range: Atlantic coast from Long Island to the Gulf of Mexico.[a]

Habitat: Inhabit all areas of the Delaware Estuary. In warmer weather they occupy shallow areas less than 4 m (13 ft) deep. They burrow into the bottom of deep channels and remain inactive in winter.[4]

Fecundity: Typically mate once in their lifetime. Mating occurs in low salinity areas. Females lay two to three broods of 1 million eggs each.[a]

Food Source: Atlantic blue crabs are omnivores, foraging on molluscs, mysids, shrimp, small crabs, worms, and plant material.[a]

Prey for: Juveniles are preyed upon by a variety of fish (eels, striped bass, weakfish) and are heavily preyed upon by adult blue crabs.[a]

Life Stage Information

Eggs:
- Hatch near high tide.[a]

Larvae:
- Carried out to sea by the current, where they remain for seven molts before returning to estuaries.[a]

Adults:
- Males prefer lower salinity while females prefer the mouth of the bay.[a]

[a] Epifanio, 1995.
Graphic from U.S. FDA, 2001.

Blueback herring (*Alosa aestivalis*)

Blueback herring is a member of the herring family, Clupeidae. It is closely related to the alewife; together they are commonly referred to as river herring. The range of blueback herring extends from Nova Scotia south to northern Florida, though they are more abundant in the southern portion of their range (Scott and Scott, 1988). Within the Delaware Estuary, blueback herring tend to be more abundant in the upper region of the estuary than do the closely related alewife (Waterfield, 1995). Economically, blueback herring are an important bait species for the blue crab industry of the Delaware and Chesapeake bays. They are also a significant prey item for many estuarine fish species.

Adults spawn from spring to early summer in upstream brackish or freshwater areas of rivers and tributaries. Spawning occurs at night in fast currents over a hard substrate (Loesch and Lund, 1977). Spawning groups have been observed diving to the bottom and releasing the semi-adhesive eggs over the substrate, but many eggs are dislodged by the current and enter the water column. Loesch and Lund (1977) reported fecundity estimates of 45,800 to 349,700 eggs per female, and noted that fecundity was positively correlated with total fish length up to approximately 300 mm. After spawning, adults move downstream and return to the ocean.

Eggs float near the bottom for 2 to 4 days until hatching, depending on temperature. At hatching, larvae are 3.1 to 5.0 mm (0.12 to 0.20 in) (Jones et al., 1978). Larvae become juveniles at approximately 20 mm (0.79 in), or at 25 to 35 days (Able and Fahay, 1998). Juveniles are distributed high in the water column and avoid bottom depths (Able and Fahay, 1998). In the early juvenile stages, fish are swept downstream by the tide. Some juveniles will move upstream until late summer before migrating downstream in late summer to early fall. Juveniles are sensitive to sudden water temperature changes, and emigrate downstream in response to a decline in temperature (Able and Fahay 1998). By late fall, most young-of-year emigrate to ocean waters to overwinter (Wang and Kernehan, 1979).

Male blueback herring mature at ages 3 to 4, and females mature at ages 4 to 5. Over half of the adults are repeat spawners, returning to natal spawning grounds every year (Scherer, 1972). Females tend to grow larger than males and dominate the older age groups. Blueback herring can live to 8 years (Froese and Pauly, 2001).

Near Salem, blueback herring juveniles are present from winter through late spring and again in fall.

BLUEBACK HERRING
(Alosa aestivalis)

Family: Clupeidae (herrings).

Common names: River herring, glut herring, summer herring, kyak, blackbelly.

Similar species: alewife, American shad, Atlantic menhaden.

Geographic range: From Nova Scotia south to northern Florida.[a]

Habitat: Euryhaline, marine. Adults form schools and overwinter near the bottom out from the coast.[b]

Lifespan: May live up to 8 years.[b]

Fecundity: Fecundity ranges from 45,800 to 349,700 eggs per female.[c] Over half of adults are repeat spawners and return to natal spawning grounds every year.[d]

Food source: Shrimp, zooplankton, finfish.

Prey for: Striped bass, weakfish, bluefish.

Life stage information:

Eggs: *pelagic*
- Eggs float near the bottom for 2-4 days.[c]

Larvae:
- Larvae are 3.1-5.0 mm at hatching.[c]
- The larval stage duration is 25-35 days.[f]

Juveniles:
- Blueback herring reach the juvenile stage at 20 mm (0.79 in), or at an age of 25-35 days.[f]
- Juveniles are distributed high in the water column and avoid bottom depths.
- Juveniles tend to move upstream until late summer before migrating downstream in late summer in response to a decline in temperature.

Adults:
- Males mature at ages 3-4, females at ages 4-5.
- Adults overwinter near the bottom and out from the coast, then return to shore in late spring to spawn.

Location:
- Range from Nova Scotia south to northern Florida.
- More common in upper region of Delaware estuary than the closely related alewife.

[a] Scott and Scott, 1988.
[b] Froese and Pauly, 2001.
[c] Loesch and Lund, 1977.
[d] Scherer, 1972.
[e] Jones et al., 1978.
[f] Able and Fahay, 1998.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Spot (*Leiostomus xanthurus*)

Spot is a member of the drum family, Sciaenidae. Its range extends along the Atlantic coast from Massachusetts Bay to Campeche Bay, Mexico, and it is most abundant from Chesapeake Bay to South Carolina (Hildebrand and Schroeder, 1928; Mercer, 1987). Spot are occasionally harvested for food, but because of their small size, are typically used as bait and in pet food and fish meal (Hales and Van Den Avyle, 1989). Spot are often caught by anglers because they take the bait easily and are often found near piers and bridges (Hales and Van Den Avyle, 1989).

Ecologically they are an important species because of their high abundance and their status on the food chain as both predator and prey for many species. Because of their short lifespan, annual landings tend to consist of a single year class and fluctuate greatly from year to year, yet show no long-term trends (Atlantic States Marine Fisheries Commission, 2000c).

Spawning occurs in deeper waters along the continental shelf from late fall through early spring (Mercer, 1987). Females produce 30,000 to 60,000 eggs (Phillips et al., 1989), and eggs are 0.72-0.87 mm (0.028 to 0.034 in) in diameter (Able and Fahay, 1998). Larvae hatch out at 1.5 to 1.7 mm (0.06 to 0.07 in) in length and begin migrating to inshore estuaries, reaching the nursery estuarine waters in early to late spring. Young larvae show a preference for low salinity waters (Wang and Kernehan, 1979), and continue to migrate to the upper areas of estuaries to spend the summer. By the fall, young-of-year reach 10 to 11 cm (3.9 to 4.3 in) (Able and Fahay, 1998). First year growth rates for spot in Chesapeake Bay have been recorded from 10.5 mm (0.4 in) per month to 19.1 mm (0.8 in) per month (Hildebrand and Schroeder, 1928; McCambridge and Alden, 1984).

As water temperatures decrease in the fall, juveniles emigrate to the ocean in October and November. Larger individuals tend to leave the estuaries earliest. In the Chesapeake Bay, some young-of-year spot have remained in the estuaries throughout the first winter.

Spot are able to avoid heavy competition with Atlantic croaker by occupying different spatial and temporal niches. While Atlantic croaker spawn from October through February in the Delaware Estuary, spot spawn from December through March (Wang and Kernehan, 1979). They share a similar diet, consisting mostly of mysid shrimp, copepods, and marine worms, but spot feed more on burrowing worm species while Atlantic croaker show a preference for worms on the bottom surface (Chao and Musick, 1977).

Spot mature at 2 to 3 years (Atlantic States Marine Fisheries Commission, 2000c). The maximum recorded age for spot is 5 years (Mercer, 1987). The largest recorded spot was 35.6 cm (14.0 in) long, although most mature adults are 17.8 to 20.3 cm (7.0 to 8.0 in) (Atlantic States Marine Fisheries Commission, 2000c).

Spot may be particularly vulnerable to I&E in intake structures because of their slow swimming speeds and low endurance (Hales and Van Den Avyle, 1989). Young spot have significantly lower swimming speeds than most estuarine fishes and cannot maintain their orientation in currents exceeding 15 cm/s. Larger spot have increased swimming capabilities, but may also be vulnerable to I&E because they tend to drift with the currents (Hales and Van Den Avyle, 1989).

SPOT
(Leiostomus xanthurus)

Family: Sciaenidae (drums).

Common names: Spot croaker.

Similar species: Red drum, weakfish, spotted seatrout, Atlantic croaker.

Geographic range: Along the Atlantic coast from Massachusetts Bay to Campeche Bay, Mexico, and most abundant from Chesapeake Bay to South Carolina.[a,b]

Habitat: Often found near piers and bridges.[c] Occurs over sandy or muddy bottoms in coastal waters up to 60 m (197 ft) in depth.[d]

Lifespan: Up to 5 years.[b]

Fecundity: Females produce 30,000 to 60,000 eggs.[c]

Food source: Worms, mysid shrimp, copepods.[f]

Prey for: Striped bass, weakfish, bluefish, flounder, bonito, sandbar shark.

Life stage information:

Eggs: *pelagic*
- Eggs are 0.72-0.87 mm (0.028 to 0.034 in) in diameter.[f]

Larvae:
- Larvae are 1.5-1.7 mm (0.06 to 0.07 in) long at hatching.[e]
- Larvae migrate to inshore estuary waters, arriving in early to late spring.
- Young larvae prefer low salinity waters and are found in upper estuary waters.

Juveniles:
- As water temperature decreases in the fall, most young-of-year spot migrate out to the ocean.
- Larger individuals tend to leave the estuary earlier.

Adults:
- Spot mature at 2-3 years.[h]
- The largest recorded spot was 35.6 cm (14.0 in) long, although most mature adults are 17.8-20.3 cm (7.0 to 8.0 in).[h]

Location:
- Range along the western Atlantic coast from Massachusetts Bay to Campeche Bay, Mexico.
- Found over sandy or muddy bottoms in coastal waters to about 60 m depth.
- Found in nursery and feeding grounds in river estuaries in summer and fall.

[a] Hildebrand and Schroeder, 1928.
[b] Mercer, 1987.
[c] Hales and Van Den Avyle, 1989.
[d] Froese and Pauly, 2000.
[e] Phillips et al., 1989.
[f] Chao and Musick, 1977.
[g] Able and Fahay, 1998.
[h] Atlantic States Marine Fisheries Commission, 2000c.
Fish graphic from South Carolina Department of Natural Resources, 2001.

Striped bass (*Morone saxatilis*)

Striped bass is a member of the temperate bass family, Moronidae. Both migratory and nonmigratory populations span the Atlantic coast, from the St. Lawrence River, Canada, to the St. John's River in Florida (Scott and Scott, 1988). Striped bass has long been an important commercial and recreational species. The perceived decline in striped bass populations was the reason behind the creation of the Atlantic States Marine Fisheries Commission in 1942 (Miller, R.W., 1995). Spawning populations of striped bass were nearly eliminated from the Delaware River in the mid-1900's, because of poor water quality. Pollution in the lower portions of the Delaware River caused a decline in striped bass reproduction due to a decrease in dissolved oxygen for several years, but cleanup efforts in the 1980's and 1990's resulted in improved water quality and increased striped bass reproduction (Chittenden, 1971; Weisberg and Burton, 1993; Miller, R.W., 1995). A moratorium was declared on striped bass fishing in the state of Delaware from 1985 through 1989 (Miller, R.W., 1995). While populations of striped bass have rebounded, the fishery is still managed closely and tight restrictions on size limits and the length of the fishing season are kept to maintain the goals established under Amendment 5 of the Striped Bass Fishery Management Plan of 1995 (Atlantic States Marine Fisheries Commission, 2000g).

Striped bass are a popular catch among recreational anglers; however, consumption advisories are currently in place for striped bass from the Delaware River and Bay as a result of bioaccumulation of PCBs (PSEG, 1999c). These advisories recommend limiting the consumption of striped bass to less than five 267 g (8-oz.) meals per year. A 1997 landings report estimated the yearly catch by recreational and commercial fisheries to be 4.094 million striped bass (Atlantic States Marine Fisheries Commission, 2000d). Angling efforts are typically centered on the C&D canal, from Port Penn to Augustine Beach, Delaware, and in the mouths of tributaries south of the canal (PSEG, 1999c). In the Delaware Bay, there are currently no directed commercial fishing efforts for striped bass, although historically commercial harvesting of striped bass was an important resource (PSEG, 1999c).

Striped bass are common along mid-Atlantic coastal waters. They are an anadromous fish that spend most of the year in saltwater but use the upper fresh and brackish water reaches of estuaries as spawning and nursery areas in spring and summer (Setzler et al., 1980). The principal spawning areas for striped bass along the Atlantic coast are the major tributaries of Chesapeake Bay, and the Delaware and Hudson rivers (NOAA, 2001c). The timing of spawning may be triggered by an increase in water temperature, and generally occurs from April to June (Fay et al., 1983c). Spawning behavior consists of a female surrounded by up to 50 males at or near the surface (Setzler et al., 1980). Eggs are broadcast loosely in the water and fertilized by the males. Females may release an estimated 14,000 to 40.5 million eggs, depending on the size of the female (Jackson and Tiller, 1952). A 23 kg (50 pound) female may produce approximately 5 million eggs (Mansueti and Hollis, 1963).

Striped bass eggs are semibuoyant, and require minimum water velocities to remain buoyant. Eggs that settle to the bottom may become smothered by sediment (Hill et al., 1989). The duration of larval development is influenced by water temperature; temperatures ranging from 24 to 15 °C (75 to 59 °F) correspond to larval durations of 23 to 68 days, respectively (Rogers et al., 1977). Saila and Lorda (1977) reported a 6 percent probability of survival for egg and yolk-sac stages of development, and a 4 percent probability of survival for the post yolk-sac stage.

At 30 mm (1.2 in), most striped bass enter the juvenile stage. Juveniles begin schooling in larger groups after age 2 (Bigelow and Schroeder, 1953). Migratory patterns of juveniles vary with locality (Setzler et al., 1980). In both the Delaware and the Hudson rivers, young-of-year migrate downstream from their spawning grounds to the tidal portions of the rivers to spend their first summer (Able and Fahay, 1998). In the Delaware River, young-of-year may spend 2 or more years within the estuary before joining the offshore migratory population (Miller, R.W., 1995). Similar trends were found in the Hudson River, where individuals were found to stay up to 3 years in estuaries before migrating offshore (Able and Fahay, 1998). Results of tagging studies reported by the Delaware Department of Natural Resources and Environmental Control (DDNREC, 2000) and Public Service Electric and Gas Company (PSEG, 1999c) showed that striped bass tagged in the Delaware Estuary were recaptured from North Carolina to Maine. However, the majority of tagged fish were recovered between Maryland and Massachusetts.

Adult striped bass feed in intervals while schooling (Fay et al., 1983c). They primarily eat smaller fish species such as herring, silversides, and anchovies (Miller, R.W, 1995). Larvae feed primarily on copepods (Miller, R.W, 1995), and stomach contents of juveniles from the Delaware Estuary show mysid shrimp as a favored food item (Bason, 1971).

Adults may live up to 30 years (Atlantic States Marine Fisheries Commission, 2000d), and have been reported at sizes up to 200 cm (79 in) (Froese and Pauly, 2001).

STRIPED BASS
(Morone saxatilis)

Family: Moronidae (temperate basses).

Common names: Striper, rockfish, linesider, and sea bass.[g]

Similar species: White perch.

Geographic range: St. Lawrence River in Canada to the St. Johns River in Florida, and from the Suwannee River in western Florida to Lake Pontchartrain, Louisiana.[a]

Habitat: Juveniles prefer shallow rocky to sandy areas. Adults in inshore areas use a variety of substrates, including rock, boulder, gravel, sand, detritus, grass, moss, and mussel beds.[a]

Lifespan: Adults may reach 30 years.[b]

Fecundity: Females release 14,000 to 40.5 million eggs, depending on the size of the female.[c]

Food sources:
- Larvae feed primarily on mobile planktonic invertebrates (beetle larvae, copepodids *Daphnia* spp.).[a]
- Juveniles eat larger aquatic invertebrates and small fishes.[a]
- Adults are piscivorous. Clupeid fish are the dominant prey and adults prefer soft-rayed fishes.[a]

Prey for: Any sympatric piscivorous fish.[a]

Life stage information:

***Eggs:** pelagic*
- Eggs and newly hatched larvae require sufficient turbulence to remain suspended in the water column; otherwise, they can settle to the bottom and be smothered.[d]

***Larvae:** pelagic*
- Larvae range from 5 to 30 mm (0.2 to 1.2 in).[a]

Juveniles:
- Most striped bass enter the juvenile stage at 30 mm (1.2 in) total length.[d]
- Juveniles school in larger groups after 2 years of age.[d]
- Juveniles in the Delaware River generally remain in estuarine areas for 2 or more years before joining the offshore migratory population.[c]

***Adults*:** Anadromous
- Adults school offshore, but swim upstream to spawn.[f]
- May grow as large as 200 cm (79 in).[g]

Location:
- Estuaries are spawning grounds and nurseries and thus critically important to their life cycle.
- Mature striped bass are found in and around a variety of inshore habitats, including areas off sandy beaches and along rocky shorelines, in shallow water or deep trenches, and in rivers and the open bay.
- St. Lawrence River in Canada to the St. Johns River in Florida, and from the Suwannee River in western Florida to Lake Pontchartrain, Louisiana.
- Migratory behavior is more complex than that of most other anadromous fish. Seasonal movements depend on their age, sex, degree of maturity, and the river in which they were born.
- Mature striped bass move from the ocean into tidal freshwater to spawn in late winter and spring. Spawning generally occurs in April, May, and early June. Shortly after spawning, mature fish return to the coast. Most spend summer and early fall months in middle New England near-shore waters. In late fall and early winter they migrate south off the North Carolina and Virginia capes.

[a] Hill et al., 1989.
[b] Atlantic States Marine Fisheries Commission, 2000d.
[c] Jackson and Tiller, 1952.
[d] Bigelow and Schroeder, 1953.
[e] Miller, R.W, 1995.
[f] Setzler et al., 1980.
[g] Froese and Pauly, 2001.
Fish graphic from NOAA, 2001b.

Weakfish (*Cynoscion regalis*)

Weakfish is a member of the family Sciaenidae (drums), which is considered an important recreational and commercial resource along the Atlantic coast (Seagraves, 1995). Weakfish are found along the eastern seaboard, primarily from Massachusetts Bay to southern Florida (Seagraves, 1995). Adults travel in schools, following a seasonal migratory pattern from offshore wintering grounds in the spring to northern inland estuarine spawning grounds with warming of coastal waters in the spring (Seagraves, 1995). Weakfish spawn in the Delaware Estuary in spring and usually move north as far as Massachusetts for the summer (Shepherd and Grimes, 1984). These same fish over-winter as far south as Cape Hatteras, North Carolina. Weakfish favor shallow waters and sandy bottoms. They typically feed throughout the water column on fish, shrimp, and other small invertebrates (Seagraves, 1995).

Steady declines in weakfish landings since 1980 caused enough concern to prompt the Atlantic States Marine Fisheries Commission to develop a management plan for the species in 1985. In addition, the commission developed three amendments in an attempt to strengthen the management plan; the third amendment called for a 5-year restoration period to bring the weakfish population back to its historical age and size structure. Since 1993, annual landings have steadily increased (Atlantic States Marine Fisheries Commission, 2000f). Weakfish are very popular as a recreational fishing target in Delaware Bay and surrounding coastline. In a survey of Delaware anglers, weakfish was consistently one of the top three species targeted by anglers from 1982 to 1996 (PSEG, 1999c). Recreational catches of weakfish in Delaware and New Jersey comprised greater than 70 percent the coastal recreational weakfish catch since 1995 (PSEG, 1999c).

Spawning occurs shortly after the inshore migration, peaking from late April to June, with some geographic variation in timing. In the fall, an offshore and southerly migration of adults coincides with declining water temperatures (Atlantic States Marine Fisheries Commission, 2000f). Specific spawning time is correlated with the size of the individual; larger fish tend to spawn earlier (Shepherd and Grimes, 1984), often resulting in a bimodal distribution of size in larvae (Able and Fahay, 1998).

Fecundity of female weakfish varies with locality. A 50 cm (20 in) female weakfish from the New York Bight produced about 306,000 ova, while southern weakfish of the same size produced 2.05 million ova. Southern weakfish reproduce until approximately age 5, while northern weakfish can reproduce longer, meaning that lifetime fecundity would be similar (Shepherd and Grimes, 1984). Shepherd and Grimes (1984) found that females may not release all ova during spawning, and fertility may only be 60-75 percent of the estimated potential fecundity.

Weakfish eggs hatch approximately 50 hours after fertilization. The pelagic larvae hatch at 1.5 to 1.7 mm (0.6 to 0.7 in) in length, and move further upstream during the summer months. Though young-of-year are most abundant in estuarine waters, they have been found in coastal ocean waters and as far upstream as freshwater nurseries. Scales begin to form when larvae are approximately 14.3 mm (5.6 in) or 26 days old. Growth rates vary considerably depending on locality, salinity, and water temperature. Weakfish in the Delaware Bay exhibited growth rates from 0.29 mm (0.1 in) per day at 20 °C (68 °F) to 1.49 mm (0.6 in) per day at 28 °C (82 °F) (Able and Fahay, 1998).

In the fall, weakfish less than 4 years of age tend to stay inshore and move southward to inner shelf waters, while older weakfish move southward to offshore areas until the spring (Seagraves, 1995).

As with most fish, size upon maturity for weakfish varies with locality. In northern weakfish, females mature at 25.4 cm (10 in), and males at 22.9 cm (9 in); in southern weakfish, both sexes mature at 17.8 cm (7 in). By age 2, all individuals are fully mature (Atlantic States Marine Fisheries Commission, 2000f). Weakfish may obtain a maximum size and age of approximately 80 cm (31.5 in) and 11 years in the northern part of their range (Shepherd and Grimes, 1983).

Weakfish larvae are most abundant near Salem from June to August (PSEG, 1999c). Juveniles occur in summer and early fall. Eggs are present in some years, primarily in June and July.

WEAKFISH
(Cynoscion regalis)

Family: Sciaenidae (drums).

Common names: Gray/bastard/saltwater trout, silver seatrout, grey/bastard/common/silver weakfish, chickwick, gray/silver, silver seatrout.[a]

Similar species: Red drum, spot, spotted seatrout, Atlantic croaker.

Geographic Range: Along the Atlantic coast from Florida to Massachusetts, in shallow coastal and estuarine waters.[b] Estuaries provide feeding areas and spawning grounds for adult weakfish and are as important as nursery areas are for juveniles.[c]

Habitat: Occurs over sand and sandy mud bottoms in shallow coastal waters.[c]

Lifespan: Can live up to 11 years.[d]

Fecundity: Reach maturity at approximately 1 year. Fecundity for fish in the New York Bight is about 306,000. Females may not release all ova during spawning, meaning that fertility may be only 60-75 percent of total fecundity.[c]

Food source: Juveniles feed primarily on shrimp and other small invertebrates. Adults consume species such as butterfish, herrings, silversides, anchovies, young weakfish, Atlantic croaker, spot, scup, and killifishes.[f]

Prey for: Bluefish, striped bass, summer flounder, and larger weakfish.[f]

Life stage information:

Eggs:
- Hatch approximately 50 hours after fertilization.[c]

***Larvae:** pelagic*
- Larvae are approximately 1.5-1.7 mm (0.6 to 0.7 in) long at hatching.[c]
- Larvae utilize tidal stream transport to move through the water column.[c]

Juveniles:
- Growth rates in the Delaware Bay range from 0.29 mm (0.1 in) per day at 20 °C (68 °F) to 1.49 mm (0.6 in) per day at 28 °C (82 °F).[c]
- Juveniles begin to migrate offshore and southward for overwintering in the fall.[c]

Adults:
- Travel in schools, and migrate seasonally from offshore wintering grounds to northern inland estuarine spawning grounds in the spring.[b]
- Adults can reach a maximum total length of 80 cm (31.5 in).[d]

Location:
- The young use the shore margins of the spawning area as nursery grounds.
- From spring through autumn, white perch are present on flats and in channels, retreating to deep channels in the winter.
- They move into waters with low salinity to freshwaters of large rivers in April through June.
- Located in estuaries and freshwater from Nova Scotia to South Carolina.
- Frequent areas with level bottoms of compact silt, mud, sand, or clay and show little preference for vegetation, structures, or other shelter.
- Able to live in salinities from zero to full strength seawater; they prefer waters < 18 percent salinity.

[a] Froese and Pauly, 2001.
[b] Seagraves, 1995.
[c] Able and Fahay, 1998.
[d] Shephard and Grimes, 1983.
[e] Shephard and Grimes, 1984.
[f] Seagraves, 1995.
Fish graphic from NOAA, 2001b.

White perch (*Morone americana*)

White perch is a member of the temperate bass family, Moronidae. Its geographic range extends from the upper St. Lawrence to South Carolina (Able and Fahay, 1998; Scott and Scott, 1988). Adults can be found in a wide range of habitats, but they prefer shallow water during warmer months (Stanley and Danie, 1983). In the winter months, adults can be found in deeper, saline waters (Beck, 1995b). At the larval stage, white perch feed mainly on plankton. Adults feed on a variety of prey, including shrimp, fish, and crab. Their diet composition changes with seasonal and spatial food availability (Beck, 1995b).

Unlike most other species, white perch has not suffered a drastic population decline in the past century. Because of their abundance, white perch are valuable for commercial fisheries and the recreational fishing industry. Their heartiness and abundance is due to their proliferation, early maturation, ability to utilize a large spawning and nursery ground, and tolerance of poor water quality (Beck, 1995b).

White perch are semi-anadromous, overwintering in deeper estuarine waters and migrating seasonally in the spring to spawn. Spawning occurs from April through early June in shallow waters of upstream brackish and freshwater tributaries. Fecundity estimates are higher for white perch than for other species of similar size, with estimates of 20,000 to 300,000 eggs per female (Stanley and Danie, 1983).

Depending on temperature, larvae hatch out between 2 to 6 days (Able and Fahay, 1998). Larvae are pelagic, remaining slightly below the surface of the water. They enter the juvenile stage in 6 weeks, at 20 to 30 mm (0.8 to 1.2 in) (Able and Fahay, 1998). Juveniles become increasingly demersal with size (Wang and Kernehan, 1979), and school in shallow, inshore waters through the summer. During the fall, juveniles tend to move offshore into more brackish, deeper waters to overwinter (Able and Fahay, 1998).

By age 1, white perch range from 72 to 93 mm (2.8 to 3.7 in). Rates of growth are positively correlated with water temperature during the first year (Able and Fahay, 1998). Most males and females reach maturity at age 2 to 3. Males were reported to mature at 72 mm (2.8 in) and females at 98 mm (3.9 in) (Stanley and Danie, 1983).

Average annual mortality rates for white perch in the Delaware River are 49 to 59 percent for males and 53 to 65 percent for females (Stanley and Danie, 1983). Mortality rates appear to be higher for females because females have higher growth rates and therefore reach a desirable harvest size earlier (Stanley and Danie, 1983). White perch up to 9 years of age have been caught in Delaware Bay (Wallace, 1971).

White perch larvae occur near Salem from April to July, with greatest abundance in April and May (PSEG, 1999c). Juveniles occur from October to May. Adults are present throughout the year.

WHITE PERCH
(Morone americana)

Family: Moronidae, temperate bass.

Common names: White perch.[a]

Similar species: Striped bass.

Geographic range: Estuaries and freshwater from the upper St. Lawrence to South Carolina.[b,c]

Habitat: Occurs in fresh, brackish, and coastal waters, but prefers brackish, quieter waters.[a]

Lifespan: To 17 years (to 9 years in Delaware Bay).

Fecundity: Semi-anadromous spawners. Spawning occurs from April to early June in shallow waters of upstream brackish and freshwater tributaries. Females produce 20,000 to 300,000 eggs.[d]

Food source: White perch feed on zooplankton as larvae and juveniles. Adults primarily consume aquatic insects, but also crustaceans and fish, including their own young.[d]

Prey for: Striped bass, bluefish, weakfish, walleye.[a]

Life stage information:

Eggs: *demersal, semipelagic*
- Hatch out between 2 and 6 days.[b]

Larvae: *pelagic*
- Larvae float slightly below the surface of the water.[b]

Juveniles:
- White perch enter the juvenile stage in 6 weeks, at 20 to 30 mm (0.8 to 1.2 in).[b]
- School in shallow, inshore waters through the summer.[b]
- Move offshore to brackish, deeper waters to overwinter.[b]
- Growth rates are positively correlated with temperature during the first year.[b]

Adults:
- Reach maturity at 2 to 3 years of age, and lengths of 72 mm (2.8 in) for most males and 98 mm (3.9 in) for most females.[d]

[a] Froese and Pauly, 2001.
[b] Able and Fahay, 1998.
[c] Scott and Scott, 1988.
[d] Stanley and Danie, 1983.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

B3-3 Salem I&E Monitoring and PSEG's Methods for Calculating Annual I&E

Salem is the only facility of the four in-scope facilities of the transition zone (Salem, Hope Creek, Deepwater, Edge Moor) that is required to collect I&E data on an on-going basis as part of their New Jersey Pollutant Discharge Elimination System (NJPDES) permit. Some I&E data are available for Hope Creek and Deepwater, but only for very limited time periods. Although Salem's data can be improved upon as discussed later in this chapter, it is one of the most comprehensive I&E data sets in the nation.

PSEG has sampled impinged and entrained organisms at Salem since station operation began in 1977. I&E data for the years 1978-1998 are available in PSEG's 1999 Permit Renewal Application for Salem (PSEG, 1999e). The application consists of 36 volumes of application material and 167 volumes of appendices and reference material. Some aspects of the sampling protocol have changed in response to changing sampling objectives, and details of these changes are outlined in Appendix F, Attachment 1 of the Application (PSEG, 1999c).

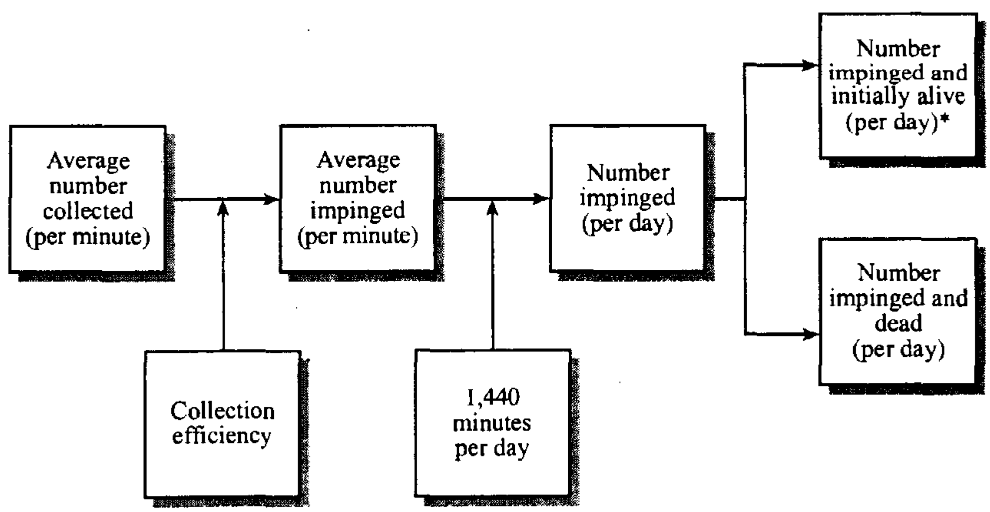
The following sections outline methods used by PSEG to estimate I&E losses based on information in Appendix F, Attachment 1 of the Application (PSEG, 1999c).. The figures outlining monitoring steps and methods for calculating I&E are based on figures from a July 1999 presentation by PSEG to the New Jersey Department of Environmental Protection (NJDEP).

B3-3.1 Impingement Monitoring

PSEG collects impingement samples by diverting screen wash water from an estuary-bound sluice to an impingement sampling pool (PSEG, 1999c, Appendix F, Attachment 1, Section II.D). Fish collected in the sampling pool are sorted by species and counted, and the condition of each specimen (live, dead, or damaged) is noted. The length of each specimen of a sample of each representative important species (RIS) is measured as well as the total weight for all specimens of each species. Information on station operations, sampling details, and environmental conditions is also recorded.

PSEG processes the impingement sampling data in a series of steps to arrive at an estimate of the number of organisms impinged and initially alive, and the number impinged and dead, per day of sampling (PSEG, 1999c, Appendix F, Attachment 2, Section III.D). The steps for processing the impingement data to estimate the number impinged in the cooling water system (CWS) per day of sampling are outlined in Figure B3-1.

Figure B3-1: Estimation of Numbered Impinged (CWS) per Day of Sampling



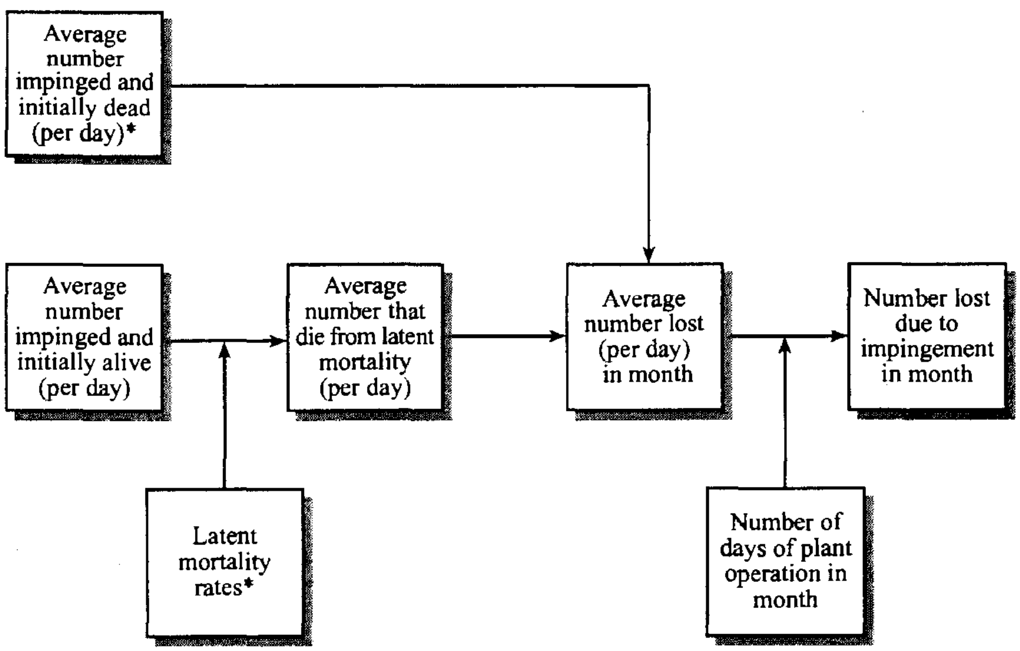
*Prior to 1996, initially alive fish were further classified as damaged or not damaged.

Since the duration of sampling varies from collection to collection, PSEG first standardizes impingement counts to fish counted per minute sampled. The number collected is adjusted by a species-specific collection efficiency factor to estimate the average number impinged per minute (PSEG, 1999c, Appendix F, Attachment 2, Section III.D.3). Factors are based on impingement collection efficiency studies conducted by PSEG from 1979 to 1982 and in 1998 (PSEG, 1999c, Appendix F, Section VI). PSEG's collection efficiency factors are duplicated in Appendix B1of this report.

For each day of impingement sampling, the daily average number of fish sampled per minute is calculated for each species, length interval, and condition (live, dead, damaged). PSEG uses the estimated number of impinged organisms in the CWS per day of sampling to calculate the number lost to impingement in the CWS and in the service water system (SWS) each month (PSEG, 1999c, Appendix F, Attachment 2, Section III.D).

Figure B3-2 outlines the steps involved in calculating the monthly impingement loss estimate for the CWS. To adjust impingement estimates for mortality that may occur after collection, PSEG multiplies the initial survival rate of live or damaged fish by a species-specific latent mortality rate determined from historical data (PSEG, 1999c, Appendix F, Attachment 2, Section III.D.5). Different latent mortality factors are used for impingement samples from old Ristroph screens (1977-1995) and new Ristroph screens (1996-1998). The latent screen mortality factors used by PSEG are duplicated in Appendix B1 of this report. For non-RIS commercial and recreational species, PSEG applied the highest impingement screen mortality observed for the other species, and bay anchovy parameters were applied to non-RIS forage species.

Figure B3-2: Estimation of Number Lost to Impingement (CWS) in Each Month

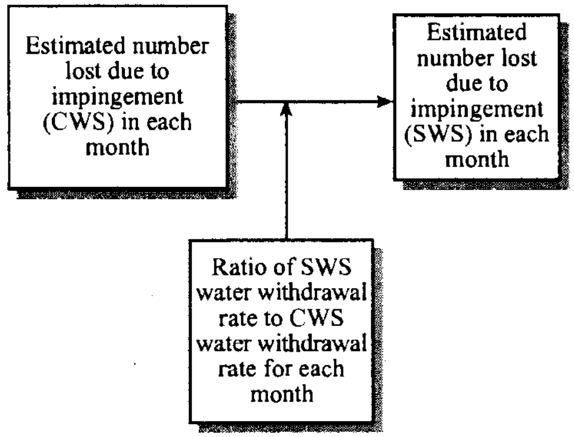


*Latent mortality represents 48 hr holding time, except for original screens (96 hr)

The average number that die from latent mortality per day is added to the average number impinged per day that are initially dead to derive the average number lost per day in each month. This number is then adjusted by the number of days of plant operation per month to determine the total number lost to impingement in the CWS per month. This number is adjusted by the ratio of SWS water withdrawal to CWS water withdrawal for each month to derive an estimate of the number lost to impingement in the SWS each month (Figure B3-3).

Total impingement loss is then calculated for actual flow conditions by species and life stage for each year (PSEG, 1999c, Appendix F, Attachment 2, Section III.D.6).

Figure B3-3: Estimation of Number Lost to Impingement (SWS) in Each Month

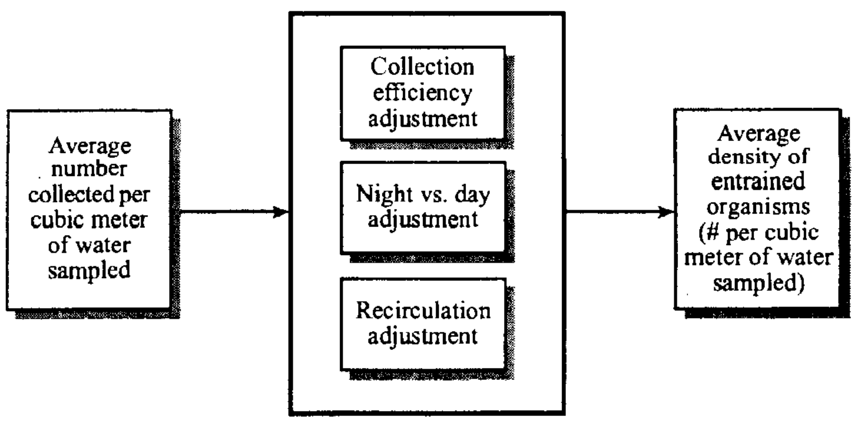


B3-3.2 Entrainment Monitoring

PSEG collects entrainment samples by pumping a volume of water ranging from 50 to 75 m^3 through an abundance net and chamber at 1.0-1.5 m^3/min (PSEG, 1999c, Appendix F, Attachment 1, Section II.C). The net is a 1 m plankton net with 0.5 mm mesh. After sampling, the net is washed and the contents are rinsed into a jar, preserved, and taken to a laboratory for identification and counting. All specimens collected are identified to the lowest practical taxon and life stage. For each sample, total length is measured to the nearest millimeter for a representative subsample of each target species and life stage.

To estimate the density of entrained organisms in the CWS for each day of sampling, PSEG adjusts the average number collected per cubic meter of water sampled by factors for collection efficiency (including net extrusion and net avoidance), time of day of sampling, and potential re-entrainment (Figure B3-4). PSEG's net extrusion and net avoidance factors are duplicated in Appendix B1 of this report. PSEG's uses the average entrainment density for days with sampling to interpolate the density of entrained organisms for days without sampling to arrive at a density for each day of the year.

Figure B3-4: Estimation of Density of Entrained Organisms for Each Day of Sampling (CWS)



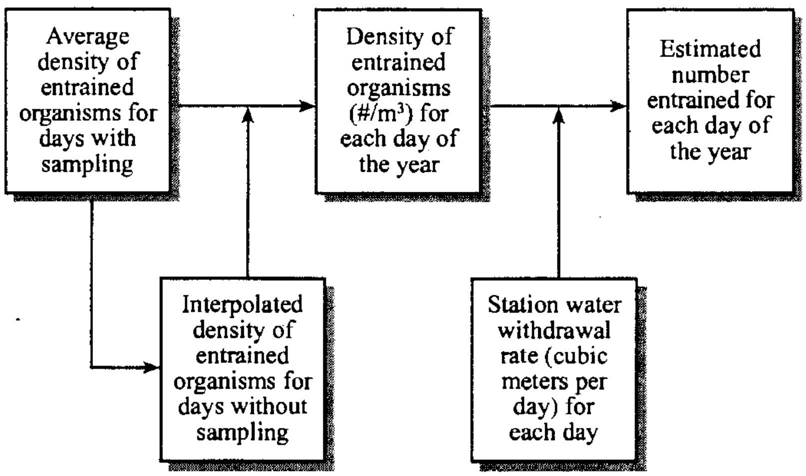
PSEG quantifies collection efficiency related to net extrusion for organisms less than 7 mm in total length by determining the relative probability of capture based on comparison of gear efficiency in the river with gear efficiency in the plant, under the assumption that densities of larvae in the river and plant are equal (PSEG, 1999c, Appendix F, Attachment 2, Section III.C.2.c.i). For organisms longer than 0.5 mm, collection bias associated with net avoidance and vertical stratification is quantified based on paired samples collected at the intake and discharge over a 2 week period in 1980 (PSEG, 1999c, Appendix F, Attachment 2, Section III.C.2.c.ii).

To correct for potential bias resulting from a lack of nighttime sampling from 1982 to 1994, PSEG analyzed sampling data to test for differences among samples taken at different times of day, and developed correction factors to adjust entrainment estimates for species and life stages that showed a statistically significant day/night effect (PSEG, 1999c, Appendix F, Attachment 2, Section III.C.2.b). Day/night correction factors used to estimate historical losses for bay anchovy juveniles, larvae of *Morone* spp., striped bass juveniles, weakfish eggs, and weakfish juveniles are presented in Appendix F, Attachment 2, Table 9 of PSEG (1999c).

Adjustment for potential recirculation of previously entrained organisms (re-entrainment) is based on results of a dye survey conducted in 1998 that indicated that 10 percent of organisms that survive through-plant transport are re-entrained (PSEG, 1999c, Appendix F, Attachment 2, Section III.C.3). PSEG's recirculation factors are duplicated in Appendix B1 of this report.

Once collection numbers are adjusted for collection efficiency, day/night sampling, and potential re-entrainment to derive estimates of daily entrainment, the daily densities are adjusted by the station water withdrawal rate for each day to estimate the total number entrained for each day of the year (Figure B3-5).

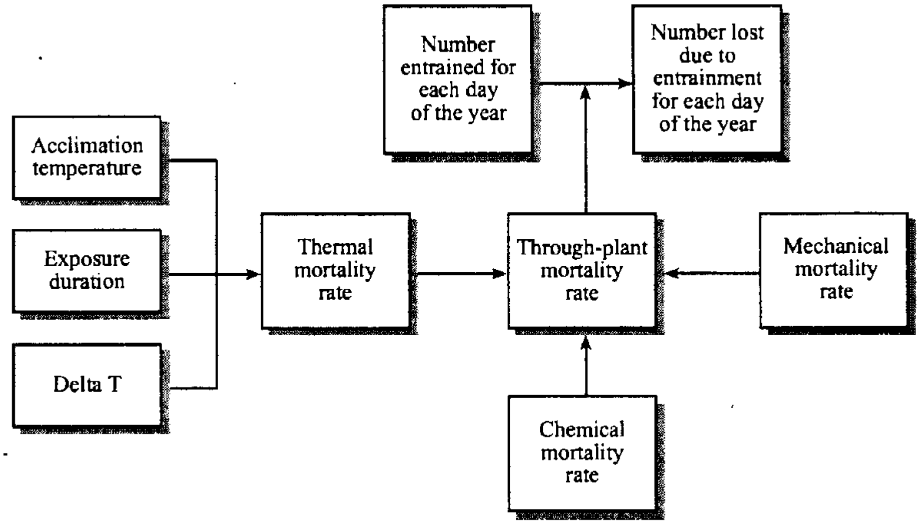
Figure B3-5: Estimation of Daily Number Entrained for Each Day of the Year (CWS)



To estimate the daily number of organisms that are actually killed by CWS entrainment, PSEG adjusts the number entrained for each day of the year by species- and life stage-specific through-plant survival rates estimated from on-site studies, model simulations, and published results of studies at other facilities (Figure B3-6) (PSEG, 1999c, Appendix F, Attachment 2, Section III.C.4).

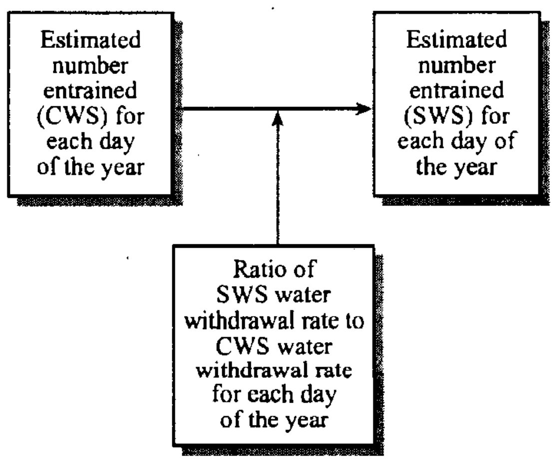
PSEG adjusts entrainment estimates for through-plant mortality resulting from thermal mortality, mechanical mortality, and chemical mortality. Because biocides are not used in the CWS, PSEG assumes that chemical mortality is zero for all species and life stages at Salem (PSEG, 1999c, Appendix F, Attachment 2, Section III.C.4.b). Thermal mortality was modeled as a function of exposure temperature, acclimation temperature, and exposure duration (PSEG, 1999c, Appendix F, Attachment 2, Section III.C.4.c.). Mechanical mortality was estimated based on studies conducted at the Indian Point Generating Station on the Hudson River in the 1980's (EA Engineering, Science, and Technology, 1989) and using data from the 1984 PSE&G 316(b) Demonstration (PSEG, 1999c, Appendix F, Attachment 2, Section III.C.4.a). PSEG's thermal and mechanical mortality factors are duplicated in Appendix B1 of this report. For non-RIS commercial/recreational species, PSEG assumed 100 percent through-plant mortality, and bay anchovy parameters were applied to non-RIS forage species.

Figure B3-6: Estimation of Daily Number Lost to Entrainment (CWS)



The number of organisms entrained in the CWS for each day of the year is adjusted by the ratio of SWS water withdrawal to CWS water withdrawal for each day to derive an estimate of the number lost to entrainment in the SWS each day of the year (Figure B3-7).

Figure B3-7: Estimation of Daily Number Entrained for Each Day of the Year



To obtain an annual entrainment loss estimate, PSEG sums all of the daily estimates over the year (PSEG, 1999c, Appendix F, Attachment 2, Section III.C.5).

B3-3.3 Potential Biases and Uncertainties in PSEG's I&E Estimates

Because of the extensive and complex biological information presented in Salem's 1999 Application, NJDEP contracted with several scientists from ESSA Technologies Ltd. to review and comment on the application (ESSA Technologies, 2000). ESSA Technologies commended PSEG for the thoroughness of the application, but expressed several concerns about potential biases and uncertainties in PSEG's estimates of I&E losses. Bias refers to a potential error in which the direction of the error is known (i.e., an under- or overestimate), whereas uncertainty refers to a potential error with no known directional bias.

ESSA Technologies (2000) identified several aspects of PSEG's sampling program that increased data uncertainties and introduced bias in PSEG's I&E estimates, and EPA shares these concerns. For example, ESSA Technologies noted that year-to-year variations in the sampling protocol created a need for data interpolation and extrapolation to fill data gaps, increasing uncertainty about the true numbers of organisms impinged and entrained. They observed that the need for adjustment of the 1980-1994 entrainment data to account for a lack of nighttime sampling during this period is a particular concern because this is the only period of complete seasonal coverage and was therefore the basis for extrapolation to other years with incomplete seasonal coverage.

ESSA Technologies (2000) expressed concern that the sampling changes necessitated the use of numerous adjustment factors that may have biased I&E estimates. Many adjustments appeared to be biased low, which would result in an underestimate of losses. For example, ESSA Technologies argued that PSEG may have underestimated the latent screen mortality of impinged organisms because they did not consider the high velocity and turbulence of exit flume waters in their estimate. The high velocity of water in the fish return sluice and the extremely turbulent conditions in the sampling pool to which impinged fish are diverted expose fish to significant stress that could increase, or at least obscure, true impingement mortality. Impingement mortality may also have been underestimated because PSEG did not take into account impairment in the ability of impinged organisms that are returned to the estuary to locate prey and avoid predators (Boreman, 1993).

ESSA Technologies (2000) expressed concern about the magnitude of correction needed to adjust entrainment estimates for net extrusion. In addition, they argued that there may be species-specific errors in PSEG's entrainment estimates because differences in collection efficiency for different species were not taken into account.

ESSA Technologies (2000) also found that PSEG may have substantially underestimated entrainment mortality by assuming only moderate rates of mortality as organisms pass through the plant. PSEG based its estimates of thermal mortality on a probit model (regression equation) that estimates thermal mortality as a function of acclimation temperature, exposure duration, and exposure temperature (PSEG, 1999c, Appendix F, Attachment 1, Section II.C). Because the model was fit to laboratory data it may not reflect actual rates of thermal mortality experienced by organisms in the condenser water and does not consider deaths due to cold shock that occur when organisms in the heated condenser water are discharged back into the cooler receiving waters of the estuary (Boreman, 1993). Mechanical mortality rates were estimated by PSEG from studies in which larvae were held in jars or aquaria (PSEG, 1999c, Appendix F, Attachment 1, Section II.C). ESSA Technologies argued that this in vitro environment does not reflect the stresses faced by larvae on exiting the discharge, and therefore they concluded that mechanical mortality was probably also underestimated by PSEG. EPA shares these concerns.

ESSA Technologies (2000) also noted some potential sources of mortality not captured by the sampling program. One of these is mortality of eggs and larvae that are impinged on material clogging intake screens. This material is cleaned off the screens with high pressure sprays and then is carried away in the impingement discharge flow system. No attempt is made by PSEG to count any eggs and larvae that are impinged within this material. In addition, certain geographic features near Salem may have caused a large back eddy, which would cause different flow dynamics depending on tidal cycle, and result in episodic entrainment patterns that might not have been captured by the sampling program.

In addition to these concerns about the sampling program and estimates of I&E losses, ESSA Technologies (2000) argued that the natural mortality rates used by PSEG were too high for many species, which would lead to an underestimate of adult equivalent and yield-per-recruit losses. They argued that rates were biased high because the "life cycle balancing" method used by PSEG assumed that fish populations in the Delaware Estuary are at equilibrium. Most fish populations in the estuary are increasing due to significant water quality improvements and fishing restrictions in recent years, and ESSA Technologies noted that natural mortality rates of an expanding population are typically lower than for an equilibrium population. In a rebuttal to the ESSA Technologies review, PSEG (2001a,f) argued that this would influence their calculations only if higher than average early survival was responsible for the increased population growth. Instead, PSEG (2001a,f) contended that the increases are largely due to increases in adult survival rates resulting from reduced harvest, and therefore there is no need to adjust their estimates of early mortality.

PSEG (2001a,f) also noted that recent spawner-recruit data from National Marine Fishery Service regional stock assessments for weakfish and striped bass indicate that density-dependent compensation is occurring as stock size increases, resulting in a decrease in the number of recruits produced per spawner. PSEG (2001a,f) argued that this implies that early mortality rates of these species are increasing, not decreasing, suggesting that if PSEG's estimates are biased, they are biased low. Relative to published values, PSEG's adjusted rates are higher for 10 species, lower for 11 species, and within the range of measured values for 7 species (PSEG, 2001b,c).

B3-3.4 Overview of EPA's Evaluation of Salem's I&E Data

Based on the potential biases and uncertainties discussed in the previous section, NJDEP's draft permit requires that "the uncertainty of the estimated historic annual entrainment loss estimates should be characterized and presented as ranges with maximum and minimum levels" (NJDEP, 2000). These data requirements were implemented in a June 29, 2001 NJPDES permit action, but this information is not yet available for review. Therefore, EPA was unable to conduct a formal evaluation of potential biases and uncertainties in the Salem I&E data for the case study analyses reported here. However, because of EPA's concern that the uncertainties associated with PSEG's assumptions about I&E survival may significantly underestimate Salem's I&E rates, particularly for extrapolation purposes, EPA adjusted Salem's estimates to eliminate PSEG's survival factors for many of its analyses, as discussed in the following sections.

- **Salem's Historical Baseline:** Developed using Salem's impingement estimates for 1978-98 and Salem's impingement survival factors (Tables B3-2 through B3-5), and Salem's entrainment estimates for 1978-98 assuming no through-plant survival (Tables B3-7 through B3-10).

- **Extrapolation Baseline:** Developed using Salem's impingement estimates for 1978-95 and 1997-98 assuming no impingement survival (Table B3-11), and Salem's entrainment estimates for 1978-95 and 1997-98 assuming no entrainment survival (Table B3-7). 1996 was eliminated from the analysis because Salem was shut down much of the year and therefore I&E during this year is not considered representative. The average impingement and entrainment rates estimated on this basis were used to extrapolate Salem's I&E rates to other transition zone CWIS on the basis of intake flow.

- **Salem's Benefits Baseline:** The baseline used in Chapter B6 to estimate the benefits of the proposed regulation for the Salem facility was developed using EPA's estimate of Salem's current I&E rates. Current I&E rates were based on Salem's impingement estimates for 1995 and 1997-1998 assuming impingement survival (Tables B3-20 through B3-22), and Salem's entrainment estimates for 1978-95 and 1997-98 assuming no through plant survival (Table B3-7). 1996 was eliminated from the analysis because Salem was shut down much of the year and therefore I&E during this year is not considered representative.

- **Benefits Baseline for Other In-scope CWIS of the Transition Zone:** EPA's estimate of current I&E at transition zone CWIS was developed using Salem's impingement estimates for 1978-95 and 1997-98 assuming no impingement survival (Table B3-11), since these facilities do not have technologies for reducing impingement mortality, and Salem's entrainment estimates for 1978-95 and 1997-98 assuming no entrainment survival (Table B3-7). 1996 was eliminated from the analysis because Salem was shut down much of the year and therefore I&E during this year is not considered representative. This baseline was used to estimate benefits of the proposed regulation for Hope Creek, Deepwater, and Edge Moor (see Chapter B6).

Because PSEG's impingement survival factors reflect the estimated effectiveness of Salem's modified Ristroph screens in reducing impingement mortality, these factors were retained for EPA's analysis of Salem's historical impingement (Tables B3-2 through B3-5) and current impingement (Tables B3-20 through B3-22). However, PSEG's impingement survival factors were eliminated for extrapolation of Salem's impingement rates to facilities without Ristroph screens (see Section B3-7 and Table B3-11). Salem's entrainment survival factors were eliminated for all analyses (Tables B37 through B3-10) because EPA found insufficient justification in Salem's 1999 Application for their use.

The results of EPA's analyses are presented in the following sections. The data tables associated with these sections present annual I&E numbers from facility monitoring and EPA's estimates of these losses expressed as age 1 equivalents, lost fishery yield, and production foregone, as calculated by EPA according to the methods discussed in Chapter A5 of Part A of this document.

B3-4 Salem's Annual Impingement

Annual impingement losses (numbers of organisms) at Salem as calculated by PSEG are presented in Appendix L, Tab 9 of Salem's 1999 Permit Renewal Application (PSEG, 1999c) and duplicated here in Table B3-2. For its estimates, PSEG assumed that some proportion of impinged organisms survive. The species-specific initial and latent screen mortality factors used by PSEG in its calculations of impingement are presented in Appendix B1. Table B3-3 presents the results of EPA's calculations to express these losses as numbers of age 1 equivalents, Table B3-4 presents impingement losses as pounds of yield lost to commercial and recreational fisheries, and Table B3-5 presents the losses as pounds of production foregone.

PSEG's impingement estimates indicate that impingement losses at Salem vary substantially by species and by year. Over the period 1978-1998, PSEG's estimates of impingement losses ranged from a minimum of 193 individuals of striped bass and other *Morone* species in 1985 to a maximum of 11,264,933 bay anchovy in 1981. In most years, bay anchovy and weakfish dominate impingement collections, followed by spot and blueback herring. However, according to PSEG's estimates, losses of Atlantic croaker, blue crab, and white perch at Salem have also been high (over 1 million) in some years.

Of interest in recent years is PSEG's estimated high losses of Atlantic croaker in 1998, when the station was operating close to its expected future intake flow rate. This occurred despite the addition of modified Ristroph screens in 1995 to increase impingement survival. This may be related in part to the increasing trend in Atlantic croaker abundance in the estuary in recent years (see Appendix J in PSEG, 1999d).

Striped bass impingement has also been generally higher during the past decade, apparently related in part to increases in the striped bass population in the estuary. Some of this increase is attributed to movement into the estuary of Chesapeake Bay striped bass via the C&D canal (see Appendix J in PSEG, 1999d).

Although both weakfish and white perch populations have shown significant increases in the estuary in recent years (see Appendix J in PSEG, 1999d), impingement rates of both species have declined since the installation in 1995 of modified Ristroph screens designed to increase impingement survival. A study by PSEG indicated that weakfish impingement mortality declined by 51 percent after installation of the new technology (Ronafalvy et al., 2000).

By contrast, bay anchovy impingement has generally been lower in the past decade. However, a corresponding decreasing trend in the population of bay anchovy in the estuary has not been detected, and some of the apparent decline in impingement numbers appears to be related to an exceptionally high year class and related high impingement in 1980 (see Appendix J in PSEG, 1999d).

Blueback herring and spot impingement has declined in the past decade at the same time populations of these species have shown significant declines within the estuary (see Appendix J in PSEG, 1999d). However, in the case of spot the decline is in part because of an exceptionally strong year class in 1988, a year that also showed exceptionally high spot impingement.

Table B3-2: Annual Impingement (numbers of organisms), by Species, at the Salem Station as Estimated by PSEG Using Impingement Survival Factors (see the initial and latent mortality factors in Appendix B1 of Part B).

Year	Alewife + 21% *Alosa* spp.	American Shad	Atlantic Croaker	Bay Anchovy	Blueback Herring + 79% *Alosa* spp.	Blue Crab	Spot	Striped Bass + 58% *Morone* spp.	Weakfish	White Perch + 42% *Morone* spp.	Non-RIS Fishery Species	Non-RIS Forage Species
1978	17,057	4,549	125,822	2,623,694	438,248	111,627	84,519	3,213	6,391,256	254,688	—	—
1979	11,513	2,144	8,494	1,321,105	651,005	97,434	292,471	9,625	580,628	541,715	—	—
1980	11,301	6,382	93,232	11,046,658	460,638	501,000	146,794	4,350	1,821,462	403,453	—	—
1981	647,832	8,820	14,996	11,264,933	364,803	347,436	857,167	1,895	1,818,578	344,726	—	—
1982	46,951	9,406	2,975	3,846,612	418,130	122,032	979,961	542	967,867	261,912	—	—
1983	19,584	5,359	2,326	3,784,994	224,303	100,953	681,704	924	1,038,356	143,904	—	—
1984	128,002	3,266	853	2,444,847	1,335,665	87,890	316,579	430	357,125	300,333	—	—
1985	4,676	11,033	275,670	3,771,190	162,478	1,011,790	183,679	193	1,263,119	582,528	—	—
1986	20,788	11,007	233,915	2,011,567	467,361	1,228,076	52,445	2,875	756,956	1,033,048	—	—
1987	74,461	24,120	1,245,098	3,346,956	157,496	834,857	2,204	6,673	1,095,105	715,912	—	—
1988	31,082	35,182	4,046	4,657,784	357,896	1,247,649	1,917,236	10,450	427;218	646,825	—	—
1989	137,998	65,138	24,168	781,653	891,085	344,310	119,381	26,006	184,538	760,842	—	—
1990	50,074	15,393	5,787	1,373,446	168,555	178,511	120,833	28,003	170,778	768,431	—	—
1991	21,275	22,874	45,535	1,719,784	137,107	307,503	134,807	10,089	575,349	688,724	1,318,756	3,759,670
1992	23,847	64,807	55,267	1,286,667	120,649	370,591	2,999	20,966	841,319	1,158,199	1,082,303	4,187,464
1993	23,267	22,087	176,279	596,243	100,999	387,190	16,869	74,100	723,366	1,043,913	248,137	1,189,847
1994	22,946	6,315	31,538	178,764	31,835	491,199	247,677	23,612	2,130,349	1,266,489	300,779	2,068,499
1995	14,745	7,940	610,261	363,601	143,846	1,012,348	27,435	10,812	890,341	321,359	1,057,789	3,541,198
1996	1,321	829	21,010	18,802	5,548	83,457	7,281	9,191	130,459	75,006	456,756	876,044
1997	5,899	819	266,558	309,018	50,879	475,443	30,245	12,779	1,582,441	228,996	1,292,807	979,870
1998	8,037	2,214	2,370,135	1,104,126	57,267	280,741	2,654	10,660	1,572,811	124,351	452,514	678,595

Non-RIS species are listed in Table B3-1.
Source: PSEG, 1999e, Appendix L, Tab 9.

Table B3-3: Annual Impingement at the Salem Station, by Species, Expressed as Numbers of Age 1 Equivalents.

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Bay Anchovy	Blue Crab	Blueback Herring +79% *Alosa* spp.	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.	Non-RIS Fishery Species	Non-RIS Forage Species
1978	2,636	400	26,237	3,207,895	106,937	45,217	47,840	2,207	237,865	205,508	NA	NA
1979	5,228	28	1,694	1,658,005	87,450	64,659	152,505	6,972	30,527	432,155	NA	NA
1980	7,399	789	18,705	12,307,910	430,887	74,240	76,140	3,979	73,243	384,326	NA	NA
1981	70,931	717	2,991	10,305,370	494,609	45,175	453,422	2,093	109,740	304,727	NA	NA
1982	24,093	435	593	4,492,784	151,012	79,830	506,074	452	54,048	232,375	NA	NA
1983	2,792	120	464	3,840,211	122,827	24,128	404,825	1,068	66,312	147,348	NA	NA
1984	20,129	4	170	3,240,737	90,517	138,154	168,227	183	23,718	248,481	NA	NA
1985	1,475	4,825	61,635	5,436,267	1,012,273	78,420	135,544	103	125,274	459,338	NA	NA
1986	2,811	13	46,652	3,111,302	1,103,054	62,359	27,780	1,621	43,753	736,078	NA	NA
1987	25,409	645	248,827	4,954,486	691,684	30,682	3,100	3,711	128,477	540,814	NA	NA
1988	7,234	1,262	807	7,457,023	1,098,308	40,597	993,151	8,014	19,004	678,298	NA	NA
1989	13,510	80	5,454	1,147,108	316,747	99,184	65,855	15,325	33,553	752,529	NA	NA
1990	4,296	1,884	3,961	1,923,258	201,566	2,053	62,524	18,440	15,173	690,946	NA	NA
1991	2,340	166	12,514	2,632,605	294,155	30,708	89,166	11,106	51,978	686,910	401,457	3,200,087
1992	2,899	419	15,441	1,998,807	477,614	15,064	3,357	13,967	65,868	1,035,386	205,300	3,032,060
1993	3,058	381	44,324	725,913	387,967	11,683	8,692	18,883	30,845	793,814	74,659	1,438,503
1994	4,323	8	6,549	199,838	439,444	12,944	127,624	17,955	86,759	872,029	101,808	1,472,900
1995	2,054	10	151,250	400,287	837,514	18,864	38,554	6,713	35,243	247,600	256,295	2,728,877
1996	136	11	7,656	19,780	65,818	755	3,797	1,844	5,125	50,414	121,929	725,920
1997	941	1	58,241	299,061	286,356	7,480	15,640	6,312	66,917	161,697	302,775	964,074
1998	3,412	1,142	485,999	876,041	282,114	12,061	2,673	4,890	65,409	93,927	88,394	747,858
Mean	9,862	635	57,151	3,344,509	427,564	42,584	161,262	6,945	65,182	464,510	194,077	1,788,785
Min	136	1	170	19,780	65,818	755	2,673	103	5,125	50,414	74,659	725,920
Max	70,931	4,825	485,999	12,307,910	1,103,054	138,154	993,151	18,883	237,865	1,035,386	401,457	3,200,087
SD	15,873	1,084	115,178	3,302,811	335,346	36,221	242,791	6,432	52,417	287,940	118,302	1,037,657
Total	207,106	13,339	1,200,163	70,234,680	8,978,851	894,257	3,386,492	145,837	1,368,830	9,754,701	1,552,617	14,310,280

Note: Impingement losses expressed as age 1 equivalents are larger than raw losses (the actual number of organisms impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start of year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details, see description of S*j in Chapter A5, Equation 4 and Equation 5). This type of adjustment is applied to all raw loss records, but the effect is not readily apparent among entrainment losses because the majority of entrained fish are younger than age 1.

NA = Not sampled

Non-RIS species are listed in Table B3-1.

Tue Feb 12 18:03:39 MST 2002; Results; 1 Plant: salemhistoric; Units: equivalent.sums Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.historic.damages/I.equivalent.sums.salem.historic.csv

Table B3-4: Annual Impingement of Fishery Species at the Salem Station Expressed as Yield Lost to Fisheries (in pounds)

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Blue Crab	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.	Non-RIS Fishery Species
1978	24	98	5,341	3,412	5,358	3,064	187,007	90	NA
1979	47	7	345	2,791	17,080	9,676	24,000	190	NA
1980	66	193	3,808	13,750	8,528	5,522	57,583	169	NA
1981	633	175	609	15,783	50,783	2,904	86,276	134	NA
1982	215	106	121	4,819	56,680	628	42,492	102	NA
1983	25	29	94	3,919	45,340	1,482	52,134	65	NA
1984	180	1	35	2,888	18,841	254	18,647	109	NA
1985	13	1,181	12,548	32,302	15,181	144	98,489	202	NA
1986	25	3	9,498	35,198	3,111	2,250	34,398	324	NA
1987	227	158	50,658	22,072	347	5,150	101,007	238	NA
1988	65	309	164	35,047	111,232	11,123	14,941	298	NA
1989	121	20	1,110	10,107	7,376	21,270	26,379	331	NA
1990	38	461	806	6,432	7,003	25,593	11,929	304	NA
1991	21	41	2,548	9,386	9,987	15,414	40,864	302	35,864
1992	26	103	3,144	15,241	376	19,386	51,784	456	18,340
1993	27	93	9,024	12,380	974	26,210	24,250	349	6,670
1994	39	2	1,333	14,023	14,294	24,921	68,209	384	9,095
1995	18	2	30,793	26,725	4,318	9,318	27,708	109	22,896
1996	1	3	1,559	2,100	425	2,559	4,029	22	10,892
1997	8	0	11,857	9,138	1,752	8,761	52,609	71	27,048
1998	30	280	98,943	9,002	299	6,787	51,423	41	7,897
Mean	88	155	11,635	13,644	18,061	9,639	51,246	204	17,338
Min	1	0	35	2,100	299	144	4,029	22	6,670
Max	633	1,181	98,943	35,198	111,232	26,210	187,007	456	35,864
SD	142	265	23,449	10,701	27,192	8,927	41,210	127	10,568
Total	1,849	3,265	244,338	286,514	379,285	202,417	1,076,157	4,292	138,702

NA = Not sampled
0 = Sampled, but none collected.
Non-RIS species are listed in Table B3-1.
Tue Feb 12 18:03:58 MST 2002; Results; I Plant: salem.historic; Units: yield Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.historic.damages/I.yield.salem.historic.csv

Table B3-5: Annual Impingement at the Salem Station, by Species, Expressed as Production Foregone (in pounds).

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Bay Anchovy	Blue Crab	Blueback Herring +79% *Alosa* spp.	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% Morone spp.	Non-RIS Fishery Species	Non-RIS Forage Species
1978	1,208	2,402	14,499	1,642	19,881	12,839	18,309	6,087	521,227	6,616	NA	NA
1979	3,026	210	820	998	17,206	17,694	43,316	26,048	58,940	13,888	NA	NA
1980	4,419	4,675	9,231	5,943	72,343	25,299	21,120	17,014	161,901	11,135	NA	NA
1981	26,788	4,315	1,448	8,021	71,992	13,044	136,883	8,059	203,167	10,451	NA	NA
1982	14,447	2,714	287	2,431	23,411	27,741	137,584	1,580	105,301	6,568	NA	NA
1983	1,170	815	225	2,435	17,183	6,700	176,815	6,228	121,846	4,710	NA	NA
1984	9,356	100	82	1,218	16,131	39,240	51,728	267	42,141	7,459	NA	NA
1985	725	27,915	40,302	2,260	185,850	25,011	88,315	147	204,726	13,629	NA	NA
1986	1,242	336	22,589	1,030	211,790	18,789	8,433	2,967	88,536	21,899	NA	NA
1987	14,314	4,262	121,273	1,546	127,351	10,436	3,325	8,304	254,259	15,727	NA	NA
1988	3,681	8,060	391	1,540	224,946	11,238	273,860	26,605	43,273	23,888	NA	NA
1989	4,840	1,986	3,637	372	62,499	29,470	23,220	38,789	74,671	23,953	NA	NA
1990	1,356	11,160	6,329	928	35,630	837	17,153	65,835	24,548	23,832	NA	NA
1991	916	1,487	11,454	922	41,847	3,585	48,968	37,896	85,143	22,367	102,927	2,273
1992	1,209	3,924	14,420	770	73,970	4,937	3,199	48,234	116,550	36,357	92,095	3,183
1993	1,331	2,700	35,867	525	67,273	2,726	2,339	52,471	64,785	25,648	18,627	586
1994	2,176	193	3,578	120	87,416	5,918	34,340	71,550	182,867	25,383	21,907	1,460
1995	920	242	119,652	284	165,441	5,795	41,326	20,774	77,204	8,423	91,452	2,745
1996	50	84	9,152	14	14,070	256	1,079	4,591	11,010	1,586	33,969	526
1997	447	25	36,180	242	58,276	2,602	4,280	18,167	139,981	5,094	102,541	741
1998	1,965	6,600	256,217	975	53,341	4,411	2,375	12,814	148,532	3,148	38,158	377
Mean	4,552	4,010	33,697	1,629	78,469	12,789	54,189	22,592	130,029	14,846	62,709	1,486
Min	50	25	82	14	14,070	256	1,079	147	11,010	1,586	18,627	377
Max	26,788	27,915	256,217	8,021	224,946	39,240	273,860	71,550	521,227	36,357	102,927	3,183
SD	6,595	6,230	61,783	1,945	66,142	11,023	71,288	21,909	110,443	9,542	37,665	1,108
Total	95,584	84,204	707,632	34,215	1,647,847	268,567	1,137,968	474,427	2,730,609	311,761	501,675	11,892

NA = Not sampled.
Non-RIS species are listed in Table B3-1.
Tue Feb 12 18:03:49 MST 2002; Results; I Plant: salem.historic; Units: annual.prod.forg Pathname:
P:/Intake/Delaware/Del-Science/scodes/tables.output.historic.damages/I.annual.prod.forg.salem.historic.csv

B3-5 SALEM'S ANNUAL ENTRAINMENT

Annual entrainment losses (numbers of organisms) at Salem as calculated by PSEG are presented in Appendix L, Tab 8 of Salem's 1999 Permit Renewal Application (PSEG, 1999e) and duplicated below in Table B3-6. For its estimates, PSEG assumed that some proportion of entrained organisms survive. The through-plant survival factors used by PSEG to calculate entrainment losses are presented in Tab 10 of Appendix L of the Salem Application and presented in Appendix B1 of Part B.

As discussed in Section B3-3.3, an independent review of Salem's 1999 Application by scientists with ESSA Technologies, Ltd. (2000) concluded that Salem's entrainment rates were most likely underestimated by PSEG because their entrainment calculations assumed substantial through-plant survival of entrained organisms. EPA concurs with ESSA that Salem's 1999 Application provides inadequate justification for PSEG's assumptions about through-plant survival, and therefore, EPA recalculated Salem's entrainment without the thermal and mechanical mortality factors used by PSEG for its calculations (see Appendix B1 for the species-specific thermal and mechanical mortality factors used by PSEG). Table B3-7 presents the results of EPA's calculations of Salem's annual entrainment rates assuming 100 percent through-plant mortality of entrained organisms. EPA's entrainment estimates (Table B3-7) are higher than PSEG's (Table B3-6) for all species except Atlantic menhaden, bay anchovy, and silversides. EPA's entrainment estimate of Atlantic croaker is three times higher than PSEG's and EPA's estimate for spot is five times higher.

EPA used its estimates of entrainment assuming 100 percent through-plant mortality to express entrainment at Salem in terms of numbers of age 1 equivalents, fishery yield, and production foregone. Table B3-8 presents numbers of age 1 equivalents entrained, Table B3-9 presents entrainment as pounds of yield lost to commercial and recreational fisheries, and Table B3-10 presents entrainment as pounds of production foregone.

As with impingement, entrainment at Salem varies substantially by species and by year. For the period 1978-1998, EPA's estimates of mean annual entrainment at Salem entrainment range from 55,575 for American shad to nearly 12.5 billion for bay anchovy. Maximum entrainment during this period was over 45 billion bay anchovy in 1986. Bay anchovy typically dominate entrainment collections, but several hundred million Atlantic croaker, weakfish, striped bass, and white perch have also been entrained in many years in the period.

In 1998, exceptionally high numbers of alewife were entrained, over 16 million, compared to a mean of about 1.2 million fo the period. In 1995 and 1998, unusually high entrainment of Atlantic menhaden occurred, reaching about 180 million compared to a mean of 20.8 million. Similarly, in 1998 blueback herring entrainment was over 66 million compared to a mean of about 5.2 million, striped bass entrainment was about 537 million compared to a mean of 39.7 million, and white perch entrainment was nearly 416 million compared to a mean of 42.6 million. Of note is that Salem's intake flow in 1998 was substantially higher than other years and close to the level of use projected by the facility over the next permit cycle.

In contrast to these recent increases in entrainment rates, spot entrainment was substantially lower than average from 1995 on. All species showed lower entrainment in 1996, but this was due to a plant shut down during that year (PSEG, 1999e).

Table B3-6: Annual Entrainment (number of organisms), by Species, at the Salem Station as Estimated by PSEG Assuming Through-Plant Survival.

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Atlantic Menhaden	Bay Anchovy	Blueback Herring +79% *Alosa* spp.	Silversides	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.	Non-RIS Fishery Species[a]	Non-RIS Forage Species[a]
1978	7,632	3,975	784,064	0	7,962,051,278	775,494	79,935,119	5,095,551	25,601	399,818,310	0	NA	NA
1979	49,684	0	14,514,986	72,137	3,535,124,407	19,274	18,082,977	1,095,197	20,304	23,192,970	625,399	NA	NA
1980	859,887	15,132	755,706	4,276,613	15,155,926,538	2,812,879	145,109,137	10,295,704	0	256,708,366	27,513,718	NA	NA
1981	2,002,234	0	8,156,747	9,206,968	11,714,057,177	11,852,670	113,240,053	5,417,848	0	45,764,940	969,236	NA	NA
1982	0	0	0	4,156,955	3,712,919,795	16,656	22,200,895	29,963,409	0	74,456,905	18,857,094	NA	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	163,133	126,276	933,196	0	29,463,744,796	1,151,370	0	183,598	0	63,615,990	447,265	NA	NA
1986	348,352	59,250	492,348	0	45,248,806,030	1,593,617	0	858,283	0	110,396,880	653,875	NA	NA
1987	0	62,364	0	0	40,172,399,532	82,394	0	54,551	0	61,266,916	628,439	NA	NA
1988	748,616	0	1,709,851	0	22,331,488,597	2,987,578	0	73,501,509	0	57,063,491	8,968,240	NA	NA
1989	540,788	0	56,341,150	0	10,163,461,645	2,395,307	0	1,026,809	47,946,144	3,026,428	192,130,782	NA	NA
1990	101,432	0	123,374,873	0	7,678,380,444	260,035	0	4,395,303	1,312,530	6,685,346	2,606,258	NA	NA
1991	0	0	131,798,465	0	19,506,554,577	0	0	1,095,693	777,984	72,477,718	1,108,499	NA	NA
1992	319,124	0	71,351,661	0	1,570,462,617	864,490	0	0	1,728,235	10,374,786	3,392,824	NA	NA
1993	675,884	0	75,030,114	0	11,774,247,388	2,339,735	0	584,884	108,064,811	122,672,393	37,634,808	NA	NA
1994	697,126	0	24,782,692	0	1,120,303,600	2,622,523	0	46,858,797	7,490,424	88,781,352	66,926,677	NA	NA
1995	477,453	14,474	31,454,237	177,220,933	1,404,485,840	81,566	31,018,748	71,245	579,481	335,082,605	2,039,275	153,969,300	967,814,700
1996	82,548	27,559	4,384,613	3,039,455	70,642,422	425,090	1,226,981	25,366	7,288,639	14,257,625	16,799,904	153,969,300	967,814,700
1997	52,865	746,895	71,819,490	16,667,564	1,811,782,029	318,483	6,919,466	7,482	6,504,598	12,600,665	7,865,126	153,969,300	967,814,700
1998	14,480,142	0	132,129,651	180,557,345	2,003,681,602	59,282,494	51,528,345	20,054	448,563,394	76,343,394	412,839,168	153,969,300	967,814,700

[a] Annual entrainment losses of non-RIS fishery and forage species were not reported in Salem's 1999 Permit Renewal Application. Instead, the facility presented an annual average for the years 1995-1998. For these years, entrainment of non-RIS fishery species was 153,969,330 organisms per year and entrainment of non-RIS forage species was 967,814,720 organisms per year (PSEG, 1999e, Appendix L, Tab 8).

NA = Not sampled.

0 = Sampled, but none collected.

Non-RIS species are listed in Table B3-1.

Source: PSEG, 1999e, Appendix L, Tab 8.

Table B3-7: Annual Entrainment (number of organisms) at the Salem Station, by Species, as Estimated by EPA Assuming 100 Percent Through-Plant Mortality.

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Atlantic Menhaden	Bay Anchovy	Blueback Herring +79% *Alosa* spp.	Silversides	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.
1978	8,544	3,975	2,177,952	0	7,962,051,277	868,182	79,935,118	24,990,602	25,601	428,114,400	0
1979	55,622	0	40,319,346	72,137	3,535,124,407	21,578	18,082,978	5,371,280	20,304	24,617,925	646,711
1980	962,662	15,132	2,099,180	4,276,613	15,155,926,538	3,149,079	145,109,137	50,494,214	0	271,959,260	27,519,051
1981	2,241,544	0	22,657,594	9,206,968	11,714,057,178	13,269,320	113,240,054	26,571,274	0	48,426,552	1,002,628
1982	0	0	0	4,156,955	3,712,919,793	18,647	22,200,895	146,952,435	0	78,517,574	18,881,133
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	182,631	126,276	2,592,205	0	29,463,744,795	1,288,984	0	900,437	0	10,075,085	462,674
1986	389,988	59,250	1,367,631	0	45,248,806,032	1,784,089	0	4,209,360	0	118,057,915	664,022
1987	0	62,364	0	0	40,172,399,531	92,242	0	267,540	0	62,702,941	650,090
1988	838,092	0	4,749,579	0	22,331,488,597	3,344,658	0	360,480,535	0	60,536,736	9,277,212
1989	605,424	0	156,502,967	0	10,163,461,644	2,681,597	0	5,035,878	57,430,456	3,254,760	194,817,233
1990	113,555	0	342,707,477	0	7,678,380,445	291,115	0	21,556,308	1,572,164	7,145,540	2,696,047
1991	0	0	366,106,309	0	19,506,554,576	0	0	5,373,713	931,878	77,073,686	1,146,689
1992	357,266	0	198,198,767	0	1,570,462,619	967,815	0	0	2,070,100	11,216,240	3,509,712
1993	756,667	0	208,416,677	0	11,774,247,387	2,619,384	0	2,868,503	129,441,302	130,205,448	38,205,582
1994	780,448	0	68,840,707	0	1,120,303,600	2,935,971	0	229,814,115	8,899,097	95,852,608	67,542,554
1995	534,519	14,474	87,372,752	177,220,933	1,404,485,841	91,315	31,018,749	349,414	694,109	356,747,253	2,109,532
1996	92,414	27,559	12,179,463	3,039,455	70,642,420	475,899	1,226,981	124,405	8,730,418	15,394,030	16,959,115
1997	59,184	746,894	199,498,293	16,667,564	1,811,782,028	356,549	6,919,466	36,695	7,786,536	13,582,304	7,936,108
1998	16,210,831	0	367,026,271	180,557,344	2,003,681,603	66,368,030	51,528,345	98,353	536,955,425	80,823,960	415,734,553
Mean	1,273,126	55,575	109,621,746	20,799,893	12,442,132,648	5,296,024	24,697,985	46,605,003	39,713,547	99,700,222	42,618,981
Min	0	0	0	0	70,642,420	0	0	0	0	3,254,760	0
Max	16,210,831	746,894	367,026,271	180,557,344	45,248,806,032	66,368,030	145,109,137	360,480,535	536,955,425	428,114,400	415,734,553
SD	3,657,744	170,575	133,246,350	55,874,625	13,411,735,891	15,089,818	42,925,237	96,477,467	124,417,960	121,478,051	101,071,419
Total	24,189,391	1,055,924	2,082,813,171	395,197,969	236,400,520,311	100,624,451	469,261,723	885,495,061	754,557,389	1,894,304,218	809,760,647

Table B3-7: Annual Entrainment (number of organisms) at the Salem Station, by Species, as Estimated by EPA Assuming 100 Percent Through-Plant Mortality (cont.)

Year	Non-RIS Fishery Species[a]	Non-RIS Forage Species[a]
1978	NA	NA
1979	NA	NA
1980	NA	NA
1981	NA	NA
1982	NA	NA
1983	NA	NA
1984	NA	NA
1985	NA	NA
1986	NA	NA
1987	NA	NA
1988	NA	NA
1989	NA	NA
1990	NA	NA
1991	NA	NA
1992	NA	NA
1993	NA	NA
1994	NA	NA
1995	153,969,300	967,814,700
1996	153,969,300	967,814,700
1997	153,969,300	967,814,700
1998	153,969,300	967,814,700
Mean	153,969,300	967,814,700
Min	153,969,300	967,814,700
Max	153,969,300	967,814,700
SD	0	0
Total	615,877,300	3,871,259,000

[a] Annual entrainment losses of non-RIS fishery and forage species were not reported in Salem's 1999 Permit Renewal Application. Instead, the facility presented an annual average for the years 1995-1998 data. Averaged for these years, entrainment of non-RIS fishery species was 153,969,330 organisms per year and entrainment of non-RIS forage species was 967,814,720 organisms per year (PSEG, 1999e, Appendix L, Tab 8).
NA = Not sampled.
0 = Sampled, but none collected.
Non-RIS species are listed in Table B3-1.
Tue Feb 12 18:23:34 MST 2002 Raw.losses. ENTRAINMENT; Plant:salem.historic;
PATHNAME:P:/Intake/Delaware/Del-Science/scodes/tables.output.historic.damages/raw.losses.ent.salem.historic.csv

Table B3-8: EPA's Estimates of Annual Entrainment at the Salem Station, by Species, Expressed as Numbers of Age 1 Equivalents.

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Atlantic Menhaden	Bay Anchovy	Blueback Herring +79% *Alosa* spp.	Silver-sides	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.	Non-RIS Fishery Species[a]	Non-RIS Forage Species[a]
1978	33	0	187,667	0	901,202,064	3,177	7,196	12,849,708	0	7,572,325	0	NA	NA
1979	214	0	7,349,321	7,856	36,089,496	79	294,761	2,767,731	0	119,038	407,951	NA	NA
1980	3,701	19	392,787	465,750	469,989,469	11,525	363,415	25,929,445	0	486,109	143,074	NA	NA
1981	8,619	0	1,106,959	1,002,696	317,219,041	48,561	1,251,766	13,691,736	0	227,950	639,195	NA	NA
1982	0	0	0	452,718	108,544,490	68	17,713	61,012,334	0	429,948	487,447	NA	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	702	155	109,948	0	19,766,087	4,717	0	463,980	0	474,167	294,964	NA	NA
1986	1,500	73	685	0	240,228,921	6,529	0	931,631	0	1,949,102	194,770	NA	NA
1987	0	76	0	0	276,775,535	338	0	137,859	0	299,142	414,445	NA	NA
1988	3,223	0	387,145	0	779,119,078	12,240	0	183,257,758	0	480,213	3,937,433	NA	NA
1989	369	0	23,972,452	0	162,851,234	1,631	0	2,594,904	2,479,335	79,595	3,123,551	NA	NA
1990	11	0	51,609,459	0	142,100,458	167	0	10,828,831	99,360	105,794	1,393,936	NA	NA
1991	0	0	66,409,497	0	1,353,741,468	0	0	2,062,486	169	826,872	731,037	NA	NA
1992	218	0	35,296,188	0	99,601,622	554	0	0	105,432	365,908	848,321	NA	NA
1993	461	0	36,627,606	0	114,994,298	1,499	0	1,478,092	4,100,226	532,087	1,371,627	NA	NA
1994	475	0	8,292,818	0	50,694,237	1,680	0	111,206,379	35,850	2,926,134	2,816,509	NA	NA
1995	1,977	18	15,049,904	19,137,281	33,360,491	52	1,743	41,596	30,092	3,214,782	1,170,460	13,879,730	6,423,701
1996	56	3	1,072,040	331,015	3,293,313	688	0	285	177,046	471,205	674,948	13,879,730	6,423,701
1997	228	913	21,801,029	1,774,949	32,344,695	1,305	0	84	48,394	381,118	137,540	13,879,730	6,423,701
1998	6,469	0	27,581,872	19,389,774	88,750,958	27,295	5,014	11,708	652,225	1,409,028	3,696,144	13,879,730	6,423,701
Mean	1,487	66	15,644,598	2,240,107	275,298,261	6,427	102,190	22,592,976	406,744	1,176,343	1,183,334	13,879,730	6,423,701
Min	0	0	0	0	3,293,313	0	0	0	0	79,595	0	13,879,730	6,423,701
Max	8,619	913	66,409,497	19,389,774	1,353,741,468	48,561	1,251,766	183,257,758	4,100,226	7,572,325	3,937,433	13,879,730	6,423,701
SD	2,422	209	19,963,265	6,016,379	362,368,419	12,217	297,009	47,806,599	1,061,913	1,798,880	1,253,917	0	0
Total	28,255	1,256	297,247,365	42,562,039	5,230,666,954	122,105	1,941,607	429,266,547	7,728,129	22,350,520	22,483,350	55,518,900	25,694,800

[a] Annual entrainment losses of non-RIS fishery and forage species were not reported in Salem's 1999 Permit Renewal Application. Instead, the facility presented an annual average for the years 1995-1998 (see Table B3-6). The age 1 equivalents presented here are derived from this annual average.

NA = Not sampled.

0 = Sampled, but none collected.

Non-RIS species are listed in Table B3-1.

Tue Feb 12 18:03:37 MST 2002; Results; E Plant: salem.historic; Units: equivalent.sums Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.historic.damages/E.equivalent.sums.salem.historic.csv

Table B3-9: Annual Entrainment of Fishery Species at the Salem Station Expressed as Yield Lost to Fisheries (in pounds).

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Atlantic Menhaden	Silversides	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.	Non-RIS Fishery Species[a]
1978	0	0	38,207	0	3	1,439,161	0	5,953,264	0	NA
1979	2	0	1,496,229	3,943	119	309,985	0	93,586	180	NA
1980	33	5	79,967	233,739	146	2,904,085	0	382,173	63	NA
1981	77	0	225,363	503,208	504	1,533,468	0	179,211	281	NA
1982	0	0	0	227,199	7	6,833,350	0	338,020	214	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	6	38	22,384	0	0	51,966	0	372,784	130	NA
1986	13	18	139	0	0	104,342	0	1,532,359	86	NA
1987	0	19	0	0	0	15,440	0	235,182	182	NA
1988	29	0	78,818	0	0	20,524,780	0	377,537	1,733	NA
1989	3	0	4,880,487	0	0	290,628	3,441,225	62,576	1,374	NA
1990	0	0	10,507,030	0	0	1,212,824	137,909	83,174	613	NA
1991	0	0	13,520,130	0	0	230,997	234	650,076	322	NA
1992	2	0	7,185,856	0	0	0	146,335	287,672	373	NA
1993	4	0	7,456,916	0	0	165,546	5,690,961	418,320	604	NA
1994	4	0	1,688,313	0	0	12,455,060	49,759	2,300,488	1,239	NA
1995	18	4	3,063,970	9,604,144	1	4,659	41,767	2,527,420	515	1,239,935
1996	1	1	218,254	166,122	0	32	245,733	370,455	297	1,239,935
1997	2	224	4,438,413	890,767	0	9	67,169	299,630	61	1,239,935
1998	58	0	5,615,319	9,730,859	2	1,311	905,264	1,107,759	1,626	1,239,935
Mean	13	16	3,185,042	1,124,209	41	2,530,402	564,545	924,826	521	1,239,935
Min	0	0	0	0	0	0	0	62,576	0	1,239,935
Max	77	224	13,520,130	9,730,859	504	20,524,780	5,690,961	5,953,264	1,733	1,239,935
SD	22	51	4,064,268	3,019,351	120	5,354,315	1,473,895	1,414,256	552	0
Total	252	307	60,515,790	21,359,980	781	48,077,640	10,726,360	17,571,690	9,893	4,959,740

[a] Annual entrainment losses of non-RIS fishery species were not reported in Salem's 1999 Permits Renewal Application. Instead, the facility presented an annual average for the years 1995-1998 (see Table B3-6). The fishery yields for non-RIS fishery species presented here are derived from this annual average.
NA = Not sampled.
0 = Sampled, but none collected.
Non-RIS species are listed in Table B3-1.
Tue Feb 12 18:03:55 MST 2002; Results; E Plant: salem.historic; Units: yield Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.historic.damages/E.yield.salem.historic.csv

Table B3-10: Annual Entrainment at the Salem Station, by Species, Expressed as Production Foregone (in pounds).

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Atlantic Menhaden	Bay Anchovy	Blueback Herring +79% *Alosa* spp.	Silver-sides	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.	Non-RIS Fishery Species*	Non-RIS Forage Species*
1978	39	162	127,801	0	5,044,739	2,267	1	3,457,903	1,560	19,665,920	0	NA	NA
1979	253	0	3,738,114	550	1,867,947	56	34	744,715	1,237	513,003	11,178	NA	NA
1980	4,375	461	196,901	32,587	8,296,371	8,221	42	6,976,999	0	5,734,506	191,150	NA	NA
1981	10,187	0	1,373,572	70,156	6,301,636	34,642	144	3,684,043	0	1,035,307	17,488	NA	NA
1982	0	0	0	31,675	2,030,206	49	2	16,441,100	0	1,723,094	137,914	NA	NA
1983	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	830	3,851	141,791	0	15,433,644	3,365	0	124,843	0	937,860	8,070	NA	NA
1986	1,772	1,807	22,087	0	23,596,774	4,658	0	265,483	0	5,003,485	7,794	NA	NA
1987	0	1,902	0	0	21,003,339	241	0	37,094	0	1,707,528	11,339	NA	NA
1988	3,809	0	332,854	0	12,097,167	8,732	0	49,313,420	0	1,711,452	152,913	NA	NA
1989	3,234	0	13,438,260	0	5,663,320	7,607	0	698,212	7,217,789	182,919	1,320,113	NA	NA
1990	592	0	29,334,516	0	4,176,184	1,606	0	2,914,184	241,566	263,136	44,881	NA	NA
1991	0	0	33,870,021	0	10,590,381	0	0	556,130	51,186	2,071,668	20,001	NA	NA
1992	1,909	0	18,016,150	0	945,053	2,748	0	0	269,665	814,321	34,974	NA	NA
1993	4,042	0	18,864,867	0	6,296,170	7,438	0	397,711	13,401,050	2,146,684	287,486	NA	NA
1994	4,169	0	5,416,038	0	630,580	8,337	0	29,959,930	627,015	6,555,749	488,538	NA	NA
1995	2,448	441	7,903,765	1,618,054	754,828	259	0	11,423	80,395	9,693,254	33,500	16,152,790	418,599
1996	494	1,126	783,827	23,160	30,794	1,321	0	1,063	773,058	1,055,400	135,192	16,152,790	418,599
1997	269	22,794	15,095,100	193,029	942,041	931	0	313	536,200	887,983	53,961	16,152,790	418,599
1998	85,638	0	20,482,086	1,750,015	1,121,473	185,336	1	3,215	33,984,300	3,718,167	2,842,755	16,152,790	418,599
Mean	6,529	1,713	8,901,987	195,749	6,674,876	14,622	12	6,083,567	3,009,738	3,443,233	305,224	16,152,790	418,599
Min	0	0	0	0	30,794	0	0	0	0	182,919	0	16,152,790	418,599
Max	85,638	22,794	33,870,021	1,750,015	23,596,774	185,336	144	49,313,420	33,984,300	19,665,920	2,842,755	16,152,790	418,599
SD	19,321	5,203	10,849,792	526,909	7,003,493	42,075	34	12,868,640	8,218,962	4,671,217	686,407	0	0
Total	124,059	32,544	169,137,748	3,719,226	126,822,647	277,813	224	115,587,800	57,185,030	65,421,430	5,799,247	64,611,140	1,674,398

* Annual entrainment losses of non-RIS fishery species were not reported in Salem's 1999 Permit Renewal Application. Instead, the facility presented an annual average for the years 1995-1998 (see Table B3-6). The production foregone estimates presented here for these species are derived from this annual average.

NA = Not sampled.

0 = Sampled, but none collected.

Non-RIS species are listed in Table B3-1.

Tue Feb 12 18:03:47 MST 2002; Results; E Plant: salem.historic; Units: annual.prod.forg Pathname:
P:/Intake/Delaware/Del-Science/scodes/tables.output.historic.damages/E.annual.prod.forg.salem.historic.csv

B3-6 Extrapolation of Salem's I&E Rates to Other Transition Zone Facilities

EPA used the results from its detailed analysis of I&E at Salem as a basis for estimating I&E at other CWIS in the transition zone of the Delaware Estuary. For extrapolation purposes, EPA used Salem's impingement estimates for the years 1978-95 and 1997-98, assuming no impingement survival (see Table B3-11), and Salem's entrainment estimates 1978-95, 1997-98, assuming no entrainment survival (see Table B3-7). 1996 was eliminated from the analysis because Salem was shut down much of the year and therefore I&E during this year is not considered representative. The average impingement and entrainment rates estimated on this basis were used to extrapolate Salem's I&E rates to other transition zone CWIS on the basis of intake flow

Extrapolation was necessary because empirical data describing actual I&E at these facilities are extremely limited or absent. Because intake characteristics, the fish community, and hydrodynamic conditions associated with transition zone CWIS are similar, EPA assumed that I&E at Salem is representative of I&E at other transition zone CWIS and that I&E is strictly proportional to intake flow. The following sections discuss in more detail how EPA used Salem I&E data to develop a model for extrapolation.

B3-6.1 Impingement Extrapolation

Except for Salem, impingement controls at transition zone CWIS are non-existent or minimal.[1] Therefore, to extrapolate Salem's impingement rates to CWIS without screens, EPA re-calculated Salem's impingement rates without the screen survival factors used by PSEG for its calculations (see Appendix B1 for the species-specific initial and latent mortality factors used by PSEG to calculate annual impingement). EPA averaged Salem's species-specific mortality rates by month of highest impingement to obtain annual initial and latent mortality rates (see shaded areas in Appendix B1) and then calculated impingement without these factors. Table B3-11 presents the results of EPA's calculations of Salem's annual impingement assuming 100 percent mortality of impinged organisms. EPA used these estimates to estimate impingement at other transition zone CWIS expressed as age 1 equivalents, fishery yield, and production foregone. These results are presented in Tables B3-12, B3-13, and B3-14, respectively. Chapter A5 of Part A of this document discusses the methods used to calculate these metrics. Note that in these tables, the data for Salem are for Salem as an extrapolation model.

B3-6.2 Entrainment Extrapolation

As outlined in Section B3-3.2, PSEG adjusted their entrainment estimates using the thermal and mechanical survival factors presented in Appendix B1. As discussed previously, EPA believes that PSEG provided insufficient justification for the use of these through-plant survival factors. Thus, for extrapolation purposes, EPA used the entrainment rates it calculated assuming no through-plant survival (presented in Table B3-7). Extrapolation results are expressed as age 1 equivalents in Table B3-15, as foregone fishery yield in Table B3-16, and as production foregone in Table B3-17. Chapter A5 of Part A of this document discusses the methods used to calculate these metrics. Note that in these tables, the data for Salem are for Salem as an extrapolation model.

B3-7 Salem's Current I&E

EPA estimated Salem's current entrainment rates using the data discussed in Section B3-5 and presented in Tables B3-7 through B3-10. Current impingement at Salem was estimated by considering only the years since 1995, when Salem's Ristroph screens were modified with improved fish handling systems that increase the survival of impinged organisms. The results of these impingement calculations are presented in Tables B3-18, B3-19, and B3-20 as age 1 equivalents, foregone fishery yield and production foregone, respectively.

[1] EPA understands that Logan has some impingement control but technical details are lacking. Therefore, for the purposes of the analysis presented here, EPA assumed none of the transition zone CWIS have impingement controls.

B3-8 Cumulative Impacts: Summary of Estimated Total I&E at All Transition Zone CWIS

Tables B3-21 and B3-22 summarize the cumulative I&E impacts of all transition zone CWIS (both in-scope and out of scope) in terms of numbers of age 1 equivalents, yield lost to fisheries (in pounds), and production foregone (in pounds). The rates for Salem in these tables are EPA's estimates of Salem's current annual I&E rates, as described above in Section B3-7. EPA estimates that total fish impingement in the transition zone is 9,648,808 age 1 equivalents, 332,767 pounds of fishery yield, and 794,381 pounds of production foregone. Total entrainment is substantially greater, estimated as 615,900,092 age 1 equivalents, 16,867,112 pounds of fishery yield, and 72,000,391 pounds of production foregone. Economic valuation of these losses is discussed in Chapters B4 and B5 of this report. EPA evaluated the data for in-scope facilities only (Salem Hope Creek, Deepwater, Edge Moór) to estimate the potential economic benefits of various regulatory options, as discussed in Chapter B6.

Table B3-11: Annual Impingement (number of organisms), by Species, at the Salem Station as Estimated by EPA Assuming No Impingement Survival.

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Atlantic Menhaden	Bay Anchovy	Blue Crab	Blueback Herring +79% *Alosa* spp.	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.	Non-RIS Fishery Species	Non-RIS Forage Species
1978	17,873	7,412	259,849	NA	2,803,345	336,611	464,023	114,685	11,459	9,260,270	514,214	NA	NA
1979	12,063	3,493	17,542	NA	1,411,564	293,812	689,293	396,853	34,314	841,270	1,093,725	NA	NA
1980	11,841	10,397	192,542	NA	11,803,050	1,510,762	487,729	199,184	15,513	2,639,110	814,573	NA	NA
1981	678,796	14,368	30,970	NA	12,036,270	1,047,688	386,261	1,163,085	6,760	2,634,932	696,003	NA	NA
1982	49,196	15,323	6,144	NA	4,110,000	367,990	442,722	1,329,707	1,936	1,402,339	528,803	NA	NA
1983	20,521	8,732	4,804	NA	4,044,164	304,423	237,494	925,002	3,298	1,504,471	290,543	NA	NA
1984	134,120	5,321	1,762	NA	2,612,252	265,032	1,414,221	429,566	1,533	517,437	606,374	NA	NA
1985	4,899	17,974	569,312	NA	4,029,411	3,051,046	172,033	249,233	688	1,830,128	1,176,126	NA	NA
1986	21,782	17,931	483,080	NA	2,149,305	3,703,258	494,850	71,162	10,251	1,096,751	2,085,730	NA	NA
1987	78,019	39,293	2,571,368	NA	3,576,131	2,517,506	166,760	2,991	23,788	1,586,694	1,445,431	NA	NA
1988	32,568	57,314	8,356	NA	4,976,715	3,762,281	378,943	2,601,491	37,262	618,996	1,305,942	NA	NA
1989	144,594	106,115	49,912	NA	835,175	1,038,268	943,494	161,989	92,719	267,377	1,536,145	NA	NA
1990	52,467	25,075	11,951	NA	1,467,489	538,302	1,892	163,959	99,842	247,441	1,551,465	NA	NA
1991	22,292	37,265	94,039	NA	1,837,543	927,273	321,747	182,919	35,972	833,621	1,390,537	1,318,756	3,759,669
1992	24,988	105,574	114,135	NA	1,374,769	1,117,518	127,746	4,069	74,753	1,218,984	2,338,407	1,082,304	4,187,465
1993	24,379	35,982	364,050	NA	637,069	1,167,566	106,938	22,889	264,201	1,048,084	2,107,665	248,137	1,189,847
1994	24,043	10,288	65,134	NA	191,004	1,481,211	33,707	336,072	84,187	3,086,656	2,557,047	300,779	2,068,499
1995	15,450	12,935	1,260,307	NA	388,498	3,052,729	152,306	37,226	38,549	1,290,012	648,825	1,057,790	3,541,200
1997	22,289	1,530	945,130	NA	448,347	7,552,705	210,344	239,578	108,717	3,091,169	2,521,240	1,292,807	979,870
1998	30,369	4,137	8,403,714	NA	1,601,949	4,459,744	236,758	21,024	90,681	3,072,358	1,369,101	452,514	678,595
Mean	71,127	26,823	772,705	NA	3,116,702	1,924,786	373,463	432,634	51,821	1,904,405	1,328,895	821,870	2,343,592
Min	4,899	1,530	1,762	NA	191,004	265,032	1,892	2,991	688	247,441	290,543	248,137	678,595
Max	678,796	106,115	8,403,714	NA	12,036,270	7,552,705	1,414,221	2,601,491	264,201	9,260,270	2,557,047	1,318,756	4,187,465
SD	148,018	30,622	1,900,129	NA	3,322,331	1,871,996	335,012	637,518	62,336	1,965,251	701,530	470,689	1,465,046
Total	1,422,549	536,460	15,454,100	NA	62,334,050	38,495,720	7,469,263	8,652,686	1,036,423	38,088,100	26,577,900	5,753,087	16,405,150

NA = Not sampled.
Non-RIS species are listed in Table B3-1.
Fri Feb 08 14:51:44 MST 2002 Raw.losses. IMPINGEMENT; Plant:salem100.extrapolation
PATHNAME:P:/Intake/Delaware/Del-Science/scodes/tables.output.extrapolation.baseline/raw.losses.imp.salem100.extrapolation.csv

Table B3-12: EPA's Estimate of Mean Annual Impingement at Salem Expressed as Numbers of Age 1 Equivalents Extrapolated to Other Transition Zone Facilities.

Facility	Operational Flow (MGD)[b]	Alewife	American Shad	Atlantic Croaker	Bay Anchovy	Blue Crab	Blueback herring	Spot	Striped Bass	Weak-fish	White Perch	Non-RIS Fishery Species	Non-RIS Forage Species	Total
Salem as extrapolation model[a]	1,722	11,438	1,099	163,425	3,773,602	1,709,674	50,307	235,509	28,438	102,131	1,094,565	204,384	1,940,623	7,920,942
Hope Creek	CBI	412	40	5,884	135,867	61,556	1,811	8,479	1,024	3,677	39,409	7,359	69,871	285,191
DuPont	7	46	4	664	15,340	6,950	205	957	116	415	4,449	831	7,889	32,199
Edge Moor	782	5,194	499	74,215	1,713,680	776,402	22,846	106,950	12,914	46,380	497,067	92,815	881,282	3,597,083
Delaware City Refinery	CBI	2,418	232	34,545	797,672	361,394	10,634	49,782	6,011	21,589	231,372	43,203	410,213	1,674,345
Deepwater	105	695	67	9,927	229,221	103,851	3,056	14,306	1,727	6,204	66,488	12,415	117,880	481,144
Chambers Cogen	37	246	24	3,511	81,082	36,735	1,081	5,060	611	2,194	23,519	4,392	41,697	170,194
General Chemical Corp.	34	225	22	3,217	74,289	33,657	990	4,636	560	2,011	21,548	4,024	38,204	155,935
SPI Polyols	5	33	3	475	10,957	4,964	146	684	83	297	3,178	593	5,635	22,999
Sun Refining	6	40	4	569	13,148	5,957	175	821	99	356	3,814	712	6,762	27,599
Logan Generating Co.	2	13	1	190	4,383	1,986	58	274	33	119	1,271	237	2,254	9,200
Hay Road	2	11	1	152	3,506	1,589	47	219	26	95	1,017	190	1,803	7,360
Totals	--	20,770	1,996	296,774	6,852,748	3,104,716	91,357	427,678	51,643	185,468	1,987,698	371,155	3,524,113	14,384,191

Note: Impingement losses expressed as age 1 equivalents are larger than raw losses (the actual number of organisms impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start of year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details, see description of S^*j in Chapter A5, Equation 4 and Equation 5). This type of adjustment is applied to all raw loss records, but the effect is not readily apparent among entrainment losses because the majority of entrained fish are younger than age 1.

[a] Based on EPA's estimate of Salem's average impingement assuming no impingement survival (see Table B3-11). Salem's data for 1996 was not included because the facility was shut down much of the year.

[b] Current operational flows from results of EPA's survey of the industry were used for all facilities except for Hay Road, Chambers Cogen, SPI Polyols, Sun Refining, and Salem. For Hay Road, Chamberts Cogen, SPI Polyols, Sun Refining, and Salem the average intake flow was used based on the EIA data presented in Chapter B1. For Salem, EPA used the average operational flow for 1978-1998 (excluding 1996, when the facility was shut down).

CBI = Confidential Business Information.

Non-RIS species are listed in Table B3-1.

Wed Feb 06 13:09:42 MST 2002; extrapolation salem.extrapolation; endpoint age.1.equiv.imp P:/INTAKE/Delaware/Del-Science/scodes/extrapolation.baseline.facilities/extrapolation.age.1.equiv.imp.csv

Table B3-13: EPA's Estimate of Mean Annual Impingement of Fishery Species at Salem Expressed as Yield Lost to Fisheries (in pounds) Extrapolated to Other Transition Zone Facilities.

Facility	Operational Flow (MGD)[b]	Alewife	American Shad	Atlantic Croaker	Blue Crab	Spot	Striped Bass	Weakfish	White Perch	Non-RIS Fishery Species	Total
Salem as extrapolation model[a]	1,722	102	269	33,271	54,556	26,377	39,471	80,294	482	18,258	241,212
Hope Creek	CBI	4	10	1,198	1,964	950	1,421	2,891	17	657	8,685
DuPont	7	0	1	135	222	107	160	326	2	74	981
Edge Moor	782	46	122	15,109	24,775	11,978	17,925	36,464	219	8,292	109,540
Delaware City Refinery	CBI	22	57	7,033	11,532	5,576	8,343	16,973	102	3,860	50,988
Deepwater	105	6	16	2,021	3,314	1,602	2,398	4,877	29	1,109	14,652
Chambers Cogen	37	2	6	715	1,172	567	848	1,725	10	392	5,183
General Chemical Corp.	34	2	5	655	1,074	519	777	1,581	9	359	4,749
SPI Polyols	5	0	1	97	158	77	115	233	1	53	700
Sun Refining	6	0	1	116	190	92	138	280	2	64	840
Logan Generating Co.	2	0	0	39	63	31	46	93	1	21	280
Hay Road	2	0	0	31	51	25	37	75	0	17	224
Totals	--	185	489	60,419	99,071	47,899	71,678	145,812	875	33,157	438,034

[a] Based on EPA's estimate of Salem's average impingement assuming no impingement survival (see Table B3-11). Salem's data for 1996 was not included because the facility was shut down much of the year.

[b] Current operational flows from results of EPA's survey of the industry were used for all facilities except for Hay Road, Chambers Cogen, SPI Polyols, Sun Refining, and Salem. For Hay Road, Chamberts Cogen, SPI Polyols, Sun Refining, and Salem the average intake flow was used based on the EIA data presented in Chapter B1. For Salem, EPA used the average operational flow for 1978-1998 (excluding 1996, when the facility was shut down).

0 = Sampled, but none collected.

CBI = Confidential Business Information.

Non-RIS species are listed in Table B3-1.

Wed Feb 06 13:09:35 MST 2002; extrapolation salem100.extrapolation; endpoint yield.lbs.imp P:/INTAKE/Delaware/Del-Science/scodes/extrapolation.baseline.facilities/extrapolation.yield.lbs.imp.csv

Table B3-14: EPA's Estimate of Mean Annual Impingement at Salem Expressed as Production Foregone (in pounds) Extrapolated to Other Transition Zone Facilities.

Facility	Operational Flow (MGD)[b]	Alewife	American Shad	Atlantic Croaker	Bay Anchovy	Blue Crab	Blueback herring	Spot	Striped Bass	Weak-fish	White Perch	Non-RIS Fishery Species	Non-RIS Forage Species	Total
Salem as extrapolation model[a]	1,722	5,334	6,931	93,769	1,850	318,159	15,283	79,316	91,414	204,299	35,017	66,815	1,624	875,327
Hope Creek	CBI	192	250	3,376	67	11,455	550	2,856	3,291	7,356	1,261	2,406	58	31,516
DuPont	7	22	28	381	8	1,293	62	322	372	830	142	272	7	3,558
Edge Moor	782	2,422	3,148	42,583	840	144,483	6,940	36,019	41,513	92,777	15,902	30,342	737	397,506
Delaware City Refinery	CBI	1,128	1,465	19,821	391	67,253	3,231	16,766	19,323	43,185	7,402	14,124	343	185,028
Deepwater	105	324	421	5,696	112	19,326	928	4,818	5,553	12,410	2,127	4,059	99	53,170
Chambers Cogen	37	115	149	2,015	40	6,836	328	1,704	1,964	4,390	752	1,436	35	18,808
General Chemical Corp.	34	105	136	1,846	36	6,263	301	1,561	1,800	4,022	689	1,315	32	17;232
SPI Polyols	5	15	20	272	5	924	44	230	265	593	102	194	5	2,542
Sun Refining	6	19	24	327	6	1,109	53	276	319	712	122	233	6	3,050
Logan Generating Co.	2	6	8	109	2	370	18	92	106	237	41	78	2	1,017
Hay Road	2	5	6	87	2	296	14	74	85	190	33	62	2	813
Totals	--	9,687	12,587	170,282	3,360	577,767	27,753	144,036	166,004	371,001	63,591	121,334	2,948	1,589,567

[a] Based on EPA's estimate of Salem's average impingement assuming no impingement survival (see Table B3-11). Salem's data for 1996 was not included because the facility was shut down much of the year.

[b] Current operational flows from results of EPA's survey of the industry were used for all facilities except for Hay Road, Chambers Cogen, SPI Polyols, Sun Refining, and Salem. For Hay Road, Chamberts Cogen, SPI Polyols, Sun Refining, and Salem the average intake flow was used based on the EIA data presented in Chapter B1. For Salem, EPA used the average operational flow for 1978-1998 (excluding 1996, when the facility was shut down).

CBI = Confidential Business Information.

Non-RIS species are listed in Table B3-1.

Wed Feb 06 13:09:38 MST 2002 extrapolation salem100.extrapolation; endpoint pf.lbs.imp P:/INTAKE/Delaware/Del-Science/scodes/extrapolation.baseline.facilities/extrapolation.pf.lbs.imp.csv

Table B3-15: EPA's Estimate of Mean Annual Entrainment at Salem Expressed as Numbers of Age 1 Equivalents Extrapolated to Other Transition Zone Facilities.

Facility	Operational Flow (MGD)[b]	Alewife	American Shad	Atlantic Croaker	Atlantic Menhaden	Bay Anchovy	Blueback herring	Silversides	Spot	Striped Bass	Weakfish	White Perch	Non-RIS Fishery Species	Non-RIS Forage Species	Total
Salem as extrapolation model[a]	1,722	1,567	70	16,454,185	2,346,168	290,409,647	6,745	107,867	23,848,126	419,505	1,215,517	1,211,578	13,879,726	6,423,701	339,404,878
Hope Creek	CBI	56	3	592,427	84,473	10,456,096	243	3,884	858,643	15,104	43,764	43,622	499,735	231,283	12,220,152
DuPont	7	6	0	66,887	9,537	1,180,527	27	438	96,944	1,705	4,941	4,925	56,422	26,113	1,379,695
Edge Moor	782	711	32	7,472,226	1,065,449	131,881,733	3,063	48,985	10,829,985	190,507	551,994	550,206	6,303,104	2,917,151	154,131,600
Delaware City Refinery	CBI	331	15	3,478,120	495,938	61,387,405	1,426	22,801	5,041,067	88,676	256,939	256,106	2,933,926	1,357,856	71,744,121
Deepwater	105	95	4	999,482	142,514	17,640,447	410	6,552	1,448,614	25,482	73,835	73,595	843,101	390,197	20,616,580
Chambers Cogen	37	34	1	353,545	50,411	6,239,929	145	2,318	512,416	9,014	26,117	26,033	298,229	138,024	7,292,672
General Chemical Corp.	34	31	1	323,924	46,188	5,717,124	133	2,124	469,484	8,259	23,929	23,852	273,242	126,460	6,681,664
SPI Polyols	5	5	0	47,776	6,812	843,234	20	313	69,245	1,218	3,529	3,518	40,301	18,652	985,496
Sun Refining	6	5	0	57,332	8,175	1,011,880	24	376	83,095	1,462	4,235	4,222	48,361	22,382	1,182,595
Logan Generating Co.	2	2	0	19,111	2,725	337,293	8	125	27,698	487	1,412	1,407	16,120	7,461	394,198
Hay Road	2	1	0	15,288	2,180	269,835	6	100	22,159	390	1,129	1,126	12,896	5,969	315,359
Totals	--	2,845	126	29,880,303	4,260,570	527,375,149	12,249	195,883	43,307,476	761,808	2,207,343	2,200,189	25,205,163	11,665,247	616,349,010

[a] Based on EPA's estimate of Salem's average entrainment assuming no entrainment survival (see Table B3-7). Salem's data for 1996 was not included because the facility was shut down much of the year.

[b] Current operational flows from results of EPA's survey of the industry were used for all facilities except for Hay Road, Chambers Cogen, SPI Polyols, Sun Refining, and Salem. For Hay Road, Chamberts Cogen, SPI Polyols, Sun Refining, and Salem the average intake flow was used based on the EIA data presented in Chapter B1. For Salem, EPA used the average operational flow for 1978-1998 (excluding 1996, when the facility was shut down).

0 = Sampled, but none collected.

CBI = Confidential Business Information.

Non-RIS species are listed in Table B3-1.

Wed Feb 06 13:09:43 MST 2002 extrapolation salem100.extrapolation; endpoint age.1.equiv.ent P:/INTAKE/Delaware/Del-Science/scodes/extrapolation.baseline.facilities/extrapolation.age.1.equiv.ent.csv

Table B3-16: EPA's Estimate of Mean Annual Entrainment of Fishery Species at Salem Expressed as Yield Lost to Fisheries (in pounds) Extrapolated to Other Transition Zone Facilities.

Facility	Operational Flow (MGD)[b]	Alewife	American Shad	Atlantic Croaker	Atlantic Menhaden	Silversides	Spot	Striped Bass	Weakfish	White Perch	Non-RIS Fishery Species	Total
Salem as extrapolation model[a]	1,722	14	17	3,349,863	1,177,437	43	2,670,978	582,257	955,624	533	1,239,935	8,943,422
Hope Creek	CBI	1	1	120,611	42,393	2	96,168	20,964	34,407	19	44,643	322,005
DuPont	7	0	0	13,617	4,786	0	10,858	2,367	3,885	2	5,040	36,355
Edge Moor	782	6	8	1,521,250	534,701	20	1,212,953	264,416	433,971	242	563,083	4,061,415
Delaware City Refinery	CBI	3	4	708,101	248,889	9	564,597	123,079	202,002	113	262,100	1,890,479
Deepwater	105	1	1	203,482	71,521	3	162,244	35,368	58,048	32	75,318	543,253
Chambers Cogen	37	0	0	71,977	25,299	1	57,390	12,511	20,533	11	26,642	192,164
General Chemical Corp.	34	0	0	65,947	23,180	1	52,582	11,463	18,813	10	24,410	176,064
SPI Polyols	5	0	0	9,727	3,419	0	7,755	1,691	2,775	2	3,600	25,968
Sun Refining	6	0	0	11,672	4,103	0	9,307	2,029	3,330	2	4,320	31,162
Logan Generating Co.	2	0	0	3,891	1,368	0	3,102	676	1,110	1	1,440	10,387
Hay Road	2	0	0	3,113	1,094	0	2,482	541	888	0	1,152	8,310
Totals	--	25	31	6,083,251	2,138,189	79	4,850,415	1,057,361	1,735,384	968	2,251,685	16,240,984

[a] Based on EPA's estimate of Salem's average entrainment assuming no entrainment survival (see Table B3-7). Salem's data for 1996 was not included because the facility was shut down much of the year.

[b] Current operational flows from results of EPA's survey of the industry were used for all facilities except for Hay Road, Chambers Cogen, SPI Polyols, Sun Refining, and Salem. For Hay Road, Chamberts Cogen, SPI Polyols, Sun Refining, and Salem the average intake flow was used based on the EIA data presented in Chapter B1. For Salem, EPA used the average operational flow for 1978-1998 (excluding 1996, when the facility was shut down).

0 = Sampled, but none collected.

CBI = Confidential Business Information.

Non-RIS species are listed in Table B3-1.

Wed Feb 06 13:09:36 MST 2002 extrapolation salem100.extrapolation; endpoint yield.lbs.ent P:/INTAKE/Delaware/Del-Science/scodes/extrapolation.baseline.facilities/extrapolation.yield.lbs.ent.csv

Table B3-17: EPA's Estimate of Mean Annual Entrainment at Salem Expressed as Production Foregone (in pounds) Extrapolated to Other Transition Zone Facilities.

Facility	Operational Flow (MGD)[b]	Alewife	American Shad	Atlantic Croaker	Atlantic Menhaden	Bay Anchovy	Blueback herring	Silver-sides	Spot	Striped Bass	Weakfish	White Perch	Non-RIS Fishery Species	Non-RIS Forage Species	Total
Salem as extrapolation model[a]	1,722	6,865	1,745	9,352,996	205,337	7,043,992	15,361	12	6,421,484	3,133,998	3,575,891	314,670	16,152,785	418,599	32,834,248
Hope Creek	CBI	247	63	336,751	7,393	253,616	553	0	231,203	112,839	128,749	11,330	581,575	15,072	1,182,185
DuPont	7	28	7	38,020	835	28,634	62	0	26,104	12,740	14,536	1,279	65,662	1,702	133,473
Edge Moor	782	3,117	793	4,247,411	93,248	3,198,839	6,976	6	2,916,144	1,423,221	1,623,895	142,899	7,335,353	190,096	14,910,791
Delaware City Refinery	CBI	1,451	369	1,977,056	43,405	1,488,974	3,247	3	1,357,387	662,471	755,879	66,516	3,414,410	88,484	6,940,573
Deepwater	105	417	106	568,132	12,473	427,875	933	1	390,062	190,369	217,211	19,114	981,174	25,427	1,994,461
Chambers Cogen	37	148	38	200,964	4,412	151,352	330	0	137,976	67,339	76,834	6,761	347,069	8,994	705,498
General Chemical Corp.	34	135	34	184,127	4,042	138,671	302	0	126,416	61,697	70,396	6,195	317,990	8,241	646,389
SPI Polyols	5	20	5	27,157	596	20,453	45	0	18,645	9,100	10,383	914	46,901	1,215	95,338
Sun Refining	6	24	6	32,589	715	24,544	54	0	22,375	10,920	12,460	1,096	56,281	1,459	114,405
Logan Generating Co.	2	8	2	10,863	238	8,181	18	0	7,458	3,640	4,153	365	18,760	486	38,135
Hay Road	2	6	2	8,690	191	6,545	14	0	5,967	2,912	3,323	292	15,008	389	30,508
Totals	--	12,466	3,170	16,984,758	372,886	12,791,676	27,895	23	11,661,222	5,691,246	6,493,709	571,431	29,332,970	760,164	59,626,003

[a] Based on EPA's estimate of Salem's average entrainment assuming no entrainment survival (see Table B3-7). Salem's data for 1996 was not included because the facility was shut down much of the year.
[b] Current operational flows from results of EPA's survey of the industry were used for all facilities except for Hay Road, Chambers Cogen, SPI Polyols, Sun Refining, and Salem. For Hay Road, Chamberts Cogen, SPI Polyols, Sun Refining, and Salem the average intake flow was used based on the EIA data presented in Chapter B1. For Salem, EPA used the average operational flow for 1978-1998 (excluding 1996, when the facility was shut down).
0 = Sampled, but none collected.
CBI = Confidential Business Information.
Non-RIS species are listed in Table B3-1.
Wed Feb 06 13:09:40 MST 2002 extrapolation salem100.extrapolation; endpoint pf.lbs.ent P:/INTAKE/Delaware/Del-Science/scodes/extrapolation.baseline.facilities/extrapolation.pf.lbs.ent.csv

Table B3-18: Salem's Current Impingement Rate Expressed as Numbers of Age 1 Equivalents.

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Bay Anchovy	Blue Crab	Blueback Herring +79% *Alosa* spp.	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.	Non-RIS Fishery Species	Non-RIS Forage Species
1995	2,054	10	151,250	400,287	837,514	18,864	38,554	6,713	35,243	247,600	256,295	2,728,877
1997	941	1	58,241	299,061	286,356	7,480	15,640	6,312	66,917	161,697	302,775	964,074
1998	3,412	1,142	485,999	876,041	282,114	12,061	2,673	4,890	65,409	93,927	88,394	747,858
Mean	2,136	384	231,830	525,130	468,661	12,802	18,956	5,972	55,856	167,741	215,821	1,480,270
Min	941	1	58,241	299,061	282,114	7,480	2,673	4,890	35,243	93,927	88,394	747,858
Max	3,412	1,142	485,999	876,041	837,514	18,864	38,554	6,713	66,917	247,600	302,775	2,728,877
SD	1,238	656	224,976	308,084	319,442	5,728	18,168	958	17,867	77,014	112,776	1,086,716
Total	6,407	1,153	695,490	1,575,389	1,405,984	38,405	56,867	17,916	167,568	503,224	647,464	4,440,810

Note: Impingement losses expressed as age 1 equivalents are larger than raw losses (the actual number of organisms impinged). This is because the ages of impinged individuals are assumed to be distributed across the interval between the start of year 1 and the start of year 2, and then the losses are normalized back to the start of year 1 by accounting for mortality during this interval (for details, see description of S*j in Chapter A5, Equation 4 and Equation 5). This type of adjustment is applied to all raw loss records, but the effect is not readily apparent among entrainment losses because the majority of entrained fish are younger than age 1.

Non-RIS species are listed in Table B3-1.

Fri Feb 01 16:43:32 MST 2002; Results; I Plant: salem100.benefits; Units: equivalent.sums Pathname:
P:/Intake/Delaware/Del-Science/scodes/tables.output.benefits.baseline/I.equivalent.sums.salem100.benefits.csv

Table B3-19: Salem's Current Impingement of Fishery Species Expressed as Yield Lost to Fisheries (in pounds).

Year	Alewife +21% *Alosa* spp.	American Shad	Atlantic Croaker	Blue Crab	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.	Non-RIS Fishery Species
1995	18	2	30,793	26,725	4,318	9,318	27,708	109	22,896
1997	8	0	11,857	9,138	1,752	8,761	52,609	71	27,048
1998	30	280	98,943	9,002	299	6,787	51,423	41	7,897
Mean	19	94	47,198	14,955	2,123	8,289	43,913	74	19,280
Min	8	0	11,857	9,002	299	6,787	27,708	41	7,897
Max	30	280	98,943	26,725	4,318	9,318	52,609	109	27,048
SD	11	161	45,802	10,193	2,035	1,330	14,047	34	10,075
Total	57	282	141,593	44,865	6,369	24,866	131,740	221	57,841

0 = Sampled, but none collected.

Non-RIS species are listed in Table B3-1.

Fri Feb 01 16:43:53 MST 2002; Results; I Plant: salem100.benefits; Units: yield Pathname:
P:/Intake/Delaware/Del-Science/scodes/tables.output.benefits.baseline/I.yield.salem100.benefits.csv

Table B3-20: Salem's Current Impingement Rate Expressed as Production Foregone (in pounds).

Year	Alewife +21% *Alosa* spp.	Americans Shad	Atlantic Croaker	Bay Anchovy	Blue Crab	Blueback Herring +79% *Alosa* spp.	Spot	Striped Bass +58% *Morone* spp.	Weakfish	White Perch +42% *Morone* spp.	Non-RIS Fishery Species	Non-RIS Forage Species
1995	920	242	119,652	284	165,441	5,795	41,326	20,774	77,204	8,423	91,452	2,745
1997	447	25	36,180	242	58,276	2,602	4,280	18,167	139,981	5,094	102,541	741
1998	1,965	6,600	256,217	975	53,341	4,411	2,375	12,814	148,532	3,148	38,158	377
Mean	1,111	2,289	137,350	500	92,353	4,269	15,993	17,252	121,906	5,555	77,383	1,288
Min	447	25	36,180	242	53,341	2,602	2,375	12,814	77,204	3,148	38,158	377
Max	1,965	6,600	256,217	975	165,441	5,795	41,326	20,774	148,532	8,423	102,541	2,745
SD	777	3,735	111,081	412	63,344	1,601	21,959	4,058	38,948	2,667	34,420	1,275
Total	3,332	6,867	412,050	1,501	277,058	12,807	47,980	51,755	365,717	16,665	232,150	3,863

Non-RIS species are listed in Table B3-1.
Fri Feb 01 16:43:43 MST 2002; Results; I Plant: salem100.benefits; Units: annual.prod.forg Pathname:
P:/Intake/Delaware/Del-Science/scodes/tables.output.benefits.baseline/I.annual.prod.forg.salem100.benefits.csv

Table B3-21: Summary of Cumulative Impingement Impacts of Delaware Estuary Transition Zone CWIS (sum of annual means of all species evaluated).

Facility	Raw Losses	# of Age 1 Equivalents	Lb of Fishery Yield	Lb of Production Foregone
Salem[a]	6,633,845	3,185,559	135,945	477,249
Hope Creek	—	285,191	8,685	31,516
DuPont	—	32,199	981	3,558
Edge Moor	—	3,597,083	109,540	397.506
Delaware City Refinery	—	1,674,345	50,988	185,028
Deepwater	—	481,144	14,652	53,170
Chambers Cogen	—	170,194	5,183	18,808
General Chemical Corp.	—	155,935	4,749	17,232
SPI Polyols	—	22,999	700	2,542
Sun Refining	—	27,599	840	3,050
Logan Generating Co.	—	9,200	280	1,017
Hay Road	—	7,360	224	813
TOTALS	—	**9,648,808**	**332,767**	**794,381**

[a] Based on EPA's estimate of Salem's current impingement (see Section B3-7).

Table B3-22: Summary of Cumulative Entrainment Impacts of Delaware Estuary Transition Zone CWIS (sum of annual means of all species evaluated).

Facility	Raw Losses	# of Age 1 Equivalents	Lb of Fishery Yield	Lb of Production Foregone
Salem[a]	14,660,055,610	338,955,960	9,569,550	45,208,635
Hope Creek	—	12,220,152	322,005	1,182,185
DuPont	—	1,379,695	36,355	133,473
Edge Moor	—	154,131,600	4,061,415	14,910,791
Delaware City Refinery	—	71,744,121	1,890,479	6,940,573
Deepwater	—	20,616,580	543,253	1,994,461
Chambers Cogen	—	7,292,672	192,164	705,498
General Chemical Corp.	—	6,681,664	176,064	646,389
SPI Polyols	—	985,496	25,968	95,338
Sun Refining	—	1,182,595	31,162	114,405
Logan Generating Co.	—	394,198	10,387	38,135
Hay Road	—	315,359	8,310	30,508
TOTALS	—	**615,900,092**	**16,867,112**	**72,000,391**

[a] Based on EPA's estimate of Salem's current entrainment (see Section B3-7).

Chapter B4: Economic Value of I&E Losses Based on Benefits Transfer Techniques

This chapter presents an analysis using benefits transfer techniques of economic losses associated with I&E in the Delaware Estuary transition zone. Most of the chapter discusses I&E impacts at the Salem facility because this is the only facility in the transition zone that reported comprehensive I&E data. I&E results from the Salem facility were extrapolated to other in-scope and out-of-scope transition zone facilities (see Section B3-6 of Chapter B3) and summed to obtain total I&E at all transition zone CWIS (see summary of results in Section B3-9 of Chapter B3). Sections B4-1 to B4-6 of this chapter discuss the economic value of I&E at the Salem facility. Section B4-7 discusses the economic value of I&E at all in-scope facilities (Salem, Hope Creek, Edge Moor, and Deepwater), and Section B4-8 discusses economic values for all in-scope and out of scope transition zone CWIS.

CHAPTER CONTENTS

B4-1 OVERVIEW OF VALUATION APPROACH

I&E at transition zone CWIS affect recreational and commercial fisheries as well as forage species that contribute to the biomass of recreational and commercial species. EPA evaluated all these species groups to capture the total economic impact of I&E at transition zone CWIS.

Recreational fishery impacts are based on benefits transfer methods, applying the results from nonmarket valuation studies. Commercial fishery impacts are based on commodity prices for the individual species. The economic value of forage species losses is determined by estimating the replacement cost of these fish if they were to be restocked with hatchery fish, and by considering the foregone biomass production of forage fish resulting from I&E losses and the consequential foregone production of commercial and recreational species that use the forage species as a prey base. All of these methods are explained in further detail in the Chapters A5 and A9 of Part A of this document.

Many of the I&E-impacted fish species at CWIS sites are harvested both recreationally and commercially. To avoid double-counting the economic impacts of I&E on these species, EPA determined the proportion of total species landings attributable to recreational and commercial fishing, and applied this proportion to the impacted fishery catch. For example, if 30 percent of the landed numbers of one species are harvested commercially at a site, then 30 percent of the estimated catch of I&E-impacted fish are assigned to the increase in commercial landings. The remaining 70 percent of the estimated total landed number of I&E-impacted adult equivalents are assigned to the recreational landings.

The National Marine Fisheries Service (NMFS) provides both recreational and commercial fishery landings data by state. To determine what proportions of total landings per state occur in the recreational or commercial fishery, EPA summed the landings data for the recreational and commercial fishery, and then divided by each category to get the corresponding percentage. The percentages applied in this analysis are presented in Table B4-1.

As discussed in Chapter A5 of Part A of this document, the yield estimates in Chapter B3 represent the total pounds of foregone yield for both the commercial and recreational catch combined. For the economic valuation discussed in this chapter, total yield was partitioned between commercial and recreational fisheries based on the landings in each fishery, as shown in Table B4-1. Because the economic evaluation of recreational yield is based on numbers of fish rather than pounds, foregone recreational yield was converted to numbers of fish. This conversion was based on the average weight of harvestable fish of each species. Table B4-2 shows these conversions for the Salem impingement data presented in Section B3-7 of Chapter B3 and Table B4-3 displays these data for the entrainment estimates given in Section B3-5. Note that the numbers of foregone recreational fish harvested are typically lower than the numbers of age 1 equivalent losses, since the age of harvest of most fish is greater than age 1.

Table B4-1: Percentages of Total Impacts in the Recreational and Commercial Fisheries of Species at Salem Facility.

Fish Species	Percent Impacts to Recreational Fishery	Percent Impacts to Commercial Fishery
Alewife[a]	0	100
American shad	56	44
Atlantic croaker	10	90
Atlantic menhaden	0	100
Blue crab	4	96
Silverside[a]	0	100
Spot	18	82
Striped bass	97	3
Weakfish	31	69
White perch	42	58
Non-RIS fishery species[b]	26	74

[a] Obtained from NMFS, 2001a and b.
[b] Table B3-1 of Chapter B3 lists non-RIS fishery species. The commercial/recreational split used is an average of the splits for the other species listed above.
Source: PSEG, 1999c, Appendix F.

Table B4-2: Summary of Salem's Mean Annual Impingement of Fishery Species.

Species	Impingement Count (#)	Age 1 Equivalents (#)	Total Catch (#)	Total Yield (lb)	Commercial Catch (#)	Commercial Yield (lb)	Recreational Catch (#)	Recreational Yield (lb)
Alewife	9,560	2,136	44	19	44	19	0	0
American shad	3,658	384	23	94	10	41	13	8
Atlantic croaker	1,082,318	231,830	28,064	47,198	25,258	42,478	2,806	674
Blue crab	589,511	468,661	53,269	14,955	51,138	14,357	2,131	85
Spot	20,111	18,956	5,120	2,123	4,199	1,741	922	55
Striped bass	11,417	5,972	743	8,289	22	249	721	1,149
Weakfish	1,348,531	55,856	8,020	43,913	5,534	30,300	2,486	1,945
White perch	224,902	167,741	318	74	184	43	133	5
Non-RIS fishery species[a]	934,370	215,821	17,895	19,280	13,242	14,267	4,653	716
Total	4,224,378	1,167,358	113,496	135,945	99,632	103,495	13,865	4,638

[a] Table B3-1 of Chapter B3 lists non-RIS species.

Table B4-3: Summary of Salem's Mean Annual Entrainment Results for Fishery Species.

Species	Entrainment Count (#)	Age 1 Equivalents (#)	Total Catch (#)	Total Yield (lb)	Commercial Catch (#)	Commercial Yield (lb)	Recreational Catch (#)	Recreational Yield (lb)
Alewife	1,338,721	1,567	32	14	32	14	0	0
American shad	57,131	70	4	17	2	8	2	8
Atlantic croaker	115,035,206	16,454,185	1,991,879	3,349,863	1,792,691	3,014,877	199,188	287,131
Atlantic menhaden	21,786,584	2,346,168	723,773	1,177,437	723,773	1,177,437	0	0
Silversides	26,001,930	107,867	3,959	43	3,959	43	0	0
Spot	49,187,259	23,848,126	6,441,601	2,670,978	5,282,113	2,190,202	1,159,488	412,094
Striped bass	41,434,832	419,505	52,189	582,257	1,566	17,468	50,624	484,105
Weakfish	104,383,899	1,215,517	174,528	955,624	120,424	659,381	54,104	253,923
White perch	44,044,530	1,211,578	2,295	533	1,331	309	964	192
Non-RIS fishery species[a]	153,969,330	13,879,726	1,150,863	1,239,935	851,639	917,552	299,224	46,055
Total	557,239,422	59,484,307	10,541,123	9,976,701	8,777,529	7,977,290	1,763,594	1,483,508

[a] Table B3-1 of Chapter B3 lists non-RIS species.

B4-2 Economic Value of Average Annual Recreational Fishery Losses at the Salem Facility

B4-2.1 Economic Values for Recreational Losses from Consumer Surplus Literature

There is a large literature that provides willingness-to-pay values for increases in recreational catch rates. These increases in value are benefits to the anglers, and are often referred to by economists as "consumer surplus." For the application of this literature to value I&E impacts, EPA focused on changes in consumer surplus per additional fish caught.

When using values from the existing literature as proxies for the value of a trip or fish at a site not studied, it is important to select values for similar areas and species. Table B4-4 gives a summary of several studies that are closest to Delaware Estuary fisheries in geographic area and relevant species.

McConnell and Strand (1994) estimated fishery values for the mid- and south Atlantic states using data from the National Marine Fisheries Statistical Survey. They created a random utility model of fishing behavior for nine states, the northernmost being New York. In this model they specified four categories of fish: small gamefish (e.g., striped bass), flatfish (e.g., flounder), bottomfish (e.g., weakfish, spot, Atlantic croaker, perch), and big gamefish (e.g., shark). For each fish category, they estimated per angler values for access to marine waters and for an increase in catch rates.

Hicks et al. (1999) used the same method as McConnell and Strand (1994) but estimated values for a day of fishing and an increase in catch rates for the Atlantic states from Virginia north to Maine. Their estimates were generally lower than those of McConnell and Strand (1994) and can serve as a lower bound for the values of fish.

Agnello (1989) estimated one value for increased weakfish catch rates in all the Atlantic states. This study is useful because it values weakfish specifically, but the area considered ranges from Florida to Maine. This large study area may differ from the Delaware Estuary, where weakfish is a very important recreational species.

Norton et al. (1983) estimated the value of the striped bass fishery for the mid-Atlantic coast, including Delaware and New Jersey.

Tudor et al. (2002; see Chapter B5 of this document) estimated willingness-to-pay (WTP) values for increases in recreational catch rates for selected species in Delaware Bay Estuary (values also were derived for the Ohio River and Tampa Bay). The analysis used random utility modeling (RUM) to estimate WTP for an additional fish per trip. These values estimated were not applied in the Salem benefits transfer analysis done here in this chapter, but are discussed and used in Chapter B5, and applied to baseline losses in Chapter B6.

Table B4-4: Selected Valuation Studies for Estimating Changes in Catch Rates.

Authors	Study Location and Year	Item Valued	Value Estimate ($2000)	
McConnell and Strand (1994)	Mid- and south Atlantic coast, anglers targeting specific species, 1988	Catch rate increase of 1 fish per trip for DE and NJ[a]	DE small game fish DE bottom fish NJ small game fish NJ bottom fish	$15.45 $0.13 $9.19 $1.75
Hicks et al. (1999)	Mid-Atlantic coast, 1994	Catch rate increase of 1 fish per trip, from catch rates at all sites, for DE and NJ	DE small game fish DE bottom fish NJ small game fish NJ bottom fish	$3.13 $2.39 $3.49 $2.01
Agnello (1989)	Atlantic coast, 1981	Mean value per fish caught, for the Atlantic coast[b]	Weakfish	$2.72
Norton et al. (1983)	Mid-Atlantic coast, 1980	Catch rate increase of 1 striped bass per trip, for mid-Atlantic	Striped bass	$15.55
Tudor et al. (2002)[c]	Delaware Estuary, 1994-1998	Catch rate increase of 1 fish per trip, for DE	Weakfish Striped bass Bluefish Flounder	$11.50 $18.14 $3.94 $3.92

[a] Value was reported as "two month value per angler for a half fish catch increase per trip." From 1996 National Survey of Fishing, Hunting and Wildlife-Associated Recreation (U.S. DOI, 1997); the average saltwater angler takes 1.5 trips in a 2 month period. Therefore, to convert to a "1 fish per trip" value, EPA divided the 2 month value by 1.5 trips and then multiplied it by 2, assuming the value of a fish was linear.
[b] These values were reported as "consumer surplus for an 20 percent increase in catch rate for all fish." The average catch rate was 4.95 fish per trip, therefore a 20 percent increase in catch is equivalent to 1 more fish.
[c] See Chapter B5 of this document.

EPA used results from these studies (all except Tudor et al., 2002; see Chapter B5 of this document) to create a range of possible consumer surplus values for the recreational fish landings foregone because of impingement and entrainment at Salem.

To estimate a unit value for recreational landings, EPA established a lower and upper value for the recreational species, based on values reported in the studies in Table B4-4. Because the studies in Table B4-4 are geographically specific, EPA created a lower and upper value for Delaware and New Jersey, and then calculated a weighted average value based on the proportion of landings from each state. These values are presented in Table B4-5.

Table B4-5: Average Recreational Value by Species for Delaware and New Jersey, 1990-1998.

Species	State	Percentage Catch	Value/Fish ($2000)		Weighted Average ($2000)	
			Low	High	Low	High
Atlantic croaker	DE	67.4%	$0.13	$2.01	$0.66	$2.27
	NJ	32.6%	$1.75	$2.39		
American shad	DE	50.0%	$0.13	$2.01	$0.94	$2.20
	NJ	50.0%	$1.75	$2.39		
Spot	DE	66.5%	$0.13	$2.01	$0.67	$2.26
	NJ	33.5%	$1.75	$2.39		
Striped bass	DE	9.2%	$3.13	$15.55[a]	$3.46	$15.55
	NJ	90.8%	$3.49			
Weakfish	DE	36.5%	$0.13	$2.72[b]	$1.16	$2.72
	NJ	63.5%	$1.75			
White perch	DE	69.6%	$0.13	$2.01	$0.62	$2.27
	NJ	30.4%	$1.75	$2.39		
Blue crab[c]	DE	-	-	-	$1.25[c]	$4.55[c]
	NJ	-	-	-		
Non-RIS fishery species[d]	DE	-	-	-	$1.25[c]	$4.55[c]
	NJ	-	-	-		

[a] Striped bass high value taken from Norton et al. (1983) and is the same for both states.
[b] Weakfish high value taken from Agnello (1989) and is the same for both states.
[c] Recreational catch and value information has not been located, thus EPA used an equally weighted average value of the other species listed in the table.
[d] Recreational values used are averaged from all other species' values. See Table B3-1 of Chapter B3 for list of non-RIS fishery species.
Source: NMFS, 2001b.

B4-2.2 Average Annual I&E Losses of Recreational Yield at Salem and Economic Value of Losses

EPA estimated the economic value of I&E impacts to recreational fisheries using the I&E estimates presented in Tables B4-2 and B4-3 and the economic values in Table B4-5. Results are displayed in Tables B4-6 and B4-7, for impingement and entrainment, respectively. The estimated total loss to recreational fisheries ranges from $16,400 to $57,600 per year for impingement, and from $1,523,400 to $5,373,000 per year for entrainment.

Table B4-6: Mean Annual Impingement of Recreational Fishery Species at Salem and Associated Economic Values Based on the Impingement Data Summarized in Table B4-2 and Discussed in Section B3-7 of Chapter B3.

Species	Loss to Recreational Catch from Impingement (number of fish)	Recreational Value/Fish[a]		Annual Loss in Recreational Value from Impingement ($2000)	
		Low	High	Low	High
American shad	13	$0.94	$2.20	$12	$28
Atlantic croaker	2,806	$0.66	$2.27	$1,847	$6,360
Atlantic menhaden	NA			NA	NA
Blue crab[b]	2,131	$1.25	$4.55	$2,667	$9,686
Silversides	NA			NA	NA
Spot	922	$0.67	$2.26	$620	$2,085
Striped bass	721	$3.46	$15.55	$2,491	$11,206
Weakfish	2,486	$1.16	$2.72	$2,881	$6,762
White perch	133	$0.62	$2.27	$83	$304
Non-RIS fishery species[c]	4,653	$1.25	$4.55	$5,816	$21,170
Total	13,865			$16,417	$57,601

NA = data not available.

[a] Recreational values stated are weighted averages, as calculated in Table B4-5, and values listed here are rounded to two digits, but are not rounded in the calculations.

[b] Recreational catch and value information has not been located, thus EPA used an equally weighted average value of the other species listed in the table.

[c] Recreational values used are averaged from all other species' values. See Table B3-1 of Chapter B3 for list of non-RIS fishery species.

Fri Feb01 16:59:11 MST 2002; Table B: recreational losses and value for selected species; Plant: salem100.benefits, type: I Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.benefits.baseline/TableB.rec.losses.salem100.benefits.I.csv

Table B4-7: Mean Annual Entrainment of Recreational Fishery Species at Salem and Associated Economic Values Based on the Entrainment Presented in Table B4-3 and Discussed in Section B3-5 of Chapter B3.

Species	Loss to Recreational Catch from Entrainment (number of fish)	Recreational Value/Fish[a]		Annual Loss in Recreational Value from Entrainment ($2000)	
		Low	High	Low	High
American shad	2	$0.94	$2.20	$2	$5
Atlantic croaker	199,188	$0.66	$2.27	$131,090	$451,384
Spot	1,159,488	$0.67	$2.26	$779,988	$2,623,574
Striped bass	50,624	$3.46	$15.55	$175,000	$787,199
Weakfish	54,104	$1.16	$2.72	$62,690	$147,162
White perch	964	$0.62	$2.27	$600	$2,193
Non-RIS fishery species[b]	299,224	$1.25	$4.55	$374,031	$1,361,471
Total	1,763,594			$1,523,400	$5,372,987

[a] Recreational values stated are weighted averages, as calculated in Table B4-5, and values listed here are rounded to two digits, but are not rounded in the calculations. Thus, annual losses that are reported here may differ from calculations made with the rounded values.

[b] Recreational values used are averaged from all other species' values. See Table B3-1 of Chapter B3 for list of non-RIS fishery species.

Fri Feb 01 16:59:27 MST 2002; Table B: recreational losses and value for selected species; Plant: salem100.benefits; type: E Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.benefits.baseline/TableB.rec.losses.salem100.benefits.E.csv

B4-3 Economic Value of Average Annual Commercial Fishery Losses at the Salem Facility

B4-3.1 Average Annual I&E Losses of Commercial Yield at Salem and Economic Value of Losses

I&E losses to commercial catch (pounds) are presented in Tables B4-2 (for impingement) and B4-3 (for entrainment) based on the commercial and recreational splits listed in Table B4-1. EPA estimates of the economic value of these losses are displayed in Tables B4-8 and B4-9 for impingement and entrainment, respectively. Market values per pound are listed as well as the total market losses experienced by the commercial fishery. Values for commercial fishing are relatively straightforward because commercially caught fish are a commodity with a market price. The estimates of market loss to the commercial fisheries are $98,000 per year for impingement, and $5,814,700 per year for entrainment.

Table B4-8: Mean Annual Impingement of Commercial Fishery Species at Salem and Associated Economic Values Based on the Impingement Data Presented in Table B4-2 and Discussed in Section B3-7 of Chapter B3.

Species	Loss to Commercial Catch from Impingement (lb of fish)	Commercial Value (lb of fish)[b]	Annual Loss in Commercial Value from Impingement ($2000)
Alewife	19	$0.11	$2
American shad	41	$0.72	$30
Atlantic croaker	42,478	$0.70	$29,735
Atlantic menhaden	NA	$0.07	NA
Blue crab	14,357	$1.02	$14,644
Spot	1,741	$0.85	$1,480
Striped bass	249	$3.18	$791
Weakfish	30,300	$1.24	$37,572
White perch	43	$1.20	$51
Non-RIS fishery species[a]	14,267	$0.96	$13,697
Total	103,495		$98,001

NA = data not available.

[a] Commercial value used is the average commercial value for the other species. See Table B3-1 of Chapter B3 for list of non-RIS fishery species.

[b] Values are rounded to two decimal places here for listing but not in the calculations.

Fri Feb 01 16:59:27 MST 2002 ; TableC: commercial losses and value for selected species; Plant: salem100.benefits; type: I Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.benefits.baseline/TableC.comm.losses.salem100.benefits.I.csv

Table B4-9: Mean Annual Entrainment of Commercial Fishery Species at Salem and Associated Economic Values Based on the Entrainment Data Presented in Table B4-3 and Discussed in Section B3-5 of Chapter B3.

Species	Loss to Commercial Catch from Entrainment (lb of fish)	Commercial Value (lb of fish)[b]	Annual Loss in Commercial Value from Entrainment ($2000)
Alewife	14	$0.11	$2
American shad	7	$0.72	$5
Atlantic croaker	3,014,877	$0.70	$2,110,414
Atlantic menhaden	1,177,437	$0.07	$88,184
Silversides	43	$0.46	$20
Spot	2,190,202	$0.85	$1,861,672
Striped bass	17,468	$3.18	$55,547
Weakfish	659,381	$1.24	$817,632
White perch	309	$1.20	$371
Non-RIS fishery species[a]	917,552	$0.96	$880,850
Total	7,977,290		$5,814,696

[a] Commercial value used is the average commercial value for the other species. See Table B3-1 of Chapter B3 for list of non-RIS fishery species.
[b] Values are rounded to two decimal places here for listing but not in the calculations.
Fri Feb 01 16:59:30 MST 2002 ; TableC: commercial losses and value for selected species; Plant: salem100.benefits; type: E Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.benefits.baseline/TableC.comm.losses.salem100.benefits.E.csv

B4-3.2 Economic Impacts of Commercial Landings Losses

The previous section expresses changes to commercial activity as changes in dockside market prices. However, to determine the total economic impact from changes to the commercial fishery, EPA also determined the losses experienced by producers wholesalers, retailers, and consumers.

The total social benefits (economic surplus) are greater than the increase in dockside landings, because the increased landings by commercial fishermen contribute to economic surplus in each of a multi-tiered set of markets for commercial fish. The total economic surplus impact thus is valued by examining the multi-tiered markets through which the landed fish are sold, according to the methods and data detailed in Chapter A9.

The first step of the analysis involves a fishery-based assessment of I&E-related changes in commercial landings (pounds of commercial species as sold dockside by commercial harvesters). The results of this dockside landings value step are described above. The next steps then entail tracking the anticipated additional economic surplus generated as the landed fish pass from dockside transactions to other wholesalers, retailers and, ultimately, consumers. The resulting total economic surplus measures include producer surplus to the watermen who harvest the fish, as well as the rents and consumer surplus that accrue to buyers and sellers in the sequence of market transactions that apply in the commercial fishery context.

To estimate producer surplus from the landings values, EPA relied on empirical results from various researchers that can be used to infer producer surplus for watermen based on gross revenues (landings times wholesale price). The economic literature (Huppert, 1990; Rettig and McCarl, 1985) suggests that producer surplus values for commercial fishing ranges from 50 to 90 percent of the market value. In assessments of Great Lakes fisheries, an estimate of approximately 40% has been derived as the relationship between gross revenues and the surplus of commercial fishermen (Cleland and Bishop, 1984, Bishop, personal communication, 2002). For the purposes of this study, EPA believes producer surplus to watermen is probably in the range of 40% to 70% of dockside landings values.

Producer surplus is one portion of the total economic surplus impacted by increased commercial stocks — the total benefits are comprised of the economic surplus to producers, wholesalers, processors, retailers, and consumers. Primary empirical research deriving "multi-market" welfare measures for commercial fisheries have estimated that surplus accruing to commercial anglers amount to approximately 22% of the total surplus accruing to watermen, retailers and consumers combined (Norton et al., 1983; Holt and Bishop, 2002). Thus, total economic surplus across the relevant commercial fisheries multi-tiered markets can be estimated as approximately 4.5 times greater than producer surplus alone (given that producer surplus is roughly 22% of the total surplus generated). This relationship is applied in the case studies to estimate total surplus from the projected changes in commercial landings.

Applying this method, estimates of the baseline economic loss to the commercial fisheries ranges from $178,200 to $311,800 per year for impingement, and from $10,572,200 to $18,501,300 per year for entrainment for the Salem facility.

B4-4 Economic Value of Forage Fish Losses

Many fish species affected by I&E are not commercially or recreationally fished. For the purposes in this study, EPA referred to these species as forage fish. Forage fish are species that are prey for other species and are important components of aquatic food webs. Table B4-10 summarizes impingement losses of forage species at Salem and Table B4-11 summarizes entrainment losses. The following sections discuss the economic valuation of these losses using two alternative valuation methods.

Table B4-10: Summary of Salem's Mean Annual Impingement of Forage Species.

Species	Impingement Count (#)	Age 1 Equivalents (#)	Production Foregone (lb)
Bay anchovy	592,248	525,130	500
Blueback herring	83,997	12,802	4,269
Non-RIS Forage[a]	1,733,222	1,480,270	1,288
Total	2,409,467	2,018,201	6,057

[a] Table B3-1 of Chapter B3 lists non-RIS species.

Table B4-11: Summary of Salem's Mean Annual Entrainment of Forage Species.

Species	Entrainment Count (#)	Age 1 Equivalents (#)	Production Foregone (lb)
Bay anchovy	13,129,437,661	290,409,647	7,043,992
Blueback herring	5,563,808	6,745	15,361
Non-RIS forage[a]	967,814,719	6,423,701	1,255,798
Forage sum	14,102,816,188	296,840,093	8,315,151

[a] Table B3-1 of Chapter B3 lists non-RIS species.

Replacement cost of fish

The replacement value of fish can be used in several instances. First, if a fish kill of a fishery species is mitigated by stocking of hatchery fish, then losses to commercial and recreational fisheries would be reduced, but fish replacement costs would still be incurred and should be accounted for. Second, if the fish are not caught in the commercial or recreational fishery, but are important as forage or bait, the replacement value can be used as a lower bound estimate of their value (it is a lower bound because it would not consider how reduction in their stock may affect other species' stocks). Third, where there are not enough data to allow calculation of the value of losses to the recreational and commercial fisheries, replacement cost can be used as a proxy for lost fishery values.

The cost of replacing forage fish lost to I&E has two main components. The first component is the cost of raising the replacement fish. Table B4-12 displays the replacement costs of two of the forage fish species known to be impinged or entrained at Salem. The costs are average costs to fish hatcheries across North America to produce the fish for stocking. The second component of replacement cost is the transportation cost, which includes costs associated with vehicles, personnel, fuel, water, chemicals, containers, and nets. The AFS (1993) estimates these costs at approximately $1.13 per mile, but does not indicate how many fish (or how many pounds of fish) are transported for this price. Lacking relevant data, EPA does not include the transportation costs in this valuation approach.

Table B4-12 also presents the annual average replacement cost for impinged and entrained forage species at Salem. The value of these losses using the replacement cost method is $2,246 per year for impingement and $130,224 per year for entrainment.

Table B4-12: Replacement Costs for Losses of Forage Fish Species at the Salem Facility.[a]

Species	Hatchery Costs ($/lb)	Annual Cost of Replacing Forage Losses ($2000)	
		Impingement	Entrainment
Bay anchovy (all U.S. regions)	$0.11	$220	$121,838
Blueback herring (all U.S. regions)	$0.52	$106	$56
Non-RIS forage species[b]	$0.34	$1,920	$8,330
Total		$2,246	$130,224

[a] Values are from AFS (1993). These values were inflated to $2000 from $1989, but this could be imprecise for current fish rearing and stocking costs.
[b] This is an average value for all species listed in AFS (1993). See Table B3-1 of Chapter B3 for list of non-RIS forage species.

Production foregone value of forage fish

This approach considers the foregone production of commercial and recreational fishery species resulting from I&E of forage species based on estimates of trophic transfer efficiency, as discussed in Chapter A5 of Part A of this document. The economic valuation of forage losses is based on the dollar value of the foregone fishery yield resulting from these losses. Table B4-13 displays the results for impingement of forage species at Salem and B4-14 displays results for entrainment. The values listed are obtained by converting the forage species into species that may be commercially or recreationally valued. The values range from $30 to $80 per year for impingement and from $48,500 to $129,900 per year for entrainment.

Table B4-13: Mean Annual Value of Production Foregone of Selected Fishery Species Resulting from Impingement of Forage Species at Salem Based on the Impingement Data Presented in Table B4-10 and Discussed in Section B3-7 of Chapter B3.

Species	Annual Loss in Production Foregone Value from Impingement of Forage Species ($2000)	
	Low	High
Atlantic croaker	$5	$9
Blue crab	$4	$9
Spot	$4	$8
Striped bass	$3	$11
Weakfish	$8	$14
White perch	$0	$1
Non-RIS fishery species[a]	$5	$11
Total	$30	$63

[a] See Table B3-1 of Chapter B3 for list of non-RIS fishery species.
Fri Feb 01 16:59:21 MST 2002; Table D: loss in selected forage species; Plant: salem100.benefits; type: I Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.benefits.baseline/TableD.forage.eco.ter.repl.salem100.benefits.I.csv

Table B4-14: Mean Annual Value of Production Foregone of Selected Fishery Species Resulting from Entrainment of Forage Species at Salem Based on the Entrainment Data Presented in Table B4-11 and Discussed in Section B3-5 of Chapter B3.

Species	Annual Loss in Production Foregone Value from Entrainment of Forage Species ($2000)	
	Low	High
Alewife	$18	$31
American shad	$161	$299
Atlantic croaker	$4,122	$7,444
Atlantic menhaden	$6,944	$12,152
Silversides	$25,247	$44,182
Spot	$10,908	$22,385
Striped bass	$909	$3,174
Weakfish	$6,705	$11,896
White perch	$451	$1,193
Non-RIS fishery species[a]	$398	$839
Total	$55,862	$103,595

[a] See Table B3-1 of Chapter B3 for list of non-RIS fishery species.
Fri Feb 01 16:59:33 MST 2002; Table D: loss in selected forage species; Plant: salem100.benefits; type: E Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.benefits.baseline/TableD.forage.eco.ter.repl.salem100.benefits.E.csv

B4-5 Nonuse Values

Recreational consumer surplus and commercial impacts are only part of the total losses that the public realizes from I&E impacts on fisheries. Nonuse or passive use impacts arise when individuals value environmental changes apart from any past, present, or anticipated future use of the resource in question. Such passive use values have been categorized in several ways in the economic literature, typically embracing the concepts of existence (stewardship) and bequest (intergenerational equity) motives. Using a "rule of thumb" that nonuse impacts are at least equivalent to 50 percent of the recreational use impact (see Chapter A9 for further discussion), EPA estimated nonuse values for baseline losses at Salem to range from $8,200 to $28,800 per year for impingement and from $761,700 to $2,686,500 per year for entrainment.

B4-6 Summary of Mean Annual Value of Economic Losses at Salem

Table B4-15 summarizes the estimated current annual I&E at the Salem facility and the economic valuation of these losses. Estimated total impacts range from $0.2 million to $0.4 million per year for impingement and from $12.9 million to $26.7 million per year for entrainment.

Table B4-15: Summary of Economic Valuation of Mean Annual I&E at Salem Facility ($2000).

		Impingement	Entrainment	Total	Percent of Impingement Impacts[a]	Percent of Entrainment Impacts[a]
Commercial: Total Surplus (Direct Use, Market)	Low	$178,184	$10,572,175	$10,750,359	81.2%	73.4%
	High	$311,822	$18,501,306	$18,813,128		
Recreational (Direct Use, Nonmarket)	Low	$16,417	$1,523,400	$1,539,816	12.3%	17.4%
	High	$57,601	$5,372,987	$5,430,588		
Nonuse (Passive Use, Nonmarket)	Low	$8,208	$761,700	$769,908	6.1%	8.7%
	High	$28,800	$2,686,493	$2,715,294		
Forage (Indirect Use, Nonmarket)					0.4%	0.5%
Production Foregone	Low	$30	$55,862	$55,893		
	High	$63	$103,595	$103,659		
Replacement		$2,246	$130,224	$132,470		
Total (Com + Rec + Nonuse + Forage)[b]	Low	$202,839	$12,913,137	$13,115,976	100%	100%
	High	$400,469	$26,691,011	$27,091,480		

[a] Midpoints of the ranges are used to calculate percentages.
[b] In calculating the total low values, the lower of the two forage valuation methods (production foregone and replacement) was used and to calculate the total high values, the higher of the two forage valuation methods was used.
Fri Feb 01 16:59:39 MST 2002 ; TableE.summary; Plant: salem100.benefits ; Pathname: P:/Intake/Delaware/Del-Science/scodes/tables.output.benefits.baseline/TableE.summary.salem100.benefits.csv

B4-7 Total Economic Damages for Generating Facilities Regulated Under Phase 2

I&E results for the Salem facility were extrapolated to other in-scope transition zone facilities (see Section B3-6 of Chapter B3) and summed to obtain total losses from I&E at all in-scope transition zone CWIS. Table B4-16 displays estimates of the economic value of these losses. Results range from $0.4 million to $0.8 million per year for impingement and from $20.0 million to $41.4 million per year for entrainment.

Table B4-16: EPA's Estimates of Average Annual Economic Losses at In-scope CWIS of the Transition Zone of the Delaware Estuary ($2000).

Facility	Impingement Losses		Entrainment Losses		Total	
	Low	High	Low	High	Low	High
Salem[a]	$202,839	$400,469	$12,913,137	$26,691,011	$13,115,976	$27,091,480
Hope Creek	$13,963	$28,920	$464,933	$961,000	$478,896	$989,921
Edge Moor	$176,114	$364,771	$5,864,154	$12,121,005	$6,040,268	$12,485,776
Deepwater (w/o Chambers Cogen)	$23,557	$48,792	$784,387	$1,621,301	$807,944	$1,670,092
Total	$416,473	$842,952	$20,026,611	$41,394,317	$20,443,084	$42,237,269

[a] Based on EPA's estimate of Salem's current I&E assuming no impingement or entrainment survival, as discussed in Section B3-7 of Chapter B3. Salem's data for 1996 was not included because the facility was shut down much of the year.
Wed Feb 06 13:15:50 MST 2002 extrapolation.summary ; salem100.extrapolation
P:/INTAKE/Delaware/Del-Science/scodes/extrapolation.benefits.facilities/extrapolation.summarynew.csv

B4-8 Total Economic Damages for All Transition Zone CWIS

Table B4-17 displays EPA's estimates of the mean annual economic losses for all transition zone CWIS (both in scope and out of scope of the proposed rule). Results for these facilities together range from $0.5 million to $1.1 million per year for impingement and from $23.4 million to $48.5 million per year for entrainment.

Table B4-17: EPA's Estimates of Average Annual Economic Losses at All CWIS of the Transition Zone of the Delaware Estuary ($2000).

Facility	Impingement Losses		Entrainment Losses		Total	
	Low	High	Low	High	Low	High
Salem[a]	$202,839	$400,469	$12,913,137	$26,691,011	$13,115,976	$27,091,480
Hope Creek	$13,963	$28,920	$464,933	$961,000	$478,896	$989,921
Dupont	$1,576	$3,265	$52,492	$108,500	$54,069	$111,765
Edge Moor	$176,114	$364,771	$5,864,154	$12,121,005	$6,040,268	$12,485,776
Delaware City Refinery	$81,976	$169,791	$2,729,606	$5,642,002	$2,811,583	$5,811,793
Deepwater (w/o Chambers Cogen)	$23,557	$48,792	$784,387	$1,621,301	$807,944	$1,670,092
Chambers Cogen	$8,333	$17,259	$277,460	$573,500	$285,793	$590,759
Gen Chem Corporation	$7,635	$15,813	$254,213	$525,450	$261,848	$541,263
SPI Polyols	$1,126	$2,332	$37,495	$77,500	$38,621	$79,832
Sun Refining	$1,351	$2,799	$44,994	$93,000	$46,345	$95,799
Logan Generating Co	$450	$933	$14,998	$31,000	$15,448	$31,933
Hay Road	$360	$746	$11,998	$24,800	$12,359	$25,546
Total	$519,282	$1,055,891	$23,449,867	$48,470,070	$23,969,149	$49,525,961

[a] Based on EPA's estimate of Salem's current I&E assuming no impingement or entrainment survival, as discussed in Section B3-7 of Chapter B3. Salem's data for 1996 was not included because the facility was shut down much of the year.
Wed Feb 06 13:09:58 MST 2002 extrapolation.summary ; salem100.extrapolation
P:/INTAKE/Delaware/Del-Science/scodes/extrapolation.baseline.facilities/extrapolation.summarynew.csv

Chapter B5: RUM Analysis

Introduction

This case study uses a random utility model (RUM) approach to estimate the effects of improved fishing opportunities due to reduced impingement and entrainment (I&E) in the Delaware River Estuary. The case study focuses on marine fishing sites in the Delaware River Estuary and the Atlantic coastal areas of Delaware and New Jersey. The study area was selected for consistency with the study area selected for the I&E analysis and does not include all recreational sites potentially affected by I&E in the Delaware Estuary.

Cooling Water Intake Structures (CWISs) withdrawing water from the Delaware Estuary impinge and entrain many of the species sought by recreational anglers. These species include striped bass, weakfish, croaker, spot, flounder, and other less prominent species. Some of these species (e.g., weakfish, flounder, and striped bass) inhabit a wide range (e.g., striped bass ranges from North Carolina to Maine). Therefore, increased fish mortality from I&E in the Delaware Estuary may affect recreational fishing from North Carolina to Maine.

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The study's main assumption is that, all else being equal, anglers will get greater satisfaction and thus greater economic value from sites with a higher catch rate. This benefit may occur in two ways: first, an angler may get greater enjoyment from a given fishing trip with higher catch rates, yielding a greater value per trip; second, anglers may take more fishing trips when catch rates are higher, resulting in greater overall value for fishing in the region.

The following sections focus on the data set used in the analysis and analytic results. Chapter A10 of Part A of this document provides a detailed description of the RUM methodology used in this analysis.

B5-1 Data Summary

EPA's analysis of improvements in recreational fishing opportunities in the Delaware Estuary relies on a subset of the Marine Recreational Fishery Statistics Survey (MRFSS) combined with the 1994 Add-on MRFSS Economic Survey (NMFS, 1999a; QuanTech, 1998).[1] The model of recreational fishing behavior relies on the subset that includes only single-day trips to sites located in the Delaware Bay or along the Atlantic coasts of Delaware and New Jersey.[2] In addition, the sample excludes respondents missing data on key variables (e.g., home town). This truncation resulted in a sample of 2,075 anglers.

The Agency included both single and multiple day trips in estimating the total economic gain from improvements in fishing site quality from reduced I&E. Details of this analysis are provided in Section B5-6 of this chapter.

[1] For general discussion of the MRFSS see Chapter A10 or "Marine Recreational Fisheries Statistics: Data user's Manual," NMFS 2001b.

[2] New Jersey included all sites located in counties bordering the Delaware Bay, but only those Atlantic coast sites located in the Cape May and Atlantic counties.

B5-1.1 Summary of Anglers' Characteristics

a. Fishing modes and targeted species

A majority of the interviewed anglers (63 percent) fish from either a private or a rental boat (see Table B5-1 below). Approximately 21 percent fish from the shore; the remaining 16 percent fish from a party or charter boat. In addition to the mode of fishing, the MRFSS contains information on the specific species targeted on the current trip. The most popular species, targeted by 29 percent of anglers, is summer/winter flounder. The second most popular species, targeted by 21 percent of anglers, is weakfish. Approximately 26 percent of anglers did not have a designated target species. Of the remaining anglers, six, five, two, and 11 percent target striped bass, bluefish, bottom fish (e.g., white perch, croaker and spot), and big game fish (e.g., yellowfin tuna), respectively.[3,4]

The distribution of target species is not uniform by fishing mode. For example, more than half the anglers fishing from private/rental boats target either flounder (35.3 percent) or weakfish (26.2 percent). The majority of shore anglers, on the other hand, either don't target any particular species (38.3 percent) or target bottom fish (18.8 percent). Flounder remains the most popular species among anglers fishing from party/charter boats (29.1 percent), followed by "no target" and bottom species (20 percent).[5] A relatively large percentage of charter boat anglers target big game species (10.8 percent) compared to a negligible percentage of anglers targeting big game species from either private or rental boats (0.7 percent) or shore (0 percent).

Anglers fishing from private or rental boats and anglers fishing from shore and charter boats target different species. EPA modeled recreational fishing behavior using anglers fishing from private or rental boats. The Agency could not extend the RUM to other fishing modes due to an insufficient number of observations for species of concern (i.e., striped bass and weakfish).

Table B5-1: Species Group Choice by Mode of Fishing

Species	All Modes		Private/Rental Boat		Party/Charter Boat		Shore	
	Frequency	Percent	Frequency	Percent by Mode	Frequency	Percent by Mode	Frequency	Percent by Mode
No target	535	25.67%	294	22.53%	70	21.02%	171	38.34%
Striped bass	134	6.43%	86	6.59%	17	5.11%	31	6.95%
Bluefish	99	4.75%	36	2.76%	11	3.30%	52	11.66%
Flounder	610	29.27%	461	35.33%	97	29.13%	52	11.66%
Weakfish	433	20.78%	342	26.21%	35	10.51%	56	12.56%
Big game fish	45	2.16%	9	0.69%	36	10.81%	0	0.00%
Bottom fish	219	10.51%	68	5.21%	67	20.12%	84	18.83%
All species	2,075	100.00%	1,305	100.00%	333	100.00%	446	100.00%

[3] Bottom fish includes dogfish sharks, catfish, white perch, white bass, black sea bass, scup, drums, spot, northern kingfish, Atlantic croaker, tautog, and Atlantic bonito.

[4] Big game fish includes mackerel, mako, and blue sharks, dolphin, tuna, bluefin tuna, and yellowfin tuna.

[5] Note that bottom species targeted by offshore anglers and charter boat anglers are different. Charter boat anglers usually target tautog, black sea bass, and drums, while offshore anglers target white perch, catfish, and dogfish sharks.

b. Anglers' characteristics

This section presents a summary of angler characteristics for the Delaware Bay region as defined above. For this data comparison the study uses both the observations valid for the site choice model and those valid for the trip participation model. Those valid for the trip participation model include only anglers who responded to the economic add-on survey. The following trip profile information relies on the 2,075 site choice observations, of which 239 responded to the economic add-on survey and therefore are valid also for the trip participation model. Table B5-2 summarizes characteristics of the sample anglers fishing the NMFS site in the Delaware Bay area.

The average income of the respondent anglers was $44,109, with 87 percent having reported their household income. Ninety-four percent of the anglers are white, with an average age of about 47 years. Educational attainment information indicates that 14 percent of the anglers had not received a high school diploma, while only 15 percent had graduated from college. The average household size was 2.95 individuals. Nearly 20 percent of the anglers are retired, while 13 percent are self-employed. Forty-seven percent of the anglers indicated that they had flexible time when setting their work schedule.

Table B5-2 shows that on average anglers spent 28 days fishing during the past year. The average duration of a fishing trip was 4.2 hours per day. Anglers made an average of 2.2 trips to the current site, with an average trip cost of $25.73 ($1994).[6] Average travel time to and from the site was just under two hours. Fifty-eight percent of the Delaware Bay anglers own their own boat. Finally, the average number of years of fishing experience was 23. This analysis does not include anglers under the age of 16, which may result in overestimation of the average age of recreational anglers and years of experience.

[6] All costs are in $1994 because that was the MRFSS survey year. All costs/benefits will be updated to $2000 later in this analysis (i.e., for welfare estimation).

Table B5-2: Data Summary for Delaware Bay/Atlantic Coast Anglers					
Variable	**N**	**Mean**[a]	**Std Dev**	**Minimum**	**Maximum**
Trip Cost	2075	24.47	21.62	0	224.73
Travel Time	2075	2.02	1.67	0	13.79
Visits	2075	2.20	5.55	1	88
Own a boat	239	0.58	0.49	0	1
High School	239	0.14	0.35	0	1
College Degree	239	0.15	0.36	0	1
Retired	239	0.20	0.40	0	1
Age	239	47.16	14.16	20	81
Years Fishing	239	23.30	14.34	1	63
Household Size	239	2.95	1.27	1	7
Flexible Time	239	0.47	0.50	0	1
Male	239	0.92	0.28	0	1
White	239	0.94	0.24	0	1
Household Income	239	$44,108.91	$23,767.07	$7,500.00	$150,000.00
Annual trips	239	28.34	39.83	1	200

a. For dummy variables such as "Own a Boat" that take the value of 0 or 1, the reported value represents a portion of the survey respondents possessing the relevant characteristic. For example, 58 percent of the surveyed anglers own a boat.

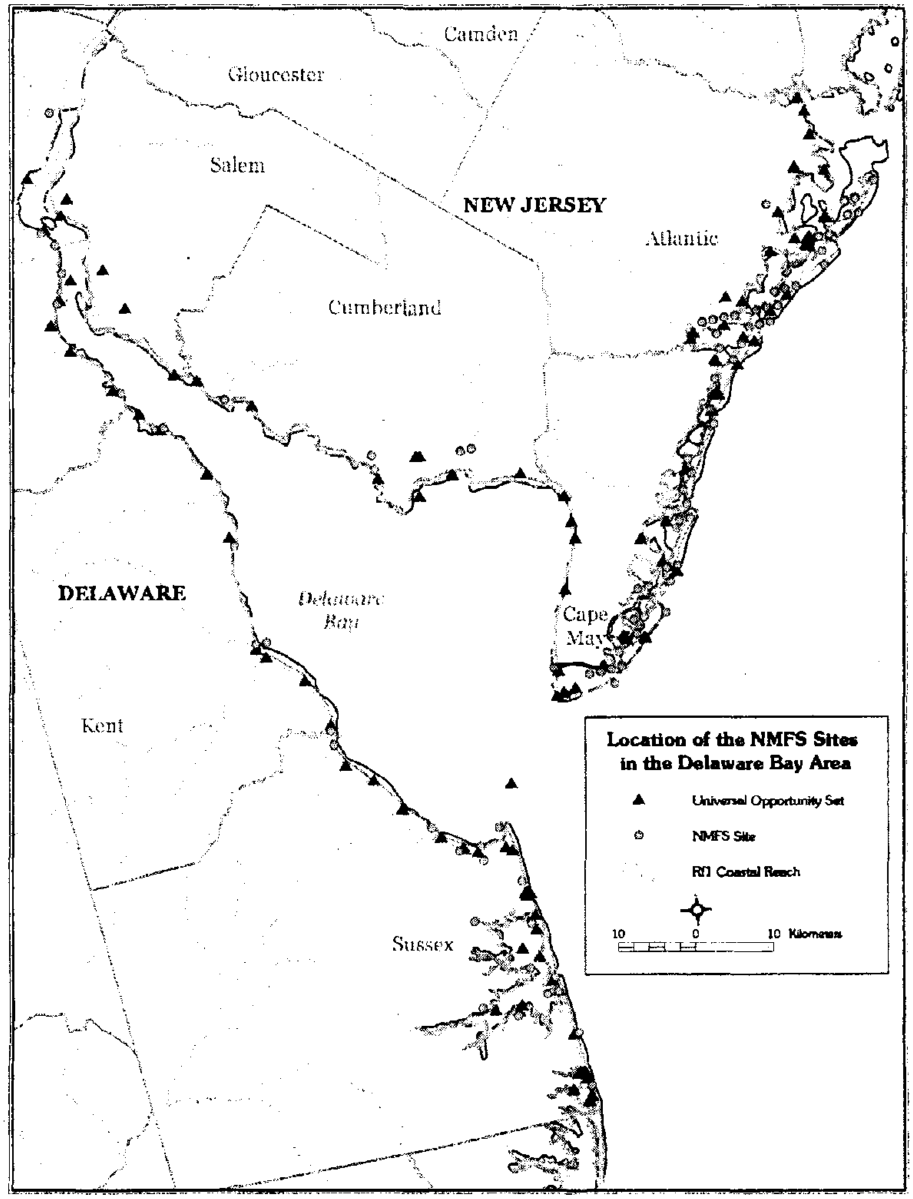
B5-1.2 Recreational Fishing Choice Sets

The National Marine Fisheries Service (NMFS) intercept sites included in the analysis are depicted in Figure B5-1. For tractability, the study aggregates NMFS intercept sites into 48 fishing zones based on Reach File version 1 (hereafter RF1) (Parsons and Needelman, 1992; McConnell and Strand, 1994). The 48 fishing zones (hereafter fishing sites), along with the angler's state of residence, define the individual's choice set. Based on the survey observations, residents of Delaware and Maryland almost exclusively visited sites within Delaware while New Jersey residents visited sites within New Jersey. Only two sampled anglers from Delaware visited New Jersey sites and one sampled person from New Jersey visited a fishing site located in Delaware. Pennsylvania residents, however, tended to visit sites located in both Delaware and New Jersey.

Based on these findings, EPA assumed that Delaware and Maryland anglers select their destination from 23 fishing zones located in the Delaware Bay and along Delaware's Atlantic coast. Similarly, EPA assumed that New Jersey residents select their destination among fishing zones located on the New Jersey side of the Delaware Bay or along New Jersey's Atlantic Coast. Given the size of the Delaware Bay, it is reasonable to assume that fishing zones on the opposite side of the bay are not included in anglers' choice set (Parsons and Hauber, 1997).[7] EPA assumed that all fishing zones on both sides of the Delaware Bay are included in the choice sets for Pennsylvania anglers. Table B5-3 summarizes choice sets available for recreational anglers residing in Delaware, Maryland, New Jersey, and Pennsylvania.

[7] EPA attempted a model in which individual choice sets for Delaware, Maryland, and New Jersey residents included fishing sites on both sides of the Delaware Bay. The Agency also attempted a nested structure, assuming that anglers first select a state and then a fishing site. Both model variations performed poorly.

Figure B5-1: NMFS Intercept Sites Included in RUM Analysis



Source: U.S. EPA, 1997.

Table B5-3: Number of Sites Available for Individual Choice Sets (by State)					
Angler's State of Residence	Number of Anglers per State	State(s) Included in Choice Set	Number of Sites in Choice Set		
			Total Number of Sites	# of Delaware Bay Sites	# of Atlantic Coast Sites
Delaware	1176	Delaware	23	16	7
Maryland	173	Delaware	23	16	7
New Jersey	320	New Jersey	25	9	16
Pennsylvania	415	Delaware, New Jersey	48	25	23

B5-1.3 Site Attributes

This analysis assumes that the angler chooses between site alternatives based on several observable attributes. The attributes included in this analysis include catch rates for fish species of concern, presence of boat launching facilities, and the site's aesthetic quality.

Catch rate is the most important attribute of a fishing site from the anglers' perspective (McConnell and Strand, 1994; Haab et al., 2000). This attribute is also a policy variable of concern because catch rate is a function of fish abundance, which is affected by fish mortality due to I&E. The catch variable in the RUM therefore provides the means to measure baseline losses in I&E and changes in anglers' welfare attributed to changes from I&E due to the 316b rule.

To specify the fishing quality of the case study sites, EPA calculated historic catch rate based on the NMFS catch rate from 1994 to 1996 for recreationally important species, such as weakfish, striped bass, bluefish, and flounder (McConnell and Strand, 1994). Other species of interest (e.g., white perch, Atlantic croaker, American shad, and spot) did not produce enough observations to permit a RUM analysis. EPA therefore bundled all species other than weakfish, striped bass, bluefish, and flounder into two aggregate groups — big game fish and bottom fish — and calculated group-specific catch rates.· No sample anglers targeted species in the "other fish" category (i.e., eel). The bottom fish and big game groups include the following species:[8]

- Big game: mako, blue, bluefin and yellowfin tuna, and dolphin; and
- Bottom fish: dogfish sharks, catfish, white perch, black sea bass, scup, drums, northern kingfish, tautog, Atlantic croaker, and spot.

The catch rates represent the number of fish caught on a fishing trip divided by the number of hours spent fishing (i.e., the number of fish caught per hour per angler). The estimated catch rates are averages across all anglers in a given year over the three-year period. The big game and bottom fish catch rates are weighted average catch rates for all species in the group, weighted by sample proportion for each species.

The catch rate variables include total catch, including fish caught and kept and fish released. Some NMFS studies use the catch-and-keep measure as the relevant catch rate. Although a greater error may be associated with measured number of fish not kept, the total catch measure is most appropriate because a large number of anglers catch and release fish. The total catch rate variables include both targeted fish catch and incidental catch. For example, striped bass catch rates include fish caught by striped bass anglers and anglers who don't target any particular species. This method may underestimate the average historic catch rate for a given site because anglers not targeting particular fish species are usually less experienced and may not have the appropriate fishing gear. EPA considered using targeted species catch rates for this analysis, but discovered that this approach did not provide a sufficient number of observations per fishing zone to allow estimation of catch rates for all fishing sites included in the analysis.

[8] None of the anglers included in the sample data set targeted small game species other than striped bass and bluefish.

EPA estimated the catch rate for each combination of recreational fishing zone in the study area and fish species of interest using a standard Inverse Distance Weighted (IDW) interpolation technique. The IDW technique estimates a value for any given location by assuming that each input value has an influence on that location. This influence diminishes with distance according to a predetermined power parameter. If available, EPA used observable catch rate values for a given site to estimate average catch rates for that site. If no observed catch rates were found, EPA used an inverse distance squared estimation technique to calculate an average catch rate for a given zone/species combination. The Agency first located any site visits within five kilometers from a given fishing zone and then used the catch rates of the nearest four sites visited as input values for calculating historic catch rates for the species in question.

For anglers who don't target any species, EPA used weakfish, flounder, and bottom fish catch rates to characterize the fishing quality of a fishing site. EPA based its assessment on the analysis of fish species caught by no-target anglers. The MRFSS provided information on species caught for 78 percent of the 532 no-target anglers. Of those, 48 percent caught bottom fish, 10 percent caught small game (i.e., either striped bass or bluefish), 13 percent caught weakfish, and ten percent caught flounder. The remaining 19 percent caught other fish species.

Anglers who target particular species generally catch more fish in the targeted category because of specialized equipment and skills than anglers who don't target these species. Of the anglers who target particular species, bottom fish anglers catch the largest number of fish per hour (0.95), followed by anglers who catch weakfish (0.89) and flounder (0.86). Anglers who target big game fish catch fewer fish than anglers targeting any other species or species group. Table B5-4 summarizes average catch rates by species for all sites in the study area.

Table B5-4: Average Catch Rate by Species/Species Group for the Delaware Bay and Coastal Sites

Species/Species Group	Average Catch Rate (fish per angler per hour)
Striped bass	0.608
Weakfish	0.894
Flounder	0.860
Bluefish	0.498
Bottom fish	0.947
Big game fish	0.275

Some RUM studies have used predicted, rather than actual, catch rates (Haab et al., 2000; Hicks et al., 1999; McConnell and Strand, 1994). This practice allows for individual characteristics to affect catch rates; for example, anglers with different levels of experience may have different catch rates. Haab et al. (2000) compared historic catch-and-keep rates to predicted catch-and-keep rates and found that historic catch-and-keep rates were a better measure of site quality. The authors also found that the choice of catch rate had little effect on the travel cost parameters. Hicks et al. (1999) found that using historic catch rates resulted in more conservative welfare estimates than predicted catch rate models. Consequently, EPA favored this more conservative approach

EPA included two additional site attributes in the model: presence of boat launching facilities and fishing site aesthetic quality.

- **Presence of boat launching facilities**. Anglers who own a boat view the presence of a boat ramp as an important factor that may affect site choice. EPA therefore obtained information on the presence of boat ramps at the study sites from the Delaware and New Jersey Atlas and Gazetteer (DeLorme, 1999; DeLorme, 1993). The Agency also used information provided in the MRFSS to supplement information from the Atlas and Gazetteer. EPA used a dummy variable (Boat_Ramp=1) for whether or not a site has a boat ramp.

- **Fishing site aesthetic quality**. Visual appearance of the site may play an important role in an angler's decision to visit a particular site because the site's aesthetic quality will likely affect the angler's recreational trip enjoyment. EPA used ambient concentrations of Total Kjeldahl Nitrogen (TKN) as a proxy for visual water quality at the fishing sites.[9] Nitrogen is the major limiting nutrient regulating primary productivity in coastal ecosystems (U.S. EPA, 1991). Excessive nitrogen loading in coastal waters can stimulate or enhance the impact of microscopic algal species and lead to algal blooms. Such blooms, sometimes referred to as brown or red tides, result in unattractive site appearance. Such algal blooms can also release potent neurotoxins to surface water that may affect higher forms of life, including humans.[10]

B5-1.4 Travel Cost

EPA used ZipFip software to estimate distances from the household Zip code to each fishing zone in the individual opportunity sets.[11] As noted above, a fishing zone is defined as a tidal river or a coastal reach. If a fishing zone has designated fishing areas, EPA assumed that anglers visited the fishing area nearest to their homes. Otherwise, EPA measured the distance between the household Zip code and the reach midpoint. The program used the closest valid Zip code to match unknown Zip codes. The average one-way distance to the visited site is 40.3 miles.

EPA estimated trip "price" as the sum of travel costs plus the opportunity cost of time following the procedure described in Haab et al. (2000). Based on Parsons and Kealy (1992), this study assumed that time spent "on-site" is constant across sites and can be ignored in the price calculation. To estimate consumers' travel costs, EPA multiplied round-trip distance by average motor vehicle cost per mile ($0.29, 1994 dollars).[12] To estimate the opportunity cost of travel time, EPA first divided round-trip distance by 40 miles per hour to estimate trip time, and used the household's wage to yield the opportunity cost of time. EPA estimated household wage by dividing household income by 2,080 (i.e., the number of full time hours potentially worked).

Only those respondents who reported that they lost income during the trip (LOSEINC=1) are assigned a time cost in the trip cost variable. Information on the LOSEINC variable was available only for a subset of survey respondents who participated in the follow-up telephone interviews. Approximately three percent of the 239 telephone interview participants reported that they lost income. Given that only a small number of survey respondents reported lost income, EPA assumed that the remaining 1836 anglers who did not participate in the telephone interview did not lose income during the trip. EPA calculated visit price as:

$$\mathit{Visit\ Price} = \begin{cases} \mathit{Round\ Trip\ Distance} \times \$.29 + \dfrac{\mathit{Round\ Trip\ Distance}}{40\ \mathit{mph}} \times (\mathit{Wage}) & \mathit{If\ LOSEINC} = 1 \\ \mathit{Round\ Trip\ Distance} \times \$.29 & \mathit{If\ LOSEINC} = 0 \end{cases} \tag{5-1}$$

For those respondents who do not lose income, the time cost is accounted for in an additional variable equal to the amount of time spent on travel. EPA therefore estimated time cost as the round-trip distance divided by 40 mph:

$$\mathit{Travel\ Time} = \begin{cases} \mathit{Round\ Trip\ Distance}/40 & \mathit{If\ LOSEINC} = 0 \\ 0 & \mathit{If\ LOSEINC} = 1 \end{cases} \tag{5-2}$$

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[9] The relevant data on TKN concentrations come from EPA's water quality database (STORET).

[10] Humans who eat seafood contaminated by toxic algae can experience shellfish poisoning, including Ciguatera Fish Poisoning, Amnesic Shellfish Poisoning, or Paralytic Shellfish Poisoning.

[11] The program was created by Daniel Hellerstam and is available through the USDA at http://usda.maunlib.cornell.edu/datasets/general/93014.

[12] EPA used the 1994 government rate ($0.29) for travel reimbursement to estimate travel costs per mile traveled. This estimate includes vehicle operating cost only.

EPA used a log-linear ordinary least square regression model to estimate wage rates for the 13 percent of the 239 survey respondents who participated in the telephone interview but did not report their income. The estimated regression equation used in wage calculation is :

$$Ln(Income) = 0.14 \times male + 0.10 \times age - 0.0017 \times age^2 + 0.32 \times employed + 0.147 \times boatown + 0.818 \log (stinc) \quad (5\text{-}3)$$

where:

INCOME	=	the reported household income;
MALE	=	1 for males;
AGE	=	age in years;
EMPLOYED	=	1 if the respondent is currently employed and 0 otherwise;
BOATOWN	=	1 if the respondent owns a boat; and
STINC	=	the average income of residents in the corresponding states.

All variables in the estimated income regression are statistically significant from zero at 99th percentile. The average imputed household income for anglers who do not report income is $61,894 per year and the corresponding hourly wage is $29.76.

B5-2 SITE CHOICE MODELS

The nature of the MRFSS data leads to the RUM as a means of examining anglers' preferences (Haab, et al., 2000). Anglers arrive at each NMFS site by choosing among a set of feasible sites. Interviewers intercept individual anglers at marine fishing sites along the Atlantic coast, including the Delaware Bay area, and collect data on the anglers' origins and catch (including number and weight of species caught).

The RUM assumes that the individual angler makes a choice among mutually exclusive site alternatives based on the attributes of those alternatives (McFadden, 1981). The number of feasible choices (J) in the study area is 48. For anglers residing in Delaware or New Jersey, the feasible choice set is restricted to the sites located in the home state. The study assumes that anglers from other states can choose from all 48 fishing zones.

An angler's choice of sites relies on utility maximization. An angler will choose site j if the utility (u_j) from visiting site j is greater than that from vising other sites (h), such that:

$$u_j > u_h \text{ for } h = 1, \ldots, J \text{ and } h \neq j \quad (5\text{-}4)$$

Anglers choose the species to seek and the mode of fishing in addition to choosing a fishing site. Available fishing modes include shore fishing, fishing from charter boats, or fishing from private or rental boats. The target species or group of species include weakfish, striped bass, bluefish, flounder, bottom fish, and big game fish. Anglers may also choose not to target any particular species.

Recreational fishing models generally assume that anglers first choose a mode and species, and then a site. The nested logit model generally avoids the independence of relevant alternatives (IIA) problem, in which sites with similar characteristics that are not included in the model have correlated error terms. The nested structure based on mode/species and then site choice therefore assumes that sites selected for certain modes and/or species have similar characteristics.[13]

Fishing modes and species do not clearly define differences among Delaware Bay area sites. The same sites feature several fishing mode/species combinations. The likely differences among all sites in the study area makes the IIA problem insignificant. The Agency did not include the angler's choice of fishing mode and target species in the model, instead assuming that the mode/species choice is exogenous to the model and that the angler simply chooses the site. EPA used the following general model to specify the deterministic part of the utility function:[14]

[13] See Chapter A10 of Part A of this document for greater detail.

[14] See Chapter A10 of Part A of this document for details on model specification.

$$v\ (site\ j) = f\ (TC_j,\ TT_j,\ BOAT\_RAMP_j,\ Ln(NMFS)_j,\ SQRT(Q_{js}) \times Flag(s),\ TKN_j) \qquad (5\text{-}5)$$

where:

v	=	the expected utility for site j (j=1,...48);
TC_j	=	travel cost at site j;
TT_j	=	travel time for survey respondents who cannot value the extra time according to the wage rate;
$BOAT\_RAMP_j$	=	presence of a boat ramp at site j; and
$Ln(NMFS)_j$	=	the log of the number of sites within a reach;
$SQRT(Q_{js})$	=	square root of the historic catch rate for species s at site j;[15]
Flag(s)	=	1 if an angler is targeting this species; 0 otherwise;
TKN_j	=	ambient concentrations of TKN at site j

The analysis assumes that each angler in the estimated model considers site quality based only on the catch rate for the targeted species. Theoretically, an angler may catch any of the available species at a given site (McFadden, 1981). If, however, an angler truly has a species preference, then including the catch variable for all species available at the site would inappropriately attribute utility to the angler for a species not pursued (Haab et al., 2000). To avoid this problem, the Agency used an interaction variable SQRT (Qjs) × Flag (s), such that the catch rate variable for a given species is turned on only if the angler targets a particular species (Flag (s) =1). Because a large number of no-target anglers catch either weakfish or flounder, and because these two species are the most frequently targeted in the Delaware Bay area, EPA used both weakfish and flounder catch rates to characterize a site's fishing quality for the no-target angler group.

The analysis tested various alternative model specifications, but the model presented here was the most successful at explaining the probability of selecting a site. For example, a model that included catch rates for bottom species, striped bass, and bluefish for no-target anglers did not produce meaningful results. The additional catch rate variables either had a wrong sign or were insignificant for no-target anglers. The analysis also ran separate models for anglers targeting each species or group of species (i.e., flounder, striped bass, weakfish, and no-target). The presented model and species-specific models produced very similar results.

The final model presented here is a site choice model that includes all fish species. The analysis therefore assumes that each angler has chosen a mode/species combination followed by a site based on the catch rates for that site and species. The model examines only private/rental boat anglers because anglers using different fishing modes target different species. The single model is appropriate for this case study because the most important valuation question is how different catch rates for the species of interest will affect recreational fishing values in the case study area. EPA estimated all RUM and Poisson models with LIMDEP™ software (Greene, 1995). Table B5-5 gives the parameter estimates for this model.

One disadvantage of the specified model is that the model looks at site choice without regard to mode or species, whereas species selection is an integral part of the nested RUM. Once an angler chooses a target species no substitution is allowed across species (i.e., the value of catching, or potentially catching, a different species is not included in the calculation). Therefore, improvements in fishing circumstances related to other species will have no effect on angler's choices.

Table B5-5 shows that most coefficients have the expected signs and are statistically significant at the 95th percentile. Travel cost and travel time have a negative effect on the probability of selecting a site, indicating that anglers prefer to visit sites closer to their homes (other things being equal). A positive sign on the boat ramp indicates that anglers owning a boat are more likely to choose sites with a boat ramp. The more interview locations within a reach, the more likely that anglers visited the reach.

[15] The analysis used the square root of the catch rate to allow for decreasing marginal utility of catching fish (McConnell and Strand, 1994).

Table B5-5: Estimated Coefficients for the Conditional Site Choice

Variable	Estimated Coefficient	t-statistics
TRIPCST	-0.024	-3.355
TIMECST	-0.893	-10.211
BT_RAMP	1.131	13.306
ln(NMFS)	1.924	56.035
SQRT ($Q_{weakfish}$)	2.811	18.219
SQRT ($Q_{striped\ bass}$)	3.551	9.880
SQRT ($Q_{bluefish}$)	2.868	3.764
SQRT ($Q_{flounder}$)	1.363	9.186
SQRT (Q_{bottom})	-0.554	-2.036
SQRT ($Q_{big\ game}$)	0.724	0.160
SQRT ($Q_{weakfish}$) x No_Target	1.256	6.515
SQRT ($Q_{flounder}$) x No_Target	1.627	7.064
TKN	-0.994	-20.593

The probability of a site visit increases as the historic catch rate for fish species increases, but bottom species and big game species form two notable exceptions. As shown in the model, the catch rate for bottom species has a negative impact on site selection. The catch rate for big game species, while positive, has an insignificant effect on site selection. These results are likely to be due to the relatively small number of anglers in the sample who actually target big game and bottom species from private or rental boats. Finally, higher ambient concentrations of nitrogen in coastal water are indicative of potential eutrophication problems and negatively affect the probability of site selection. In other words, anglers prefer sites with more fish and cleaner water, all else being equal.

EPA used historic catch rates for the two most popular species in the area, weakfish and flounder, to characterize fishing site quality for no-target anglers. The models presented in Table B5-5 show that no-target anglers seem to place a lower value on the catch rate of particular species such as weakfish than anglers targeting this species. This result is not surprising. Many species can contribute to sites' perceived quality for no-target anglers because they catch whatever bites. As indicated by similar coefficient values on the historic catch of weakfish and flounder, no-target anglers would almost equally enjoy catching either of these two species.

B5-3 Trip Frequency Model

EPA also examined effects of changes in fishing circumstances on an individual's choice concerning the number of trips to take during a recreation season. EPA used the negative binomial form of the Poisson regression model to estimate the number of fishing trips per recreational season. The participation model relies on socioeconomic data and estimates of individual utility (the inclusive value) derived from the site choice model (Parsons et al., 1999; Feather et al, 1995). This section discusses results from the Poisson model of recreational fishing participation, including statistical and theoretical implications of the model. A detailed discussion of the Poisson model is presented in Chapter A10 of Part A.

The dependent variable, the number of recreational trips within past 12 months, is an integer value ranging from one to 200. The Agency first tested the Delaware and New Jersey data on the number of fishing trips for overdispersion to determine whether to use the Poisson model of the negative binomial model. If the dispersion parameter is equal to zero, then the Poisson model is appropriate; otherwise the negative binomial is more appropriate. The analysis found that the overdispersion parameter is significantly different from zero and therefore the negative binomial model is the most appropriate for this case study.

Independent variables of importance include age, ethnicity, gender, education, household size, whether or not the individual has a flexible work schedule, and whether he (or she) owns a boat. Variable definitions for the trip participation model are:

- IVBASE: an inclusive value estimated using the coefficients obtained from the site choice model;
- NOHS: equals 1 if the individual did not complete high school, 0 otherwise;
- COLLEGE: equals 1 if the individual completed college, 0 otherwise;
- RETIRED: equals 1 if the individual is retired, 0 otherwise;
- AGE: individual's age in years. If not reported, the individual's age is set to the sample mean;
- YRSFISH: number of years participating in recreational fishing. If the individual did not report years of fishing experience, this variable is set to the sample mean;
- HOUSE_SZ: household size;
- OWNBT: equals 1 if individual owns a boat, 0 otherwise;
- FLEXTIM: equals 1 if the individual can set a flexible work schedule; 0 otherwise;
- Constant: a constant term
- α (alpha): overdispersion parameter estimated by the negative binomial model.

Table B5-6 presents the results of the trip participation model. All but one parameter estimate in the participation model have the expected signs. The model shows that the most significant determinants of the number of fishing trips taken by an angler are the quality of the fishing sites (IVBASE), fishing experience (YRSFISH), and boat ownership (OWN_BOAT).

Table B5-6: Trip Participation Model (Negative Binomial Model)

Variable	Coefficient	t-statistics
Constant	2.22	4.267
IVBASE	.146	2.727
NOHS	.326	1.359
COLLEGE	-0.221	-1.212
RETIRED	-0.071	-0.284
AGE	-0.012	-1.577
YRSFISH	0.012	2.129
HOUSE_SZ	-0.040	-0.626
OWN_BOAT	.565	3.500
FLEXTIM	.051	0.313
α (alpha)	2.976	10.596

The positive coefficient on the inclusive value index (IVBASE) indicates that the quality of recreational fishing sites has a positive effect on the number of fishing trips per recreational season. EPA therefore expects improvements in recreational fishing opportunities, such as an increase in fish abundance and catch rate, to result in an increase in the number fishing trips to the affected sites.

The model shows that education also influences trip frequency. People who did not complete high school (NOHS=1) tend to take more fishing trips than those with a high school diploma. Respondents who attended college are less likely to participate in fishing than those who have only a high school education.

Both the AGE and RETIRED variables are negative, meaning that .younger people are more likely to go fishing. A negative sign on the retired variable is counterintuitive because retirees have more leisure time to pursue their interests. A negative sign on the household size variable (HOUSE_SZ) indicates that anglers who have larger families tend to take fewer recreational trips.

A flexible work schedule (FLEXTIM=1) and boat ownership (OWN_BOAT) have a positive effect on an individuals' decision to take a fishing trip. Finally, more experienced anglers (YRSFSH) take more recreational fishing trips than less experienced anglers.

B5-4 Welfare Estimates

This section presents estimates of welfare losses to recreational anglers from fish mortality due to I&E, and potential welfare gains from improvements in fishing opportunities due to reduced fish mortality stemming from the 316b rule.

B5-4.1 Estimating Changes in the Quality of Fishing Sites

To estimate changes in the quality of fishing sites under different policy scenarios, EPA relied on the recreational fishery landings data by state and the estimates of recreational losses from I&E on the relevant species corresponding to different technology options. The National Marine Fisheries Service provided the recreational fishery landings data for the states of Delaware and New Jersey. EPA estimated the losses to recreational fisheries using the physical impacts of I&E on the relevant fish species and the percentage of total fishery landings attributed to recreational fishery, as described in Chapter B4 of this document.

The Agency estimated changes in the quality of recreational fishing sites under different policy scenarios in terms of the percentage change in the historic catch rate. EPA assumed that catch rates will change uniformly across all marine fishing sites along the Delaware and New Jersey coast because species considered in this analysis (i.e., weakfish, striped bass, and flounder) inhabit a wide range of states (e.g., from North Carolina to Massachusetts). EPA used five-year recreational landing data (1994 through 1998) for inland sites to calculate an average landing per year for weakfish and striped bass.[16] EPA then divided losses to the recreational fishery from I&E by the total recreational landings for the states of Delaware and New Jersey to calculate the percent change in historic catch rate from eliminating I&E completely. Table B5-7 presents results of this analysis for the Salem NGS facility only, for all Phase 2 facilities in the transitional estuary, and for all facilities in the Transitional Estuary.[17]

Estimates were not provided for other species because of data limitations. For example, flounder was not included as a representative important species (RIS) in the I&E monitoring performed by Salem NGS, therefore, the Agency was not able to estimate baseline losses of benefits due to the regulation of this species. For other species such as Atlantic croaker and spot, EPA was unable to estimate an empirical model of anglers' behavior due to insufficient number of observations.

[16] Inland sites include sounds, inlets, tidal portions of rivers, bay, estuaries, and other areas of salt or brackish water (NMFS, 2001b).

[17] Other facilities include Hope Creek, Dupont Nemours, Edge Moor, Motiva, Deepwater.

Table B5-7: Estimated Changes in Catch Rates from Eliminating all I&E of Weakfish and Striped Bass in the Transitional Estuary										
	Estimated Fishery I&E						Total Recreational Landings for DE and NJ Combined (fish per year)[a]	Percent Increase in Recreational Catch from Elimination of I&E		
	Number of Fish Impinged			Number of Fish Entrained						
Species	Salem Only	Phase 2	All	Salem Only	Phase 2	All		Salem Only	All Phase 2 Facilities[b]	All Facilities[c]
Weakfish	2,486	4,990	6,196	54,104	83,904	98,253	2,790,234	2.03%	3.19%	3.74%
Striped bass	721	1,201	1,432	50,624	78,508	91,933	395,744	12.97%	20.14%	23.59%

a. *Source:* The Marine Recreational Fishery Statistics Survey, 1994-1998. Total recreational Landings are calculated as a five year average (1994-1998) for inland sites.
b. Facilities included in this analysis are: Salem, Hope Creek, Edge Moor, Deepwater (without Chambers Cogen).
c. Facilities included in this analysis are: Salem, Hope Creek, DuPont, Edge Moor, Delaware City Refinery, Deepwater (without Chambers Cogen), Chambers Cogen, Gen Chem Corporation, SPI Polyols, Sun Refining, Logan Generating Co., and Hay Road.

B5-4.2 Estimating Losses from I&E in the Delaware Estuary

The recreational behavior model described in the preceding sections provides a means for estimating the economic effects of changes in recreational fishery losses from I&E in the Delaware Bay Estuary. First, EPA estimated welfare gain to recreational anglers from eliminating fishery losses due to I&E. This estimate represents economic damages to recreational anglers from I&E of recreational fish species in the Delaware Estuary under the baseline scenario. EPA then estimated benefits to recreational anglers from implementing various CWIS technologies (see Section B5-4.3 and Chapter B6).

EPA estimated anglers' willingness to pay for improvements in the quality of recreational fishing due to I&E elimination by first calculating an average per trip welfare gain based on the expected changes in catch rates from eliminating I&E. Table B5-8 presents the compensating variation per trip (averaged over all anglers in the sample) associated with reduced fish mortality from eliminating I&E for each fish species of concern.[18]

Results shown in Table B5-8 are not surprising. The more desirable the fish, the greater the per trip welfare gain. Anglers targeting striped bass have the largest per trip gain ($9.77) from eliminating I&E in the Delaware Estuary. Striped bass is a small game species prized for both its fighting skills and taste. In contrast, the per trip welfare gain for anglers targeting weakfish is much smaller ($2.00). Because weakfish is smaller and more abundant in the Delaware Estuary than striped bass, it is less valued by recreational anglers. Finally, no-target anglers, who don't have well-defined preferences and who derive satisfaction from catching a variety of fish species, have the lowest welfare gain ($0.74) from eliminating I&E of the affected species.

Table B5-8 also reports the willingness to pay for a one-unit increase in historic catch rate by species. The estimated values are consistent with those available from previous studies (see Table B4-2 in this document). The value of increasing the historic catch rate varies significantly by species and by angler type. Target anglers value the increase of one additional striped bass the most, followed by weakfish, with bluefish and flounder following. The value of increasing the historic catch rate for a given species is generally lower for no-target anglers.

[18] A compensating variation equates the expected value of realized utility under the baseline and post-compliance conditions. For more detail see Chapter A10 of Part A of this document.

Table B5-8: Per Trip Welfare Gain from Eliminating I&E of Weakfish and Striped Bass in the Transitional Estuary

Targeted Species	Per Trip Welfare Gain (2000$) Salem Only	All Phase 2 Facilities	All Facilities in the Delaware River Estuary	WTP for an Additional Fish per Trip (2000$)
Weakfish	$1.08	$1.71	$2.00	$11.50
Striped bass	$5.38	$8.35	$9.77	$18.14
Bluefish[a]	N/A	N/A	N/A	$3.94
Bottom fish[b]	N/A	N/A	N/A	N/A
Flounder[a]	N/A	N/A	N/A	$3.92
No target[c]	$0.41	$0.64	$0.74	$5.02

a. Not estimated due to limitations of I&E data.
b. Not estimated due to a wrong sign on the catch rate variable for bottom fish.
c. The value is based on weakfish caught by no-target anglers.

EPA calculated the total economic value of eliminating I&E in the Delaware estuary by combining the estimated per trip welfare gain with the total number of fishing days at the Delaware and New Jersey coastal sites. NMFS provided information on the total number of fishing trips by state and by fishing mode; this total number of fishing days includes both single- and multiple-day trips. Table B5-9 presents the NMFS number of fishing days by state and fishing mode

Table B5-9: Recreational Fishing Participation by Fishing Mode and by State

State	Fishing Mode	Total Number of Fishing Days per Year
DE	Private Rental Boat	390,578
DE	Shore	367,402
DE	Charter Boat	43,339
NJ	Private Rental Boat	2,596,380
NJ	Shore	1,596,531
NJ	Charter Boat	403,523
	Total	5,397,753

Source: NMFS, 2001b.

The Agency assumed that the welfare gain per day of fishing is independent of the fishing mode and the number of days fished per trip and therefore equivalent for all modes (i.e., private or rental boat, shore, and charter boat) for both single- and multiple-day trips. However, per trip welfare gain differs across recreational species. EPA therefore estimated the number of fishing trips associated with each species of concern and the number of trips taken by no-target anglers. EPA used the MRFSS sample to calculate the proportion of recreational fishing trips taken by no-target anglers and anglers targeting each species of concern and applied these percentages to the total number of trips to estimate species-specific participation. Table B5-10 shows the calculation results. Anglers targeting flounder account for the largest number of fishing days at the Delaware and New Jersey NMFS sites (2,044,291). No-target anglers and anglers targeting weakfish rank second and third, fishing 1,133,742 and 969,714 days per year, respectively. Anglers targeting big game species have the lowest number of fishing days per year (49,747).

The estimated number of trips represents the baseline level of participation. Anglers may take more fishing trips as recreational fishing circumstances change. EPA used the estimated trip participation model to estimate the percentage increase in the number of trips due to I&E elimination. The estimated percentage increase ranges from 0.2 percent for no-target anglers to 3.3 percent for anglers targeting striped bass. This result is not surprising because anglers historically respond slowly to demographic trends, circumstances in the fisheries, and competing opportunities for anglers. EPA calculated the number of recreational fishing trips under the eliminated I&E scenario by applying the estimated percentage increase to the baseline number of trips. The estimated increase in the total number of recreational fishing days ranges from 2,608 days for no target anglers to 5,915 trips for anglers seeking weakfish (see Table B5-10). The estimated aggregate increase in the number of fishing days for no target anglers and anglers targeting weakfish and striped bass is 10,870.

Tables B5-11, B5-12, and B5-13 provide welfare estimates for three policy scenarios. First, Table B5-11 presents losses to recreational anglers from baseline I&E of weakfish and striped bass from Salem NGS. Estimates presented in Table B5-12 represent the welfare gain to recreational anglers from the elimination of I&E of weakfish and striped bass from all Phase 2 CWIS, and Table B5-13 details the losses that occur from baseline I&E of weakfish and striped bass by all facilities in the transitional estuary. Recreational losses (2000$) to Delaware and New Jersey anglers from I&E of 2 species at Salem NGS, at all Phase 2 facilities in the transitional estuary, and all facilities in the transitional estuary range from $2.69to $2.70 million, from $4.23 to $ 4.26 and from $4.95 to $ 4.99 million, respectively.

B5-5 Limitations and Uncertainty

B5-5.1 Geographic Area of the Case Study

Limiting the case study area to the Delaware River Estuary and the Atlantic coastal sites of Delaware and New Jersey may result in missed benefits. Many popular target species that spawn in the Delaware River Estuary inhabit a wide range of areas. For example, weakfish, flounder, and striped bass that together attract 56 percent of all anglers in the area can be found from North Carolina to Massachusetts (flounder and weakfish) or to Maine (striped bass). A watershed-based approach that restricts its analysis to recreation activities within the watershed boundary state misses benefits that occur at more remote locations. This omission will likely be more significant for species that spawn mainly in the Delaware Estuary (i.e., weakfish).

B5-5.2 Extrapolating Single-Day Trip Results to Estimate Benefits from Multiple-Day Trips

Use of per day welfare gain estimated for single-day trips to estimate per day welfare gain associated with multiple-day trips can either understate or overstate benefits to anglers taking multiple-day trips. Inclusion of multi-day trips in the model of recreational anglers' behavior can be problematic because multi-day trips are frequently multi-activity trips. An individual might travel a substantial distance, participate in several recreation activities including shopping and sightseeing, all as part of one trip. Recreational benefits from improved recreational opportunities for the primary activity are overstated if all travel 1costs are treated as though they apply to the one recreational activity of interest. EPA therefore limited the recreational behavior model to single-day trips only and then extrapolated single-day trip results to estimate benefits to anglers taking multiple-day trips.

Table B5-10: Recreational Fishing Participation by Species and Fishing Mode

	Mode: Private Rental Boats Number of Fishing Days				Mode: Off Shore Number of Fishing Days				Mode: Charter Boat Number of Fishing Days				Total Number of Fishing Days per Year			
		With Improved Fishing Quality				With Improved Fishing Quality				With Improved Fishing Quality				With Improved Fishing Quality		
Species	Baseline	Salem	In-scope Facilities	All Facilities	Baseline	Salem	In-scope Facilities	All Facilities	Baseline	Salem	In-scope Facilities	All Facilities	Baseline	Salem	In-scope Facilities	All Facilities
Weakfish	651,942	653,735	654,765	655,267	294,744	295,554	296,020	296,247	23,029	23,092	23,129	23,146	969,714	972,381	973,913	974,660
Striped bass	36,949	37,229	37,385	37,459	60,681	61,323	61,579	61,700	3,909	3,939	3,955	3,963	101,718	102,491	102,919	103,122
Bluefish	233,171	NA	NA	NA	105,322	NA	NA	NA	1,630	NA	NA	NA	340,122	NA	NA	NA
Flounder	1,483,921	NA	NA	NA	438,381	NA	NA	NA	121,990	NA	NA	NA	2,044,291	NA	NA	NA
Bottom fish	116,442	NA	NA	NA	462,776	NA	NA	NA	177,249	NA	NA	NA	756,467	NA	NA	NA
Big game fish	47,468	NA	NA	NA	0	NA	NA	NA	2,280	NA	NA	NA	49,747	NA	NA	NA
No target	414,957	415,372	415,625	415,741	602,010	602,612	602,979	603,147	116,776	116,893	116,964	116,997	1,133,742	1,134,876	1,135,568	1,135,885
Total[a]	2,986,958				1,963,933				446,862				5,397,753			

a. Sum of individual values may not add up to totals due to the rounding error.

Table B5-11: Total Estimated Baseline Losses from I&E of Weakfish and Striped Bass from Salem NGS (2000$)

Species	Total Losses	
	Low Value	High Value
Weakfish	$1,046,127	$1,049,580
Striped bass	$4.16,873	$423,751
No target	$1,223,081	$1,224,548
Total recreational use	$2,686,082	$2,697,880

Table B5-12: Total Estimated Baseline Losses from I&E of Weakfish and Striped Bass in the Transitional Estuary by In-Scope Phase 2 Facilities[a] (2000$)

Species	Total Losses	
	Low Value	High Value
Weakfish	$1,653,557	$1,662,156
Striped bass	$646,872	$663,561
No target	$1,933,257	$1,936,931
Total recreational use	$4,233,686	$4,262,647

a. Facilities included in this analysis are: Salem, Hope Creek, Edge Moor, Deepwater (without Chambers Cogen).

Table B5-13: Total Estimated Baseline Losses from I&E of Weakfish and Striped Bass in the Transitional Estuary by All Facilities[a]

Species	Total Losses	
	Low Value	High Value
Weakfish	$1,934,774	$1,946,756
Striped bass	$756,480	$776,401
No target	$2,262,043	$2,267,246
Total recreational use	$4,953,295	$4,993,223

a. Facilities included in this analysis are: Salem, Hope Creek, DuPont, Edge Moor, Delaware City Refinery, Deepwater (without Chambers Cogen), Chambers Cogen, Gen Chem Corporation, SPI Polyols, Sun Refining, Logan Generating Co., and Hay Road.

B5-5.3 Considering Only Recreational Values

This study understates the total benefits of improvements in fishing site quality because estimates are limited to recreation benefits. Many other forms of benefits, such as habitat values for a variety of species (in addition to recreational fish), nonuse values, etc., are also likely to be important.

B5-5.4 Potential Sources of Survey Bias

The survey results could suffer from bias, such as recall bias and sampling effects.

a. Recall bias

Recall bias can occur when respondents are asked, such as in the MRFSS survey, the number of their recreation days over the previous season. Some researchers believe that recall bias tends to lead to the number of recreation days being overstated, particularly by more avid participants. Avid participants tend to overstate the number of recreation days because they count days in a "typical" week and then multiply them by the number of weeks in the recreation season. They often neglect to consider days missed due to bad weather, illness, travel, or when fulfilling "atypical" obligations. Some studies also found that the more salient the activity, the more "optimistic" the respondent tends to be in estimating the number of recreation days. Individuals also have a tendency to overstate the number of days they participate in activities that they enjoy and value. Taken together, these sources of recall bias may result in an overstatement of the actual number of recreation days.

b. Sampling effects

Recreational demand studies frequently face observations that do not fit general recreation patterns, such as observations of avid participants. These participants can be problematic because they claim to participate in an activity an inordinate number of times. This reported level of activity is sometimes correct but often overstated, perhaps due to recall bias. Even where the reports are correct, these observations tend to be overly influential (Haab et al., 2000). EPA set the upper limit of the number of fishing trips per year to 180 days to correct for potential bias caused by these observations when estimating trip participation models. Instead of dropping four survey observations with the number of annual trips reported as greater than 180, the Agency set the number of annual trips to the upper bound (i.e., 180 trips).

Chapter B6: Benefits Analysis for the Delaware Estuary

This chapter presents the results of EPA's evaluation of the economic benefits associated with reductions in estimated current I&E at CWIS in the transition zone of the Delaware Estuary. The economic benefits that are reported here are based on the values presented in Chapter B4, and EPA's estimates of current I&E at in-scope facilities (summarized in Section B3-9 of Chapter B3). Sections B6-1 and B6-2 summarize the estimates of economic loss developed in Chapters B4 and B5. Section B6-3 presents the economic benefits of reducing I&E with the proposed rule, and Section B6-4 discusses uncertainties in the analysis.

CHAPTER CONTENTS

B6-1 Summary Figures of Salem's Baseline Losses

The flowchart in Figure B6-1 summarizes how the economic estimates for the Salem facility were derived from the I&E estimates presented in Chapter B3. Figures B6-2 and B6-3 indicate the distribution of I&E losses by species category and associated economic values. These diagrams reflect the baseline losses based on current technology (including screens). All dollar values (and loss percents) reflect midpoints of the ranges for the categories of commercial, recreational, nonuse, and forage.

Figure B6-1: Overview and Summary of Average Annual I&E at Salem and Associated Economic Values (based on current in-place technologies, e.g., Ristroph screens; all results are annualized)[a]

1. Number of organisms lost (eggs, larvae, juveniles, etc.)
I: 6.6 million organisms[b]
E: 14.7 billion organisms[c]

2. Age 1 equivalents lost (number of fish)
I: 3.2 million fish (2.0 million forage, 1.2 million commercial and recreational)[d]
E: 356.3 million fish (297 million forage, 59 million commercial and recreational)[e]

3. Loss to recreational and commercial harvest
I: 113,500 fish (136,000 lb)[d]
E: 10.5 million fish (9.98 million lb)[e]

4. Value of commercial losses[f]
I: 99,600 fish (103,500 lb)
$245,000 (56.5% of total $I loss)
E: 8.78 million fish
(7.98 million lb)
$14.5 million
(63.7% of total $E loss)

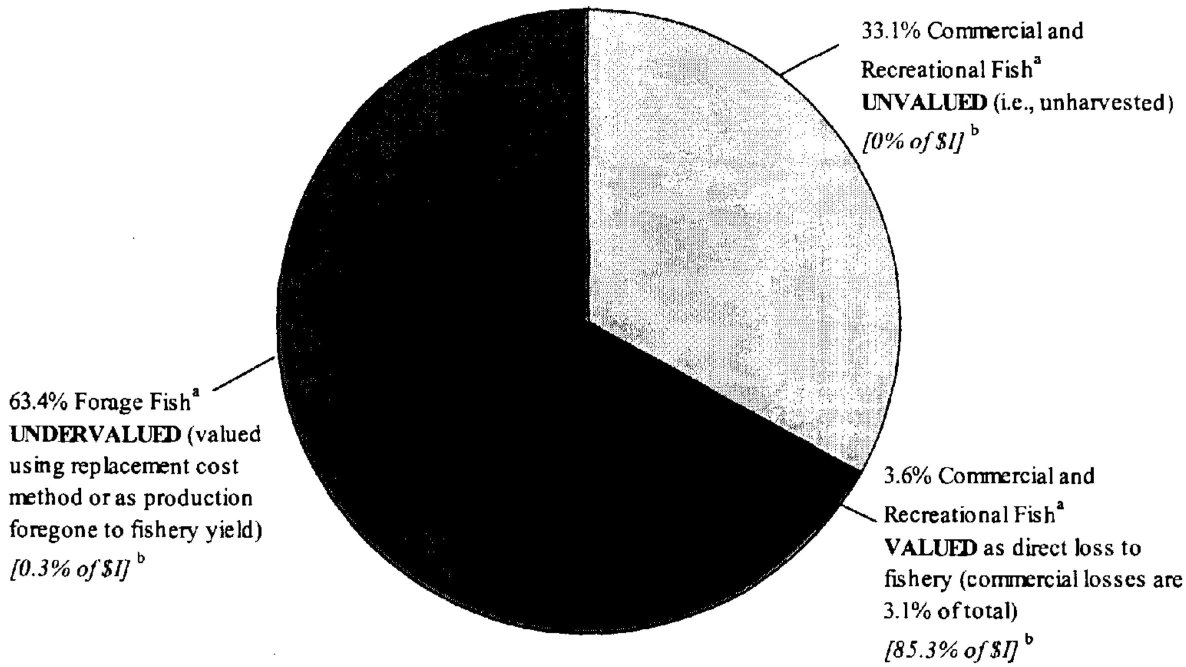
5. Value of recreational losses
I: 13,900 fish (4,600 lb)
$99,600 RUM[g]
(23.0% of total $I loss)
$25,300 BT[f]
(5.8% of total $I loss)
E: 1.76 million fish
(1.48 million lb)
$2.59 million RUM[g]
(11.4% of total $E loss)
$2.86 million BT[f]
(12.5% of total $E loss)

6. Value of forage losses
(valued using either replacement cost method or as production foregone to fishing yield)[f]
I: 2.0 million fish
$1,100 (0.3% of total $I loss)
E: 297 million fish
$93,000 (0.4% of total $E loss)

7. Value of nonuse losses[f]
I: $62,500 (14.4% of total $I loss)
E: $2.73 million (12.0% of total $E loss)

[a] All dollar values are the midpoint of the range of estimates.
[b] From Table B3-21 in Chapter B3.
[c] From Table B3-22 in Chapter B3.
[d] From Tables B4-2 and B4-10 in Chapter B4.
[e] From Tables B4-3 and B4-11 in Chapter B4.
[f] Benefits transfer, Chapter B4.
[g] Random Utility Model, Chapter B5.

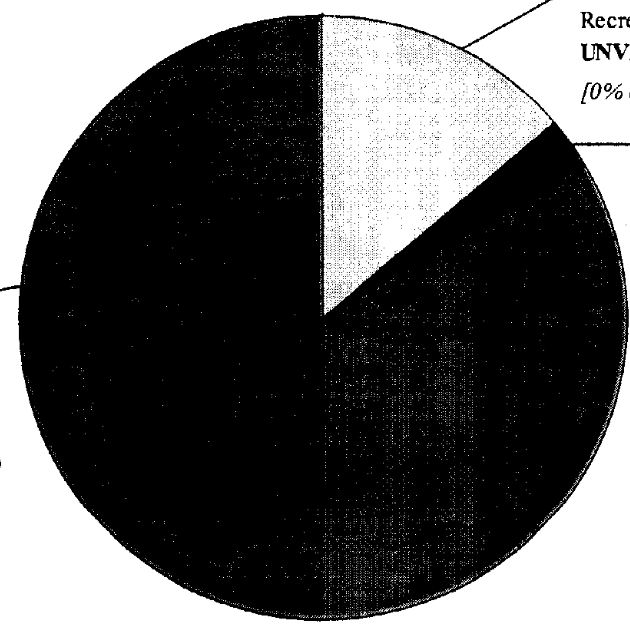
Figure B6-2: Salem: Distribution of Impingement Losses by Species Category and Associated Economic Values



Total: 3.2 million fish per year (age 1 equivalents)[a]
Total impingement value = $433,500[b]

[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages vulnerable to the fishery.
[b] Midpoint of estimated range. Nonuse values are 14.4 percent of total estimated $I loss.

Figure B6-3: Salem: Distribution of Entrainment Losses by Species Category and Associated Economic Values



Total: 356.3 million fish per year (age 1 equivalents)[a]
Total entrainment value = $22.8 million[b]

[a] Impacts shown are to age 1 equivalent fish, except impacts to the commercially and recreationally harvested fish include impacts for all ages vulnerable to the fishery.
[b] Midpoint of estimated range. Nonuse values are 12.0 percent of total estimated $E loss.

Tables B6-1 and B6-2 summarizes losses to commercial and recreational landings due to I&E at CWIS of the Delaware Estuary transition zone.

Tables B6-3 and B6-4 display the economic losses to recreation combining the benefits transfer and RUM analysis methods. For all of the in-scope facilities, the losses range from $173,800 to $219,100 per year for impingement and from $6,069,900 to $10,984,800 per year for entrainment.[1]

[1] The RUM results have been disaggregated between impingement (3.7 percent) and entrainment (96.3 percent) on the basis of their relative impacts on weakfish and striped bass. Although the RUM results are nonlinear with respect to the number of fish impacted, the relatively small amount of impingement effects (relative to those for entrainment) suggests that linearity may be acceptable as a disaggregation approach for the small increment involved.

Table B6-1: EPA's Estimate of Current Average Annual I&E of Commercial Fishery Species at Delaware Transition Zone Facilities Expressed as Lost Commercial Fishery Yield (in pounds). Commercial Yield is a Species-Specific Fraction of Total Yield as Outlined in Table B4-1. I&E Estimates are Discussed in Section B3-6 of Chapter B3.

Species	Salem		In-Scope Facilities (Salem, Hope Creek, Deepwater, Edge Moor)		All Transition Zone Facilities	
	Loss to Commercial Catch from Impingement (lb of fish)	Loss to Commercial Catch from Entrainment (lb of fish)	Loss to Commercial Catch from Impingement (lb of fish)	Loss to Commercial Catch from Entrainment (lb of fish)	Loss to Commercial Catch from Impingement (lb of fish)	Loss to Commercial Catch from Entrainment (lb of fish)
Alewife	19	14	158	22	185	25
American shad	41	7	184	12	215	14
Atlantic croaker	42,478	3,014,877	46,437	4,675,471	54,378	5,475,017
Atlantic menhaden	NA	1,177,437	NA	1,825,969	NA	2,138,225
Blue crab	14,357	0	81,220	0	95,110	0
Silversides	NA	43	NA	67	NA	79
Spot	1,741	2,190,202	33,542	3,396,565	39,278	3,977,407
Striped bass	249	17,468	1,836	27,089	2,150	31,721
Weakfish	30,300	659,380	85,919	1,022,567	100,612	1,197,435
White perch	43	309	433	480	507	562
Non RIS fishery species[a]	14,267	917,552	20,953	1,422,940	24,536	1,666,274
Total	103,495	7,977,290	270,684	12,371,181	316,973	14,486,758

[a] Non-RIS species are listed in Table B3-1.
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Table B6-2: EPA's Estimate of Current Average Annual I&E of Recreational Fishery Species at Delaware Transition Zone Facilities Expressed as Lost Recreational Fishery Yield (number of fish). Recreational Yield is a Species-Specific Fraction of Total Yield as Outlined in Table B4-1. I&E Estimates are Discussed in Section B3-6 of Chapter B3.

Species	Salem		In-scope Facilities (Salem, Hope Creek, Deepwater, Edge Moor)		All Transition Zone Facilities (in-scope and out of scope)	
	Loss to Recreational Catch from Impingement (number of fish)	Loss to Recreational Catch from Entrainment (number of fish)	Loss to Recreational Catch from Impingement (number of fish)	Loss to Recreational Catch from Entrainment (number of fish)	Loss to Recreational Catch from Impingement (number of fish)	Loss to Recreational Catch from Entrainment (number of fish)
American shad	13	2	33	4	42	4
Atlantic croaker	2,806	199,188	3,896	308,915	4,420	361,719
Blue crab	2,131	0	6,413	0	8,473	0
Blueback herring						
Non-RIS fishery species[a]	4,653	299,224	7,080	464,059	8,248	543,383
Spot	922	1,159,488	7,229	1,798,217	10,265	2,105,596
Striped bass	721	50,624	2,611	78,511	3,521	91,931
Weakfish	2,486	54,104	4,990	83,908	6,195	98,250
White perch	134	964	613	1,495	844	1,751
Total	13,865	1,763,594	32,866	2,735,107	42,010	3,202,634

[a] Non-RIS species are listed in Table B3-1.
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Table B6-3: EPA's Estimate of Current Recreational Economic Losses from Impingement at Facilities Located in the Delaware Estuary Transition Zone ($2000).

Species	Salem				In-scope Facilities in the Transition Zone				All Transition Zone Facilities			
	Basic Analysis		Rum Analysis		Basic Analysis		Rum Analysis		Basic Analysis		Rum Analysis	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Striped bass	$2,491	$11,206	$15,424	$15,679	$3,861	$17,369	$23,934	$24,552	$4,524	$20,350	$27,990	$28,727
Weakfish[a]	$2,881	$6,762	$83,961	$84,143	$4,466	$10,481	$132,712	$133,166	$5,232	$12,280	$155,282	$155,918
Other species	$11,045	$39,633	NA	NA	$17,120	$61,431	NA	NA	$20,058	$71,974	NA	NA
Total[b]	$110,430 to $139,455				$173,766 to $219,149				$203,330 to $256,619			

NA = Not Available.
Salem baseline losses stated here will differ slightly from the historical losses reported in Chapter B4 because different years are used in the baseline analysis of current I&E than in the historical analysis.
[a] Weakfish results include RUM results for "no target" anglers because there is virtually no overlap between the catch reported by "no target anglers" and the species included in the "other species" category.
[b] Total are based on summing results of the RUM analysis for weakfish and striped bass with the "other species" results from the basic benefits transfer analysis.

Table B6-4: EPA's Estimate of Current Recreational Economic Losses from Entrainment at Facilities Located in the Delaware Estuary Transition Zone ($2000).

Species	Salem				In-scope Facilities in the Transition Zone				All Transition Zone Facilities			
	Basic Analysis		Rum Analysis		Basic Analysis		Rum Analysis		Basic Analysis		Rum Analysis	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Striped bass	$175,000	$787,199	$401,449	$408,072	$271,250	$1,220,158	$622,938	$639,009	$317,800	$1,429,553	$728,490	$747,674
Weakfish[a]	$62,690	$147,162	$2,185,247	$2,189,985	$97,170	$228,101	$3,454,102	$3,465,921	$113,845	$267,246	$4,041,535	$4,058,084
Other species	$1,285,711	$4,438,627	NA	NA	$1,992,852	$6,879,872	NA	NA	$2,334,851	$8,060,547	NA	NA
Total[b]	$3,872,407 to $7,036,684				$6,069,892 to $10,984,802				$7,104,876 to $12,866,305			

NA = Not Available.
Salem baseline losses stated here will differ slightly from the historical losses reported in Chapter B4 because different years are used in the baseline analysis of current I&E than in the historical analysis.
[a] Weakfish results include RUM results for "no target" anglers because there is virtually no overlap between the catch reported by "no target anglers" and the species included in the "other species" category.
[b] Total are based on summing results of the RUM analysis for weakfish and striped bass with the "other species" results from the basic benefits transfer analysis.

B6-2 POTENTIAL ECONOMIC BENEFITS DUE TO REGULATION

Table B6-5 summarizes the total annual benefits from I&E reductions, as well as remaining economic losses, under scenarios ranging from 10 percent to 90 percent reductions in I&E. Table B6-6 considers the benefits of two options with varying percent reductions of I&E. Table B6-6 indicates that the benefits are expected to range from $107,000 to $162,000 for a 20 percent reduction in impingement and from $10.2 million to $18.1 million for a 40 percent reduction in entrainment. The benefits of another option range from $320,000 to $487,000 for a 60 percent reduction in impingement and from $15.3 million to $27.2 million for a 60 percent reduction in entrainment.

B6-5: Summary of Current Economic Losses and Benefits of a Range of Potential I&E Reductions at Four In-Scope Facilities on the Delaware Estuary ($2000).

		Impingement	Entrainment	Total
Baseline losses	low	$533,000	$25,493,000	$26,027,000
	high	$812,000	$45,268,000	$46,080,000
Benefits of 10 percent reductions	low	$53,000	$2,549,000	$2,603,000
	high	$81,000	$4,527,000	$4,608,000
Benefits of 20 percent reductions	low	$107,000	$5,099,000	$5,205,000
	high	$162,000	$9,054,000	$9,216,000
Benefits of 30 percent reductions	low	$160,000	$7,648,000	$7,808,000
	high	$243,000	$13,581,000	$13,824,000
Benefits of 40 percent reductions	low	$213,000	$10,197,000	$10,411,000
	high	$325,000	$18,107,000	$18,432,000
Benefits of 50 percent reductions	low	$267,000	$12,747,000	$13,013,000
	high	$406,000	$22,634,000	$23,040,000
Benefits of 60 percent reductions	low	$320,000	$15,296,000	$15,616,000
	high	$487,000	$27,161,000	$27,648,000
Benefits of 70 percent reductions	low	$373,000	$17,845,000	$18,219,000
	high	$568,000	$31,688,000	$32,256,000
Benefits of 80 percent reductions	low	$427,000	$20,395,000	$20,821,000
	high	$649,000	$36,215,000	$36,864,000
Benefits of 90 percent reductions	low	$480,000	$22,944,000	$23,424,000
	high	$730,000	$40,742,000	$41,472,000

Table B6-6: Summary of Benefits of Potential I&E Reductions at Four In Scope Facilities on the Delaware Estuary ($2000).

		Impingement	Entrainment	Total
Option A	low	$107,000	$10,197,000	$10,304,000
(20% reduced impingement, 40% reduced entrainment)	high	$162,000	$18,107,000	$18,269,000
Option B	low	$320,000	$15,296,000	$15,616,000
(60% reduced impingement, 60% reduced entrainment)	high	$487,000	$27,161,000	$27,648,000

B6-3 Summary of Omissions, Biases, and Uncertainties in the Benefits Analysis

Table B6-7 presents an overview of omissions, biases, and uncertainties in the benefits estimates. Factors with a negative impact on the benefits estimate bias the analysis downward, and therefore would raise the final estimate if they were properly accounted.

Table B6-7: Omissions, Biases, and Uncertainties in the Benefits Estimates.

Issue	Impact on Benefits Estimate	Comments
Long-term fish stock affects not considered	Understates benefits[a]	EPA assumed that the effects on stocks are the same each year, and that the higher fish kills would not have cumulatively greater impact.
Effect of interaction with other environmental stressors	Understates benefits[a]	EPA did not analyze how the yearly reductions in fish may make the stock more vulnerable to other environmental stressors. In addition, as water quality improves over time due to other watershed activities, the number of fish impacted by I&E may increase.
Recreation participation is held constant[a]	Understates benefits[a]	Recreational benefits only reflect anticipated increase in value per activity outing; increased levels of participation are omitted. RUM analyses for striped bass and weakfish do embody participation increases, however.
Boating, bird-watching, and other in-stream or near-water activities are omitted[a]	Understates benefits[a]	The only impact to recreation considered is fishing.
Effect of change in stocks on number of landings	Uncertain	EPA assumed a linear stock to harvest relationship, that a 13 percent change in stock would have a 13 percent change in landings; this may be low or high, depending on the condition of the stocks.
Nonuse benefits	Uncertain	EPA assumed that nonuse benefits are 50 percent of recreational angling benefits.
Use of unit values from outside Delaware Estuary	Uncertain	The recreational and commercial values used are from the state and or mid-Atlantic region, but are not from studies of Delaware Estuary specifically.
Extrapolation from Salem to Other Facilities	Uncertain	Unknown whether $/MGD basis for extrapolation over- or understates benefits of other facilities in the estuary.

[a] Benefits would be greater than estimated if this factor were considered.

Part C: The Ohio River Watershed Case Study

Chapter B7: Conclusions

The results of EPA's evaluation of I&E rates at CWIS in the Delaware Estuary transition zone indicate that cumulative impacts can be substantial. As summarized in Chapter B3, Tables B3-21 and B3-22, the cumulative impingement impact amounts to over 9.6 million age 1 equivalent fish per year (over 332,000 lb of fishery yield foregone), and the entrainment-related losses are much greater, at nearly 616 million age 1 equivalent fish lost (and more than 16 million lb of fishery yield foregone).

EPA's analysis shows that even when losses at individual facilities in the transition zone appear insignificant, the total of all I&E impacts on the same fish populations can be sizable. For example, an estimated 43,764 age 1 equivalents of weakfish are lost as a result of entrainment at Hope Creek, which operates with closed cycle cooling and therefore has relatively low entrainment rates. However, the number of total weakfish age 1 equivalents lost as a result of entrainment at all transition zone CWIS is over 2.2 million (Chapter B3, Table B3-15).

EPA has conservatively estimated such cumulative impacts on Delaware Estuary species by considering the I&E impacts of only transition zone CWIS. In fact, many of the species affected by CWIS within the transition zone move in and out of this area, and therefore may be exposed to many more CWIS than those considered here (see Figure B1-1 in Chapter B1). Regardless of the geographic extent of an evaluation of cumulative impacts, it is important to consider how I&E rates relate to the relative abundance of species in the source waterbody. Thus, low I&E does not necessarily imply low impact since it may reflect low population abundance, which can result from numerous natural and anthropogenic factors, including long-term I&E impacts of multiple CWIS. On the other hand, high population abundance in the source waterbody and associated high I&E may reflect waterbody improvements that are independent of impacts from or improvements in CWIS technologies. Or, high levels of I&E impacts on a species may indicate a high susceptibility of that given species to CWIS effects.

In addition to estimating the physical impact of I&E in terms of numbers of fish lost because of the operation of all in-scope and out-of-scope CWIS in the Delaware Estuary transition zone, EPA also examined the estimated economic value of the losses from I&E. Chapter B4 provides an indication of the estimated cumulative impact of I&E at the all in-scope and out-of-scope CWIS in the case study area, based on data available for the Salem facility and then extrapolated to the other facilities on the basis of flow. As indicated in Chapter B4, average baseline losses from all facilities in the case study area for impingement are valued at between roughly $0.5 million and $1.1 million per year, and average baseline losses from entrainment are valued at between approximately $23.4 million and $48.5 million per year (all in $2000).

EPA also developed a random utility model (RUM) to provide primary estimates of the recreational fishery losses associated with I&E in the Delaware case study area. As shown in Chapter B5, the average annual recreation-related fishery losses at all facilities in the transition zone amount to approximately $5.0 million per year (impingement and entrainment impacts combined). For the in-scope facilities covered by the proposed Phase 2 rule, the losses due to I&E were estimated via the RUM to amount to approximately $4.2 million per year. Results for the RUM analysis (Chapter B5) were merged with the benefits transfer-based estimates (Chapter B4) in a manner that avoids double counting.

EPA also estimated the economic benefits of a range of I&E reductions for the four in-scope CWIS in the case study area (Chapter B6). For the benefits analysis, adjustments to I&E rates were made to suitably reflect the regulatory baseline (i.e., to reflect changes some facilities made over the years to reduce I&E). Benefits estimates were then based on percentage reductions (from 10 percent to 90 percent) in estimated current I&E for the regulation-impacted facilities (Salem, Hope Creek, Edge Moor, and Deepwater). The resulting estimates of the economic value of benefits for reduced I&E range from $0.3 million to $0.5 million per year for 60% impingement loss reductions, and from $17.8 million to $31.7 million per year for 70% entrainment loss reductions (all in $2000).

In interpreting the results of the case study analysis, it is important to consider several critical caveats and limitations of the analysis. These caveats have been detailed in each preceding chapter. In the economic valuation component of the analysis, valuation of I&E losses is often complicated by the lack of market value for forage species, which may comprise a large proportion of total losses. For example, EPA estimates that over 527 million age 1 equivalents of bay anchovy may be lost to entrainment at transition zone CWIS each year (over 85 percent of the total of more than 616 million estimated lost age 1 individuals for all species combined, as shown in Chapter B3, Table B3-15). Bay anchovy has no direct market value, but it is nonetheless a critical component of estuarine food webs. EPA included forage species impacts in the economic benefits calculations as discussed in Chapter A9 of Part A, but because techniques for valuing such losses are limited, the final estimates may well underestimate the full ecological and economic value of these losses. Thus, on the whole, EPA believes the estimates developed here underestimate the economic benefits of reducing I&E.

Appendix B1: Survival Factors and Other Parameters Used by PSEG to Estimate I&E Losses at Salem

The tables in this appendix present the survival factors and other parameters used by PSEG to estimate I&E losses at the Salem facility. This information is taken from Appendix L of Salem's 1999 Permit Renewal Application (PSEG, 1999e).

Table B1-1: Parameters Used by PSEG to Calculate Historic Losses for Alewife at the Salem Station, 1978-1998

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
Egg	NA	NA	1		0	0.1	1
Yolk Sac	<4 mm, = 1/0.11; 4-7 mm,	5-32 mm, = 1/(1.13486 - 0.02697 * length);	0.883	$-14.194 - 0.015T_A + 2.158 \log_{10}t + 0.473T_E$	0	0.1	1
Post-yolk Sac	= 1/(-1.0767 + 0.2967 * length)	32-60 mm, = 1/(0.36294 - 0.00285 * length);	0.883		0	0.1	1
Juvenile	NA	> 60 mm, = 1/0.1919	0.883		0	0.1	1

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Live[a] (1977-1995)														
Age 0	0.7737	1	1	1	0.992	1	0.996	1	1	1	1	0.709	0.728	0.71
Age 1	0.7737	1	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.763	0.994
Age 2	0.7737	1	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.763	0.994
Damaged[a] (1977-1995)														
Age 0	0.7737	1	1	1	0.992	1	0.996	1	1	1	1	0.709	0.728	0.71
Age 1	0.7737	1	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.763	0.994
Age 2	0.7737	1	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.763	0.994
Live and Damaged[b] (1996-1998)														
Age 0	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
Age 1	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
Age 2	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208

T_A = Acclimation temperature, T_E = Exposure temperature, t = transit time.

[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.

[b] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix G, Attachment 1 of the 1999 Salem Application.

Shaded area = data used by EPA to calculate impingement assuming no survival.

Source: PSEG, 1999e.

Table B1-2: Parameters Used by PSEG to Calculate of Historic Losses for American Shad at the Salem Station, 1978-1998

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
Egg	NA	NA	1		0	0.1	1
Yolk Sac	<4 mm, = 1/0.11; 4-7 mm,	5-32 mm, = 1/(1.13486 - 0.02697 * length);	0.883	$-14.194 - 0.015T_A + 2.158 \log_{10}t + 0.473T_E$	0	0.1	1
Post-yolk Sac	= 1/(-1.0767 + 0.2967 * length)	32-60 mm, = 1/(0.36294 - 0.00285 * length);	0.883		0	0.1	1
Juvenile	NA	> 60 mm, = 1/0.1919	0.883		0	0.1	1

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality: Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live[a] (1977-1995)											
Age 0	0.7737	1	0.239	0.61	0.61	0.581	0.61	0.61	0.61	0.61	0.61	0.61	0.286	0.149
Age 1	0.7737	1	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273
			Damaged[a] (1977-1995)											
Age 0	0.7737	1	0.239	0.61	0.61	0.581	0.61	0.61	0.61	0.61	0.61	0.61	0.286	0.149
Age 1	0.7737	1	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273	0.273
			Live and Damaged[b] (1996-1998)											
Age 0	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
Age 1	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208

T_A = Acclimation temperature, T_E = Exposure temperature, t = transit time.

[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.

[b] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix G, Attachment 1 of the 1999 Salem Application.

Shaded area = data used by EPA in the calculation of impingement assuming no survival.

Source: PSEG, 1999e.

Table B1-3: Parameters Used by PSEG to Calculate Historic Losses for Atlantic Croaker at the Salem Station, 1978-1998

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
Egg	NA	NA	1		0	0.1	1
Yolk Sac	<4 mm, = 1/0.11; 4-7 mm,	5-32 mm, = 1/(1.13486 - 0.02697 * length);	0.36	$-35.451 - 0.751T_A + 0 \log_{10}t + 1.663T_E$	0	0.1	1
Post-yolk Sac	= 1/(-1.0767 + 0.2967 * length)	32-60 mm, = 1/(0.36294 - 0.00285 * length);	0.36		0	0.1	1
Juvenile	NA	> 60 mm, = 1/0.1919	0.36		0	0.1	1

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live[a] (1977-1995)											
Age 0	0.8448	1	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286
Age 1	0.8448	1	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286	0.286
			Damaged[a] (1977-1995)											
Age 0	0.8448	1	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833
Age 1	0.8448	1	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833
			Live and Damaged[b] (1996-1998)											
Age 0	0.8448	1	0.387	0.387	0.387	0.387	0.313	0.271	0.102	0.387	0.387	0.019	0.005	0.107
Age 1	0.8448	1	0.387	0.387	0.387	0.387	0.313	0.271	0.102	0.387	0.387	0.019	0.005	0.107

T_A = Acclimation temperature, T_E = Exposure temperature, t = transit time.

[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.

[b] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix G, Attachment 1 of the 1999 Salem Application.

Shaded area = data used by EPA to calculate impingement assuming no survival.

Source: PSEG, 1999e.

Table B1-4: Parameters Used by PSEG to Calculate Historic Losses for Bay Anchovy at the Salem Station, 1978-1998.

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
Egg	NA	NA	1		0	0.1	1
Yolk Sac	<4 mm, = 1/0.11; 4-7 mm,	5-32 mm, = 1/(1.13486 - 0.02697 * length);	1	$-7.751 - 0.174T_A + 0.995 \log_{10}t + 0.427T_E$	0	0.1	1
Post-yolk Sac	= 1/(-1.0767 + 0.2967 * length)	32-60 mm, = 1/(0.36294 - 0.00285 * length);	1		0	0.1	1
Juvenile	NA	> 60 mm, = 1/0.1919	1		0	0.1	1
Adult	NA		1		0	0.1	1

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Live[a] (1977-1995)														
Age 0	0.7496	1	0.815	0.815	0.815	0.815	0.815	0.815	0.815	0.805	0.81	0.718	0.675	0.815
Age 1	0.7496	1	0.884	0.884	0.815	0.815	0.718	0.884	0.857	0.805	0.81	0.718	0.675	0.815
Age 2	0.7496	1	0.884	0.884	0.884	0.815	0.718	0.884	0.857	0.805	0.81	0.718	0.675	0.815
Age 3	0.7496	1	0.884	0.884	0.884	0.884	0.718	0.884	0.857	0.805	0.81	0.718	0.675	0.815
Damaged[a] (1977-1995)														
Age 0	0.7496	1	0.946	1	0.946	1	1	1	1	0.863	0.946	1	0.946	0.946
Age 1	0.7496	1	1	1	0.946	0.953	0.965	0.908	0.975	0.863	0.946	1	0.946	0.946
Age 2	0.7496	1	1	1	1	0.953	0.965	0.908	0.975	0.863	0.946	1	0.946	0.946
Age 3	0.7496	1	1	1	1	1	0.965	0.908	0.975	0.863	0.946	1	0.946	0.946
Live and Damaged[b] (1996-1998)														
Age 0	0.7496	1	0.761	0.761	0.761	0.49	0.483	0.741	0.761	0.761	0.761	0.194	0.255	0.761
Age 1	0.7496	1	0.761	0.761	0.761	0.49	0.483	0.741	0.761	0.761	0.761	0.194	0.255	0.761
Age 2	0.7496	1	0.761	0.761	0.761	0.49	0.483	0.741	0.761	0.761	0.761	0.194	0.255	0.761
Age 3	0.7496	1	0.761	0.761	0.761	0.49	0.483	0.741	0.761	0.761	0.761	0.194	0.255	0.761

T_A = Acclimation temperature, T_E = Exposure temperature, t = transit time.

[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.

[b] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix G, Attachment 1 of the 1999 Salem Application.

Shaded area = data used by EPA to calculate impingement assuming no survival.

Source: PSEG, 1999e.

Table B1-5: Parameters Used by PSEG to Calculate Historic Losses for Blueback Herring at the Salem Station, 1978-1998.

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
Egg	NA	NA	1		0	0.1	1
Yolk Sac	<4 mm, = 1/0.11; 4-7 mm,	5-32 mm, = 1/(1.13486 - 0.02697 * length);	0.883	$-14.194 - 0.015T_A$ $+2.158 \log_{10}t + 0.473T_E$	0	0.1	1
Post-yolk Sac	= 1/(-1.0767 + 0.2967 * length)	32-60 mm, = 1/(0.36294 - 0.00285 * length);	0.883		0	0.1	1
Juvenile	NA	> 60 mm, = 1/0.1919	0.883		0	0.1	1

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live[a] (1977-1995)											
Age 0	0.7737	1	0.636	0.636	1	1	1	1	1	1	1	0.636	0.636	0.636
Age 1	0.7737	1	1	1	1	1	1	1	1	0.636	0.636	0.636	0.636	0.636
Age 2	0.7737	1	1	1	1	1	1	1	1	0.636	0.636	0.636	0.636	0.636
Age 3	0.7737	1	1	1	1	1	1	1	1	0.636	0.636	0.636	0.636	0.636
Age 4	0.7737	1	1	1	1	1	1	1	1	0.636	0.636	0.636	0.636	0.636
Age 5	0.7737	1	1	1	1	1	1	1	1	0.636	0.636	0.636	0.636	0.636
			Damaged[a] (1977-1995)											
Age 0	0.7737	1	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982
Age 1	0.7737	1	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982
Age 2	0.7737	1	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982
Age 3	0.7737	1	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982
Age 4	0.7737	1	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982
Age 5	0.7737	1	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982
			Live and Damaged[b] (1996-1998)											
Age 0	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
Age 1	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
Age 2	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
Age 3	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208

Table B1-5: Parameters Used by PSEG to Calculate Historic Losses for Blueback Herring at the Salem Station, 1978-1998 (cont.).

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality: Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Live and Damaged[b] (1996-1998)														
Age 4	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208
Age 5	0.7737	1	0.208	0.208	0.208	0.139	0.208	0.208	0.208	0.208	0.208	0.208	0.208	0.208

T_A = Acclimation temperature, T_E = Exposure temperature, t = transit time.

[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.

[b] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix G, Attachment 1 of the 1999 Salem Application.

Shaded area = data used by EPA to calculate impingement assuming no survival.

Source: PSEG, 1999e.

Table B1-6: Parameters Used by PSEG to Calculate Historic Losses for Spot at the Salem Station, 1978-1998.

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
Egg	NA	NA	1		0	0.1	1
Yolk Sac	<4 mm, = 1/0.11; 4-7 mm,	5-32 mm, = 1/(1.13486 - 0.02697 * length);	0.185	$-37.16428 - 0.66867T_A$ $+0 \log_{10}t + 1.78425T_E$	0	0.1	1
Post-yolk Sac	= 1/(-1.0767 + 0.2967 * length)	32-60 mm, = 1/(0.36294 - 0.00285 * length);	0.185		0	0.1	1
Juvenile	NA	> 60 mm, = 1/0.1919	0.185		0	0.1	1

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality: Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Live[a] (1977-1995)														
Age 0	0.7965	1	0.559	0.559	0.559	0.559	0.444	0.11	0.239	0.294	0.382	0.559	0.307	0
Age 1	0.7965	1	0.559	0.559	0.559	0.559	0.444	0.11	0.239	0.294	0.382	0.559	0.307	0
Damaged[a] (1977-1995)														
Age 0	0.7965	1	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Age 1	0.7965	1	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96

Table B1-6: Parameters Used by PSEG to Calculate Historic Losses for Spot at the Salem Station, 1978-1998 (cont.).

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live and Damaged[b] (1996-1998)											
Age 0	0.7965	1	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Age 1	0.7965	1	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045

T_A = Acclimation temperature, T_E = Exposure temperature, t = transit time.

[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.

[b] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix G, Attachment 1 of the 1999 Salem Application.

Shaded area = data used by EPA to calculate impingement assuming no survival.

Source: PSEG, 1999e.

Table B1-7: Parameters Used by PSEG to Calculate Historic Losses for Striped Bass at the Salem Station, 1978-1998.

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
Egg	NA	NA	1		0	0.1	1
Yolk Sac	<4 mm, = 1/0.11; 4-7 mm,	5-32 mm, = 1/(1.13486 - 0.02697 * length);	0.484	$-7.771 - 0.096T_A$ $+2.300 \log_{10}t + 0.346T_E$	0	0.1	1
Post-yolk Sac	= 1/(-1.0767 + 0.2967 * length)	32-60 mm, = 1/(0.36294 - 0.00285 * length);	0.484		0	0.1	1
Juvenile	NA	> 60 mm, = 1/0.1919	0.484		0	0.1	1

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live[a] (1977-1995)											
Age 0	0.9269	1	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
Age 1	0.9269	1	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
Age 2	0.9269	1	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
			Damaged[a] (1977-1995)											
Age 0	0.9269	1	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333
Age 1	0.9269	1	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333
Age 2	0.9269	1	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333

Table B1-7: Parameters Used by PSEG to Calculate Historic Losses for Striped Bass at the Salem Station, 1978-1998 (cont.).

Impingement

			Latent Screen Mortality											
	Collection Efficiency[a]	SWS Mortality[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live and Damaged[b] (1996-1998)											
Age 0	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015
Age 1	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015
Age 2	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015

T_A = Acclimation temperature, T_E = Exposure temperature, t = transit time.

[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.

[b] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix G, Attachment 1 of the 1999 Salem Application.

Shaded area = data used by EPA to calculate impingement assuming no survival.

Source: PSEG, 1999e.

Table B1-8: Parameters Used by PSEG to Calculate Historic Losses for Weakfish at the Salem Station, 1978-1998.

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
Egg	NA	NA	1		0	0.1	1
Yolk Sac	<4 mm, = 1/0.11; 4-7 mm,	5-32 mm, = 1/(1.13486 - 0.02697 * length);	0.64	$-9.01577 - 0.09229T_A$ $+1.2856 \log_{10}t +$	0	0.1	1
Post-yolk Sac	= 1/(-1.0767 + 0.2967 * length)	32-60 mm, = 1/(0.36294 - 0.00285 * length);	0.64	$0.42717T_E$	0	0.1	1
Juvenile	NA	> 60 mm, = 1/0.1919	0.5		0	0.1	1

Impingement

			Latent Screen Mortality											
	Collection Efficiency[a]	SWS Mortality[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live[a] (1977-1995)											
Age 0	0.7915	1	0.563	0.563	0.563	0.563	0.563	0.274	0.346	0.422	0.334	0.563	0.376	0.376
Age 1	0.7915	1	0.422	0.422	0.422	0.422	0.422	0.274	0.346	0.422	0.334	0.422	0.422	0.422
			Damaged[a] (1977-1995)											
Age 0	0.7915	1	0.864	0.864	0.864	0.864	0.864	0.781	0.767	0.784	0.734	0.864	0.781	0.781
Age 1	0.7915	1	0.781	0.781	0.781	0.781	0.781	0.781	0.767	0.784	0.734	0.781	0.781	0.781

Table B1-8: Parameters Used by PSEG to Calculate Historic Losses for Weakfish at the Salem Station, 1978-1998 (cont.).

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live and Damaged[b] (1996-1998)											
Age 0	0.7915	1	0.579	0.579	0.579	0.579	0.579	0.494	0.579	0.315	0.079	0.579	0.579	0.579
Age 1	0.7915	1	0.579	0.579	0.579	0.579	0.579	0.494	0.579	0.315	0.079	0.579	0.579	0.579

T_A = Acclimation temperature, T_E = Exposure temperature, t = transit time.

[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.

[b] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix G, Attachment 1 of the 1999 Salem Application.

Shaded area = data used by EPA to calculate impingement assuming no survival.

Source: PSEG, 1999e.

Table B1-9: Parameters Used by PSEG to Calculate Historic Losses for White Perch at the Salem Station, 1978-1998.

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
Egg	NA	NA	1	$= -7.594 - 0.063T_A + 4.057 \log_{10}t + 0308T_E$	0	0.1	1
Yolk Sac	<4 mm, = 1/0.11; 4-7 mm,	5-32 mm, = 1/(1.13486 - 0.02697 * length);	0.829	$= -15.814 - 0.112T_A + 2.796 \log_{10}t + 0.545T_E$	0	0.1	1
Post-yolk Sac	= 1/(-1.0767 + 0.2967 * length)	32-60 mm, = 1/(0.36294 - 0.00285 * length);	0.829	$= -7.594 - 0.063T_A + 4.057 \log_{10}t + 0.308T_E$	0	0.1	1
Juvenile	NA	> 60 mm, = 1/0.1919	0.829	$= -7.594 - 0.063T_A + 4.057 \log_{10}t + 0.308T_E$	0	0.1	1

Impingement

	Collection Efficiency[a]	SWS Mortality[a]	Latent Screen Mortality Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live[a] (1977-1995)											
Age 0	0.9269	1	0	0	0.072	0.13	0	0.044	0.044	0.044	0.044	0.021	0.025	0.015
Age 1	0.9269	1	0	0	0.072	0.13	0	0.044	0.044	0.044	0.044	0.021	0.025	0.015
Age 2	0.9269	1	0	0	0.072	0.13	0	0.044	0.044	0.044	0.044	0.021	0.025	0.015
Age 3	0.9269	1	0	0	0.072	0.13	0	0.044	0.044	0.044	0.044	0.021	0.025	0.015
Age 4	0.9269	1	0	0	0.072	0.13	0	0.044	0.044	0.044	0.044	0.021	0.025	0.015
Age 5	0.9269	1	0	0	0.072	0.13	0	0.044	0.044	0.044	0.044	0.021	0.025	0.015

Table B1-9: Parameters Used by PSEG to Calculate Historic Losses for White Perch at the Salem Station, 1978-1998 (cont).

Impingement

			Latent Screen Mortality											
	Collection Efficiency[a]	SWS Mortality[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live[a] (1977-1995)											
Age 6	0.9269	1	0	0	0.072	0.13	0	0.044	0.044	0.044	0.044	0.021	0.025	0.015
Age 7	0.9269	1	0	0	0.072	0.13	0	0.044	0.044	0.044	0.044	0.021	0.025	0.015
Age 8	0.9269	1	0	0	0.072	0.13	0	0.044	0.044	0.044	0.044	0.021	0.025	0.015
			Damaged[a] (1977-1995)											
Age 0	0.9269	1	0.84	0.974	0.672	0.97	0.815	0.75	0.405	0.405	0.405	0.639	0.655	0.84
Age 1	0.9269	1	0.84	0.974	0.672	0.97	0.815	0.75	0.405	0.405	0.405	0.639	0.655	0.84
Age 2	0.9269	1	0.84	0.974	0.672	0.97	0.815	0.75	0.405	0.405	0.405	0.639	0.655	0.84
Age 3	0.9269	1	0.84	0.974	0.672	0.97	0.815	0.75	0.405	0.405	0.405	0.639	0.655	0.84
Age 4	0.9269	1	0.84	0.974	0.672	0.97	0.815	0.75	0.405	0.405	0.405	0.639	0.655	0.84
Age 5	0.9269	1	0.84	0.974	0.672	0.97	0.815	0.75	0.405	0.405	0.405	0.639	0.655	0.84
Age 6	0.9269	1	0.84	0.974	0.672	0.97	0.815	0.75	0.405	0.405	0.405	0.639	0.655	0.84
Age 7	0.9269	1	0.84	0.974	0.672	0.97	0.815	0.75	0.405	0.405	0.405	0.639	0.655	0.84
Age 8	0.9269	1	0.84	0.974	0.672	0.97	0.815	0.75	0.405	0.405	0.405	0.639	0.655	0.84
			Live and Damaged[b] (1996-1998)											
Age 0	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015
Age 1	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015
Age 2	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015
Age 3	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015
Age 4	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015
Age 5	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015
Age 6	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015
Age 7	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015
Age 8	0.9269	1	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.054	0.015

T_A = Acclimation temperature, T_E = Exposure temperature, t =transit time.
[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of PSEG, 1999e.
[b] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix L, Attachment 4 of PSEG, 1999e.
Shaded area = data used in the calculation of impingement losses assuming no survival.
Source: PSEG, 1999e.

Table B1-10: Parameters Used by PSEG to Calculate Historic Losses for *Gammarus* sp. at the Salem Station, 1978-1998.

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
All life stages	NA	1.25	0.014	$-11.942 - 0.269T_A + 1.205 \log_{10}t + 0.585T_E$	0	0.1	1

T_A = Acclimation temperature, T_E = Exposure temperature, t =transit time.
[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.
Source: PSEG, 1999e.

Table B1-11: Parameters Used by PSEG to Calculate Historic Losses for *Neomysis americana* at the Salem Station, 1978-1998.

Entrainment

	Net Extrusion[a]	Net Avoidance[a]	Mechanical Mortality[a]	Thermal Mortality[a]	Biocide[a]	Recirculation[a]	SWS Mortality[a]
All life stages	NA	1.25	0.1151	$-9.444 - 0.133T_A + 1.3301 \log_{10}t + 0.486T_E$	0	0.1	1

T_A = Acclimation temperature, T_E = Exposure temperature, t =transit time.
[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.
Source: PSEG, 1999e.

Table B1-12: Parameters Used by PSEG to Calculate Historic Losses for Blue Crab at the Salem Station, 1978-1998.

Impingement

			Latent Screen Mortality											
	Collection Efficiency[a]	SWS Mortality[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live[a] (1977-1995)											
Age 0	0.7496	1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Age 1	0.7496	1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Age 2	0.7496	1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Age 3	0.7496	1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
			Damaged[a] (1977-1995)											
Age 0	0.7496	1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Age 1	0.7496	1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Age 2	0.7496	1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Age 3	0.7496	1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

Table B1-12: Parameters Used by PSEG to Calculate Historic Losses for Blue Crab at the Salem Station, 1978-1998 (cont.).

Impingement

			Latent Screen Mortality											
	Collection Efficiency[a]	SWS Mortality[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Live and Damaged[b] (1996-1998)											
Age 0	0.7496	1	0.182	0.023	0.023	0.026	0.024	0.023	0.026	0.025	0.023	0.023	0.023	0.031
Age 1	0.7496	1	0.182	0.023	0.023	0.026	0.024	0.023	0.026	0.025	0.023	0.023	0.023	0.031
Age 2	0.7496	1	0.182	0.023	0.023	0.026	0.024	0.023	0.026	0.025	0.023	0.023	0.023	0.031
Age 3	0.7496	1	0.182	0.023	0.023	0.026	0.024	0.023	0.026	0.025	0.023	0.023	0.023	0.031

[a] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix F, Attachment 2 of the 1999 Salem Application.
[b] The parameters used by PSEG in the calculation of entrainment and impingement are described in Appendix G, Attachment 2 of the 1999 Salem Application.
Shaded area = data used by EPA to calculate impingement assuming no survival.
Source: PSEG, 1999e.

Table B1-13: Initial Impingement Mortality, Old and New Screens, as Used by PSEG to Calculate Impingement.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SGS Initial Impingement Mortality (Old Screens, 1977-1995)												
Blue crab	40.0%	60.0%	22.2%	1.0%	1.2%	2.7%	2.2%	1.6%	1.6%	1.0%	0.1%	0.3%
Blueback herring	14.5%	25.3%	17.0%	18.0%	22.9%	25.0%	19.0%	43.5%	7.7%	13.9%	12.3%	14.9%
Alewife	12.5%	12.6%	8.6%	19.7%	14.1%	26.4%	25.0%	20.0%	15.4%	55.8%	8.0%	7.6%
American shad	5.7%	5.1%	10.3%	16.7%	10.5%	NA	50.0%	66.7%	NA	7.9%	9.3%	10.1%
Bay anchovy	54.9%	41.7%	42.9%	34.3%	35.5%	41.6%	49.0%	39.9%	27.5%	20.3%	21.7%	21.8%
White perch	8.9%	5.3%	8.0%	7.1%	18.4%	17.6%	17.3%	16.1%	10.3%	9.5%	7.2%	7.4%
Striped bass	5.7%	3.8%	8.0%	8.2%	7.7%	2.6%	5.6%	8.8%	18.2%	3.8%	3.5%	5.0%
Weakfish	NA	NA	NA	NA	16.7%	43.8%	22.8%	18.2%	12.3%	9.3%	13.7%	10.0%
Spot	8.4%	NA	NA	NA	21.1%	18.7%	24.5%	20.2%	19.8%	10.6%	9.7%	9.8%
Atlantic croaker	23.4%	12.1%	NA	NA	11.5%	14.3%	16.7%	16.7%	3.0%	3.5%	5.3%	19.2%
SGS Initial Impingement Mortality (New Screens, 1996-1998)												
Blue crab	NA	20.0%	8.3%	2.2%	0.5%	0.4%	0.5%	1.0%	1.7%	1.0%	2.4%	NA
Blueback herring	2.1%	2.1%	2.6%	3.4%	NA	NA	NA	NA	9.1%	2.6%	NA	2.7%
Alewife	NA	8.3%	5.3%	0.0%	NA	NA	50.0%	NA	NA	25.0%	3.7%	NA
American shad	33.3%	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	33.3%
Bay anchovy	18.0%	40.0%	9.1%	36.9%	14.3%	11.1%	16.3%	15.7%	19.4%	21.7%	14.4%	40.0%
White perch	2.6%	0.9%	1.8%	0.7%	2.1%	11.6%	3.9%	NA	2.6%	0.9%	0.5%	0.7%

Table B1-13: Initial Impingement Mortality, Old and New Screens, as Used by PSEG to Calculate Impingement (cont.).

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SGS Initial Impingement Mortality (New Screens, 1996-1998)												
Striped bass	NA	2.1%	1.1%	1.8%	NA	6.7%	5.8%	7.8%	NA	NA	2.4%	NA
Weakfish	NA	NA	NA	NA	NA	10.5%	13.1%	6.5%	3.7%	2.5%	NA	NA
Spot	2.4%	NA	NA	NA	NA	5.0%	12.5%	NA	2.4%	3.0%	2.3%	4.4%
Atlantic croaker	19.1%	10.6%	11.9%	3.1%	4.6%	2.9%	6.5%	7.4%	2.7%	1.9%	3.0%	5.4%

Shaded area = data used by EPA to calculate impingement assuming no survival.
Source: PSEG, 1999c.