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INTERFACES OF STEAM ELECTRIC POWER PLANTS WITH AQUATIC ECOSYSTEMS

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SUMMARY

Growth and reproduction may be stimulated by increased temperature in the cooling system and thermal plume during seasons when ambient water temperature is less than optimum, but growth, reproduction and survival are reduced when the elevated temperatures become excessive. Some fish species congregate in the warm thermal plumes during cold seasons but are excluded from this living space by temperatures above their preference in the summer. However, the warm refuge provided by a thermal plume in cold seasons can be a death trap if a power plant shuts down suddenly and exposes the fish to cold shock exceeding their lower thermal tolerance limits.

Each of the factors tend to affect different segments of the biota. For example, impingement involves primarily juvenile and adult life stages of fish and species of large invertebrates; pumped entrainment affects are restricted to the smaller planktonic forms that include egg and larval stages of fish; and chemical and thermal discharges may affect all segments of the biota but in ways that vary dramatically among segments, species or even life stages of a species.

Death and injury of aquatic organisms by power plant operations is a non-consumptive form of cropping, in that dead and injured specimens are returned to receiving waters and can be utilized by various trophic levels.

Mortality of aquatic organisms, and stresses resulting in changes not manifested in mortality imposed by power plant operations do not necessarily cause detectable adverse effects on populations in receiving waters. This fact has been demonstrated by a considerable number of studies at existing plants. However, fairly extensive damage to aquatic biota in the vicinity of a relatively few power plants also indicates that there are local and ecosystem-wide limits on the electric generating capacity that can be sustained without significant adverse effects on aquatic life.

Aquatic populations have natural but limited capacities to withstand predation and other forms of stress before significant damage results. In fact, many if not all species require some level of cropping in order to sustain healthy, productive populations.

Aquatic populations are known to compensate for cropping by various mechanisms that include increased growth rates, reproduction rates, and survival rates. As a result, cropped laboratory populations of some species are known to sustain annual production rates as much as 10 to 20 times higher than uncropped populations. But populations in natural bodies of water are already subjected to cropping by other animal species, and by man in the case of many fish species. The ultimate question for which answers must now be sought is, how much additional cropping by power plant operations can aquatic populations sustain without significant damage to the populations?

Both types of cooling systems (closed and once-through) involve construction effects, and interface with aquatic life at the water intake structure, in the cooling system (pumped entrainment) and at the discharge plume. The closed systems withdraw much less water, so expose many fewer organisms to risk of impingement and entrainment than do the once-through systems. On the other hand it is generally assumed that all organisms entrained into closed cycle systems are killed compared to mortality estimates ranging from 2% up to 100% for organisms entrained through various plants with once through cooling systems. The once-through systems discharge much more heat, that may or may not cause significant adverse effects, but utilize much more of the assimilative capacity of the receiving water than closed cycle systems. Consequently, closed cycle cooling systems permit installation of much more generating capacity on a body of water. On the other hand closed cycle systems consume considerably more water by evaporation, an important consideration in areas already faced with water shortages, and they cost much more than once-through systems. There are also esthetic and terrestrial environmental effects associated with closed cycle systems.

Research to evaluate adverse effects of steam electric power plant operation on aquatic life has focused almost entirely on the discharge plume of heated water. Recently, many investigators have become convinced that potential for adverse effects by the thermal plumes may be relatively inconsequential compared to impingement and pumped entrainment. Most legislation and regulatory effort is still focused on thermal discharge from power plants but consid-

eration of impingement, pumped entrainment and other environmental effects is increasing rapidly.

Clearly plant design and regulatory efforts to minimize adverse environmental effects of power plant operations should involve an integrated analysis of the effects of all interfaces for all existing and proposed power plants on a body of water relative to the costs and benefits likely to be achieved by abatement efforts. Utility management and regulatory agency decisions based on a piece-meal approach and inadequate information may result either in unacceptable environmental impacts or unwarranted capitol expenditures.

INTRODUCTION

Steam electric power plants use large amounts of water for cooling the condensers and auxiliary systems, and for boiler feed make-up, maintenance cleaning, wet ash handling systems, air pollution control devices, intake screen backwash and disposal of sanitary and chemical wastes.

The cooling water requirements for steam electric plants in the United States now amounts to about 60 trillion gallons per year, which is roughly equivalent to 15% of the total flow in U.S. rivers and streams. Other industries use an additional 10 trillion gallons of water per year for cooling (1).

A nuclear fueled plant requires from 40 to 50 percent more cooling water flow than a fossil-fueled plant of the same generating capacity and condenser cooling water temperature rise (ΔT) design because a nuclear plant rejects from 40 to 50 percent more heat to the cooling water per killowat-hour (KWh) than a fossil-fueled plant. Fossil fueled plants reject from 10 to 20 percent of their waste heat through the stacks to the atmosphere and have a higher thermal efficiency (39% for a well - designed, well-run plant) than nuclear-fueled plants. Nuclear plants reject virtually all of their waste heat to the condenser cooling water and have thermal efficiencies that seldom exceed 34% even under ideal conditions. Thus a 600 MW fossil-fueled unit operating at capacity may require about 600,000 gallons/minute of cooling water heated to 9 degrees centigrade (15-16 degrees F) above ambient compared to about 840,000 gallons/minute heated to 9°C for a 600 MW nuclear unit.

The water requirements for auxillary uses vary widely, depending upon plant design, from a few hundred to about 1000 gallons per minute per 100 Megawatts of generating capacity.

Steam electric power plants employ two basic types of cooling water systems, once-through and closed, along with a host of supplemental modifications and combinations of those systems.

Once-through systems withdraw water from a source, pump it through the condensers one or more times, and then discharge the heated water back to the source.

Closed cycle systems pass the heated water from the condensers through cooling ponds, canals or cooling towers where the excess heat is rejected to the air, before the water is again recycled through the condenser cooling system. After initial filling of the cooling system the only additional water required is the amount necessary to make up for losses by evaporation, to dilute concentrated dissolved solid and chemical discharges from the cooling system and to service auxiliary systems. Some plant designs provide for cycling the service water through the closed cycle cooling system, which reduces the amount of water required from source bodies of water. In general the use of closed cycle cooling systems reduces the water requirements of a plant to about 3 to 10 percent of the amount required for once-through systems. The amount over about 2.5-3% consists of service water not treated in the closed cycle cooling system.

Both types of cooling systems interface with aquatic life at the water intake structure, in the cooling system (pumped entrainment) and at the discharge plume. Other factors that may cause power plants to impact on aquatic ecosystems include construction, spillage of coal and oil during unloading operations, scouring by tug boat traffic, leaching from coal piles, discharges from fly ash ponds, and discharge of chemical and sanitary wastes.

Site Selection and Facility Design

Site selection and facility design are planning functions that do not of themselves cause aquatic impacts, but site selection and design decisions substantially determine the kinds and degree of impacts that will result from construction and operation. A wholistic appraisal and balancing of environmental consequences of alternative sites and designs can minimize the aquatic impacts, but it is technically impossible to achieve an impact-free power plant facility.

Construction Impacts

Construction activities that affect aquatic ecology include excavation both on land and in the water required to build the facility. Erosion of silt from land excavations into adjacent waters may smother benthic organisms and fish eggs and produce turbid conditions that inhibit primary production by phytoplankton and rooted aquatic plants. Damage to aquatic life and habitats by this factor can be minimized by careful selection of the site and construction methods, and specific control and abatement techniques.

Excavation directly in water bodies for the purpose of constructing intake and discharge structures, diffuser pipes, docks, bulkheads, jetties and other such structures affect aquatic life in various ways.

Benthic organisms are most vulnerable. A large fraction of those in the dredged material are likely to be killed. Many species of organisms inhabiting the bottom in the vicinity of the dredged area are likely to be killed or damaged by siltation, which is especially difficult to control at underwater excavations. The time required for bottom habitats to return to pre-excavation condition depends both on the effectiveness of post construction rehabilitation efforts and natural recovery processes. Recovery by natural processes tends to take much longer in low flow velocity waters such as lakes and coves where sediment and drift-organism transport is normally more dynamic.

More motile organisms will differ in their reactions to dredging operations. Some animals such as fish and large crustaceans may leave the area during construction and would probably return later. Others might not react or might move into the construction area to feed on organisms exposed by the dredging. In general, these motile organisms should be able to avoid any adverse impact.

Planktonic species could experience a short term impact as a result of shading effects from material suspended in the water column.

Impacts of excavation are generally transitory, but are one of the environmental trade-offs to be considered when choosing from among cooling system alternatives.

Hard under-water surfaces of installed structures provide many species with suitable habitats that are frequently in short supply. These structures also provide a haven for many species of fish that prefer to live around submerged objects. Indeed, this tendency for fish to be attracted to submerged objects is one of the reasons why pre-construction biological surveys are frequently of limited value for evaluating potential fish impingement on intake screens, the next subject for discussion.

Impingement of Biota on Intake Screens

Aquatic organisms, mostly species of fish and a few invertebrates, too large to pass through the mesh of cooling system intake screens are subject to being impinged on the screens. Many of these impinged organisms are severely injured or killed.

Trash racks made of a series of vertical steel bars approximately 2 to 3 inches apart and vertical traveling screens developed in the 1920's are still the major equipment used for removing trash from the cooling water before it is pumped through the condenser system. The traveling screens of most stations in the U.S. are made of 3/8 inch square mesh. Figure 1 shows two basic types of intake structures used at steam electric power stations. Many modifications of these are also in use.

Both designs illustrated have traveling screens recessed some distance "downstream" of the opening into the intake structure, a feature common to many existing cooling water intakes that is conducive to trapping of fish and large invertebrates until they tire of swimming against the intake flow velocity and become impinged on the screens. Placement of the screens at the front of the intake canal opening precludes entrapment in the canal.

Because vigorous monitoring has been done at only a few plants during the past three or four years adequate records are scant, but fish impingement on cooling water intake screens of steam electric stations has almost certainly grown in proportion to the increase in the number and size of the stations and intake structures.

Twenty years ago when most units were smaller than 200 $MW_{(e)}$ fish losses probably were relatively small. Until very recently the station operator's major concern was that, occasionally, impingement of large numbers of fish might block passage of water into the cooling system or crush the intake screens and require shutting down the plant. Now utility management and regulatory agencies must give considerable attention to environmental implications of fish impingement on intake screens.

Fish impingement is becoming a pivotal environmental issue in the licensing hearings for many new units. Unfortunately, information on the host of factors that appear to influence the rate of fish impingement on intake screens is grossly inadequate for making reliable predictions of the kinds and quantities of fish likely to be impinged at proposed intake structures.

The abundance, temporal and spatial distribution, and behavior of fish relative to the location and design of intake structures are likely to be important factors. The species composition, abundance and spatial distribution of fish populations at any given location are known to vary at different times of the day, seasonally and annually because of species specific differences in habitat preference, reproductive cycles migratory patterns and response to a host of physical, chemical, hydrological and biological variables.

Indian Point Unit 1 on the Hudson River estuary has been intensively monitored for fish impingement data during the past 4 years. Fish impingement is one of the vital issues in the controversy as to whether the present once-through cooling system should be replaced with closed cycle cooling towers.

The numbers of fish impinged is extremely erratic, an observation that probably applies to most other power station intakes. The rate of impingement is very low for extended periods of time, then suddenly, large numbers of fish are collected on a single day. It is not uncommon for over 90% of the annual fish impingement to occur in less than 10% of the time. Adjacent intake structures only a couple of feet apart frequently collect dramatically different numbers of fish. There appears to be some correlation between sporadic high impingement rates and intrusion of saline water into the area of the Indian Point plant.

An apparent substantial reduction in the number of fish impinged at Indian Point by reducing the average flow velocity approaching the screens to 0.5 feet per second or less has often been cited as an intake structure design criterion that will prevent fish impingement. In fact, many fish continue to be impinged on the Indian Point station intake screens at that calculated approach velocity. In any case the observed reduction in fish impingement might well have been caused by the reduction in flow volume rather than the reduced approach velocity that was accomplished by reducing the cooling water flow volume.

A relatively small number of species constitute the bulk of the fish collected at the Indian Point intake screens. White perch, striped bass, tomcod, blue-back herring and the bay anchovy are the principle species involved. The relative abundance of fish species collected on the screen is different than the species composition taken in gear in the immediate vicinity of the plant. This indicates either that some species are much more prone to impingement than others, or that species composition in the estuary is not accurately measured by the gear employed. Definite seasonal variations have occurred in the species collected on the screens.

Based on the assumption that new Indian Point units (2 and 3) will impinge fish at the same annual rate per unit volume of flow as the existing Unit No. 1 and the additional liberal assumption that three units would run at full capacity every day of the year, Consolidated Edison (2) projected annual fish impingement for Indian Point as follows:

		Number	Weight (lbs)
Unit 1		372,863	4,089
Unit 2		1,118,584	12,263
Unit 3		1,118,584	12,615
	TOTAL	2,610,031	28,615

Published accounts of the large numbers of fish impinged on the Indian Point intake screens have frequently prompted the suggestion that a commercial processing operation ought to be established to make use of the fish. However, most of the fish impinged by the Indian Point plant are 2 to 4 inches long, so that the total annual weight of fish (28,615 lbs) projected to be impinged is far less than needed to support a commercial processing operation.

Sound, electrical fields, bubble screens, light and velocity have been tried at various locations in the United States in attempts to repell or guide fish away from water intake structures. With few exceptions these trials have been unsuccessful. Frequently, initial success has soon been followed by failure as fish rapidly adapted to the stimulus. In other cases the stimulus has been effective for some species but not others. Reduction of intake flow volume and velocity would appear to be effective measures for reducing the numbers of fish impinged on intake screens. Indeed, considerable attention has been focused on the swim-speed capability of fishes in relation to intake flow velocity, the theory being that if fish can swim faster than the intake velocity they will do so to avoid impingement. There are dramatic examples to the contrary, such as the large numbers of white perch that are impinged at Indian Point despite the fact that they can swim faster than the intake velocity. These examples illustrate the importance of fish behavior as a factor.

Screens still appear to be the most effective and reliable means of keeping fish out of water intakes. Considerable research and development effort on new screens and intake structure designs is in progress (1) (3). Much additional information is needed on the many factors involved with fish impingement, including the extent to which fish populations can compensate for losses by impingement.

Pumped and Plume Entrainment Impacts:

Organisms small enough to pass through intake trash screen are pumped through the cooling water systems of power plants. These pump-entrained organisms are exposed to abrupt changes in temperature, hydrostatic pressure, mechanical buffeting, velocity shear forces, and chemicals introduced to the cooling systems by the plants.

Organisms contained in receiving water entrained into discharge plumes (plume entrainment) are exposed to elevated temperature, discharged chemical residuals and velocity shear forces, but these potential stresses are reduced as dilution and dissipation progress.

Organism groups subject to entrainment include planktonic bacteria, phytoplankton, zooplankton, and the planktonic eggs and larvae of invertebrates and fish. These groups differ greatly with respect to abundance, reproductive strategies, generation time, trophic or food-chain function, and other life processes.

The spatial distribution of these potentially entrainable organisms is notably uneven. Distributions are clumped and are subject to change on diel, seasonal, and yearly cycles. Life stages critical to population maintenance may be subject to entrainment only for short periods of the year--periods that may or may not coincide with operating conditions that would cause substantial damage to that life stage. This is true for striped bass eggs and various life stages of other species that move with the salt front in estuaries. The probability of being entrained may vary considerably from one life stage to another, at different ages within a life stage, or among species, depending on where they are in the river and in the water column relative to the location of the cooling water intake and the discharge plume.

Temperature Stress

Water temperature, in conjunction with light, flow velocity and many other interacting biotic and abiotic factors, has a pervasive influence on the composition, behavior and function of biological communities. Aquatic organisms with the exception of mammals have body temperatures almost identical to the temperature of the water they inhabit. The natural temperautres of surface waters in the United States vary from about 32°F to over 104°F depending on the season, latitude, altitude, time of day depth and circulation of water, etc. Surface water temperatures vary with air temperature, and tend to be much more variable in the temperate zone than in either the tropical or arctic zones.

For a given set of physical and chemical conditions, organisms have upper and lower thermal tolerance limits and an optimum temperature range for growth and reproduction. Over time, species have evolved with different ranges of optimal temperature. Some are restricted to cold water conditions such as found in the Arctic and Antarctic zones; and in the deep,cold water of thermally stratified lakes and reservoirs of the temperate zone. Other species prefer warm water habitats such as hot springs. Most species, however, thrive in an intermediate range.

The optimum temperature range is typically closer to the upper range of tolerance for species in surface waters that experience relatively small variation in temperature such as in the sub-tropical and tropical zones, than in temperate zone waters that experience more variable temperature. The assemblages of species in aquatic communities usually contain some species that are relatively prominent throughout the year, and considerable numbers of species that become prominent only during the spring summer or fall in response to seasonal changes in temperature and other prime requisites for growth and reproduction. As a result there is a seasonal succession of species that carry on each of the basic trophic (food-energy flow) functions such as primary production, herbivore consumption, carnivore consumption and decomposition of wastes and detritus.

For this and other reasons, the ultimate consideration of temperature effects on biota must be evaluated at the community or ecosystem level in conjunction with the structure and functioning of the ecosystem. In short, adverse effects on individual organisms or even a species may be insignificant if other species move in to fill the same trophic function in the community, unless the adversely affected species have some special value to humans other than its trophic function in the ecosystem.

Natural temperature variations create conditions in the aquatic medium that are optimum at some times, but in general are above or below the optimum for physiological behavioral and interspecific competitive functions of the biota present. It follows that, "to label any thermal increase in a water body as pollution, regardless of season or other consideration, is to strike a misleading oversimplification. Rather, temperature exerts effects, which alone or in concert with most other environmental factors (including time), may yield results that are favorable or unfavorable to particular human interests. Only when they are clearly unfavorable are we justified in asserting pollution" (4). The mean design ΔT among existing units in the United States is 15°F, with most units being included in the range from 10 to 20°F (5). The calculated transit time (exposure time) from the condensers to discharge back to the receiving water is less than 5 minutes for most existing units, but may extend to 30 minutes or even several hours in the case of a few units (Figure 2).

One of the more notable aspects of the temperature response of aquatic species is the very small difference (about 2 to 3°C) between their upper safe temperature and 100 percent lethal temperature for a given exposure time (Figure 3). The importance of exposure time is illustrated by the fact that a temperature that kills 100 percent of the test organisms in 60 minutes is a safe temperature if the exposure time is 5 minutes or less (Figure 3).

Predicted levels of damage to entrained organisms have usually been much higher than actually found by direct observation. Most of the estimates in the literature have been derived from test exposure times in excess of 24 hours, whereas the transport times (exposure time) from the condensers to the receiving waters for most power plants is less than 30 minutes, and exposure times to temperature elevations more than a few degrees above ambient for organisms entrained into the discharge plume is usually less than an hour.

The time-dose aspect of organisms' tolerance to temperature has long been recognized, but biologists got "locked in" to the procedure of running temperature tolerance experiments for 24, 48 and 96-hours because those times were adopted for standard methods.

Studies conducted in our laboratory during the last 2 years reveal that aquatic organisms can generally tolerate considerably higher temperatures for short periods of time than would be predicted from standard bioassay exposures. For example, the 48-hour TL_{50}* for Gammarus sp. was approximately 5°C lower than the 60-minute TL_{50} at an ambient temperature of about 25°C (Figure 3).

Ambient temperature has been shown to exert a profound effect on the thermal tolerance of an aquatic organism. This is illustrated by the temperature tolerance data

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* The 48-hour TL_{50} is the temperature that causes 50 percent mortality of the test organisms by the end of a 48-hour exposure time.

for Gammarus determined over most of the ambient temperature range of the Hudson River estuary (Figure 4). These data indicate that Gammarus sp. can tolerate approximately 11°C higher temperature in the summer than during the winter but Gammarus sp. can tolerate a greater temperature change ΔT in the winter (approximately 22°C for 30 minutes) than in the summer (approximately 11°C for 30 minutes).

The "decay rate" of elevated temperatures in discharge plumes to within 3 to 4°F of ambient temperature varies considerably, depending on the rate and amount of dilution affected by natural and induced mixing (Figure 2). Exposure times to the higher temperature elevations in the near-field portions of the plumes are usually momentary for plankton and larger invertebrates that drift through plumes, but may be prolonged for the more resident benthic organisms and for fish that can maintain position at preferred elevated temperatures in the plumes. Exposure of plankton and drift organisms to low temperature elevation (4°F or less) in the far-field portions of plumes tend to be more prolonged than in the near field.

Keeping in mind that there are often important exceptions to generalizations one might make about the effects of thermal discharges on aquatic life, and that these exceptions must be dealt with on a site specific basis, attempts to generalize do nevertheless help to provide important perspective.

With very few exceptions, existing information indicates that species and populations of plankton and drift organisms in temperate zone surface waters tolerate the time-temperature elevation conditions encountered in the cooling system and thermal plumes of most power plants during the winter, when ambient temperatures are below 4-5°C. The usual effect of the elevated temperature exposure under these ambient conditions is to stimulate metabolism and growth. However, the growth that results from this stimulation appears to be slight because of the shortness of exposure time to elevated temperature relative to the generation times for most species during these low ambient temperature conditions.

Benthos and periphyton subject to more prolonged exposure to elevated temperature exhibit increased growth and species diversity during the winter, spring and early summer, until the elevated temperature exceeds about 30°C. Further increases in temperature above 30°C become inhibitory to increasing numbers of species subjected to prolonged exposures. However, maintenance of natural seasonal cycles of temperature is important for some species that require a winter diapause to initiate reproduction in the next season. Also, fish and possibly other organisms that remain in the elevated temperature long enough to become acclimated to it may be killed by cold shock in the winter if the supply of heated water is suddenly cut off by a shutdown of a plant, and the lower thermal tolerance of the organisms are exceeded.

The relationship of temperature tolerance to ambient temperature is linear. These data are valuable as predictive tools for estimating entrainment mortalities when superimposed over ambient and discharge (projected) temperatures. Figure 5 illustrates the effects of exposure time and ambient temperature on the temperature tolerances (TL_{95}) of two Hudson River invertebrates. Analysis of these data reveals projected mortalities of Neomysis americana during an 8.33°C ΔT at ambient temperatures exceeding 22°C. Gammarus sp. should be able to tolerate the projected ΔT at all ambient temperatures. Direct observations of entrained organisms have generally been in close agreement with our predicted levels of temperature induced mortality based on laboratory temperature tolerance tests.

Many investigators have become distrustful of the predictive accuracy of temperature tolerance data from laboratory assays. However, we have found that laboratory assay tests designed to closely simulate actual time-temperature conditions encountered by entrained organisms produce data which permit quite accurate predictions of mortality by excessive temperature.

The transitory (less than 5 to 30 minute) exposure to ΔT's in the cooling system and the near-field portion of plumes begin to cause damage and death of more temperature sensitive warm-water species of planktonic and drift organisms when the summer ambient (24-27°C for most source waters) plus the ΔT results in a temperature of about 31°C. Another grouping of species can tolerate short-term exposures of up to 34°C, and still another group up to 35-36°C or more before they incur mortality.

The effect of the low (1-2°C) temperature rise above ambient in the far-field portion of the plumes is to stimulate metabolism and growth of aquatic life throughout the year in temperate regions where summer ambient temperatures do not usually exceed 26-27°C, and to exclude some cold water species from living space for a longer period of the year than would be the case if there were no thermal discharge. However, in sub-tropic and tropic regions, where organism's optimal range for growth tends to be closer to maximum summer ambient temperatures, such far-field plume temperature elevations may cause some inhibition of growth and changes in species composition of aquatic populations.

Chemical Stress

Various chemicals are discharged into the cooling water systems of steam electric plants. Most of the chemicals are not acutely toxic during the relatively short exposure times encountered during entrainment.

Chlorine has long been used in power plants to control biofouling because it is toxic to most aquatic organisms at relatively low concentrations, has been inexpensive, easy to apply, and was thought to decompose rapidly to non-toxic by-products. It is now recognized that some of the chlorine applied to condenser cooling water combines with ammonia and other nitrogenous materials to form chlorinated amines that are thought to persist much longer than free chlorine. Pump entrianed organisms are exposed to free chlorine during applications to the cooling system, and plume entrained organisms are exposed to any remaining free chlorine and chloramine residual.

Power plants located on fresh water bodies normally require chlorine applications infrequently so that chlorine may be applied during a small percentage of the total plant operating time. Much more frequent and in some cases continuous chlorination is often required at marine-sited plants to control fouling, especially by attached bivalves. Consequently, the potential for damage to entrained organisms is increased. Bio-fouling and frequency of chlorination required for control are normally greatest during maximum ambient temperature and reduced during cooler periods.

Formulation and adoption of minimal chlorination schedules and dosage rates necessary to achieve control at each site will eliminate unecessary damage to entrained organisms and reduce associated costs. The toxicity of chlorine to aquatic life is a function of exposure time, dose, chemical form of the chlorine and species specific differences in tolerance. Exposure time and dose are determined by the application protocol, and by volatization, decomposition and dilution rates subsequent to application.

The decomposition rate of free chlorine concentrations added to power plant cooling water can be expected to vary considerably depending on the "chlorine demand" (ammonia and organic concentration), temperature, pH, and chemical and photochemical reaction rates in the receiving waters. Almost nothing is known about the decomposition rates of combined forms of chlorine (principally chlorinated amines) although they are thought to be more persistent and pose greater chronic toxic potential than the free chlorine molecule.

The currently proposed EPA criteria for maximum acceptable residual chlorine concentrations are based on a conglomeration of data produced by a variety of experimental methods on waters of widely different quality, many of which were trout waters with low chlorine demands. Information on the decomposition rates and acute and chronic toxicity of free and combined chlorine in definitively characterized water quality types most used by power plants is urgently needed to provide bases for criteria relevant to local water quality characteristics.

Mechanical Stress

Entrained organisms experience stress resulting from mechanical buffeting, velocity shear forces, and changes in hydrostatic pressure. Abrupt changes in pressure occur at various points in the circulating water system. As water approaches the impeller of the intake pump there is a rapid drop in pressure which is immediately followed by a pressure increase on the back side of the impeller. The magnitude of the pressure differential experienced by entrained organisms depends on the depth from which they are withdrawn and the design of the intake pump impeller. The positive pressure* behind the intake pumps rapidly drops to as low as 2 psia in the condenser system. The reduction to negative pressure is concurrent with the temperature rise and occurs within 5 to 10 seconds during condenser passage. The maximum negative pressure is expected to occur at the condenser water box. As the flow enters the discharge system, there is a rapid return to positive pressure, the magnitude of which is dependent on the depth of the organism in the discharge system. Although relatively little work has been directed towards the effects of pressure changes encountered in power plants, it appears that negative pressures have the greater potential for damaging entrained organisms, especially fishes.

Mechanical buffeting and velocity shear exposure may be important factors in considering potential entrainment damage, especially with larger soft-bodied organisms. The magnitude of these forces is dependent on the physical characteristics of the cooling water system and the location of the organism in the flow. Both of these factors are difficult to measure in an operating power plant and even more difficult to simulate in laboratory situations. Therefore, little information is available concerning dose-response relationships.

Coal Pile Drainage and Ash Pond Overflow:

The characteristics of these wastes from coal burning plants differ greatly, because of such factors as differences in the chemical composition of coal, amount of rainfall, the initial quality of water used for ash handling, and design of settling ponds. Dissolved solids, suspended solids, a variety of trace metals, mineral acid (from coal piles) and sulfate in the wastes are potentially harmful to aquatic life. Synergism among a number of the metals may increase their toxicity. Harmful effects of iron, copper and zinc solutions can be greater in acid water produced by coal pile drainage than in neutral or alkaline water. The effects of these wastes on aquatic life in receiving waters are usually negligible but can be substantial in cases where the volume of the wastes is large relative to flow in receiving waters.

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* The terms positive and negative pressure refer to increases and decreases in pressure, respectively, relative to the absolute pressure experienced by the organisms before being entrained.

Spillage of Coal and Oil

Spillage of coal and oil into surface waters during unloading operations is a threat to aquatic life. The oil and substances leached from coal are unsightly, can be toxic, and cause tainting of fish and shellfish that may render them unfit to eat. Oil is also a hazard to waterfowl. Excessive spillage of coal is damaging to most bottom dwelling organisms because they can not tolerate the abrasiveness of a shifting layer of coal. The effects of these factors on aquatic life is usually local, but may be severe in those localized areas. In the cases of several coal-fired plants we have studied, the only damage to aquatic populations in the receiving waters that we could detect was to the benthos caused by spilled coal and scouring by the prop wash of tug boats used to maneuver coal barges into and away from unloading morrages.

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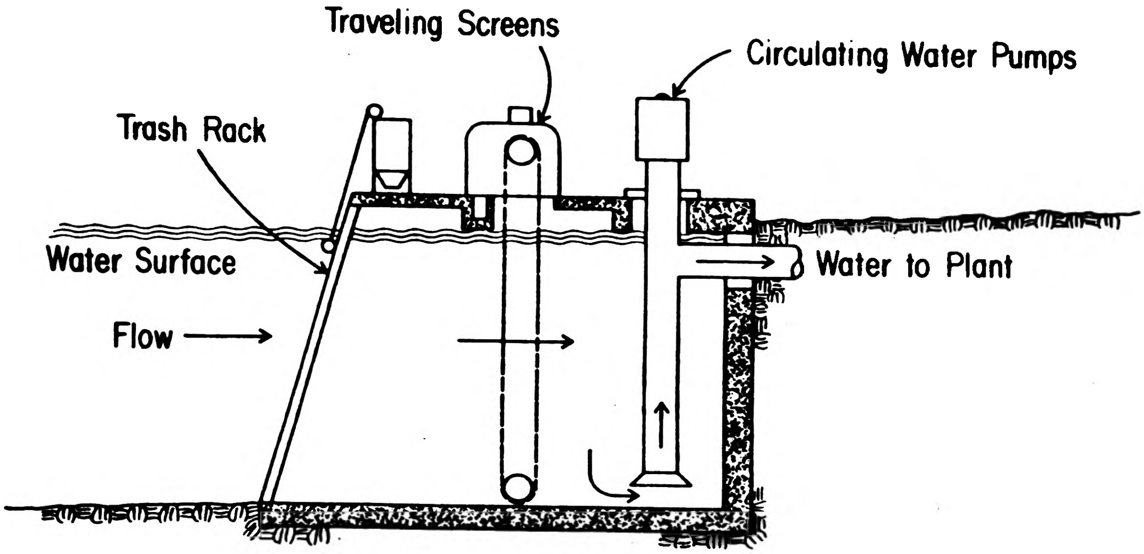
Shoreline Intake Structure



Offshore Intake Structure

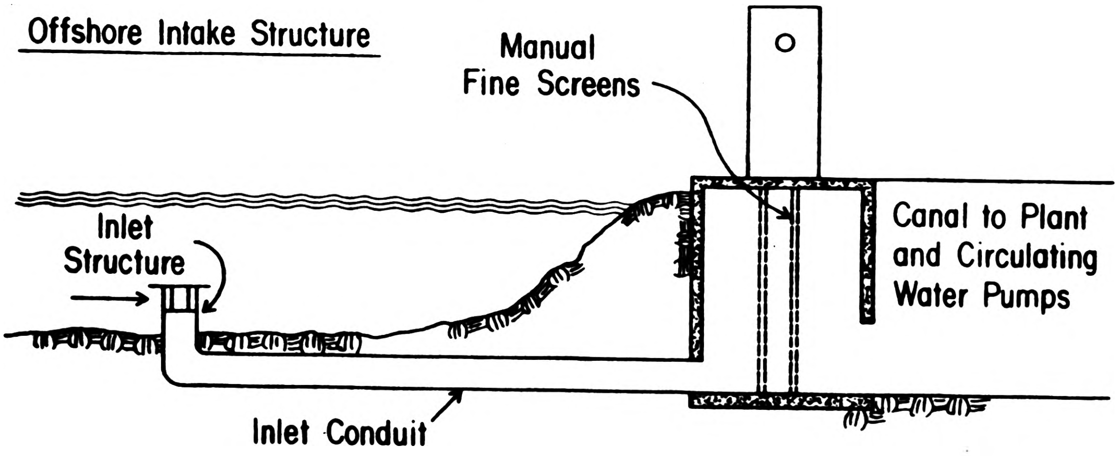


Figure 1. Schematic Diagrams of Typical Intake Structures
(Point of Water Inlet to the Water Screening Facility)

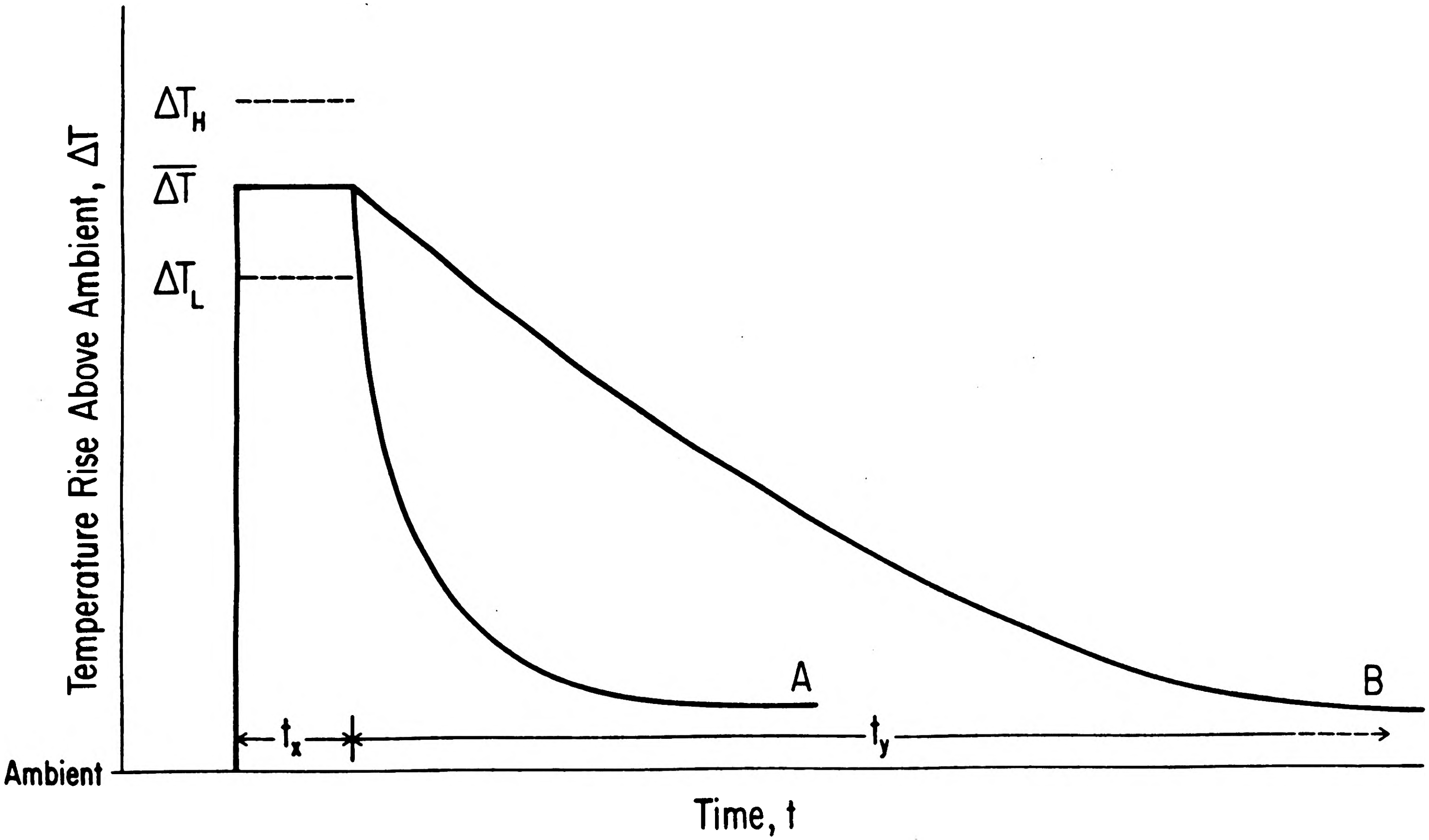


Figure 2. Generalized temperature exposure diagram for organisms entrained in a once-through, steam electric power plant cooling system. ΔT_L and ΔT_H represent the range and ΔT the average temperature increase experienced in the condenser. Inplant and post-discharge exposure times are represented by Tx and Ty, respectively. Curves A and B represent high and low rates of mixing, respectively.

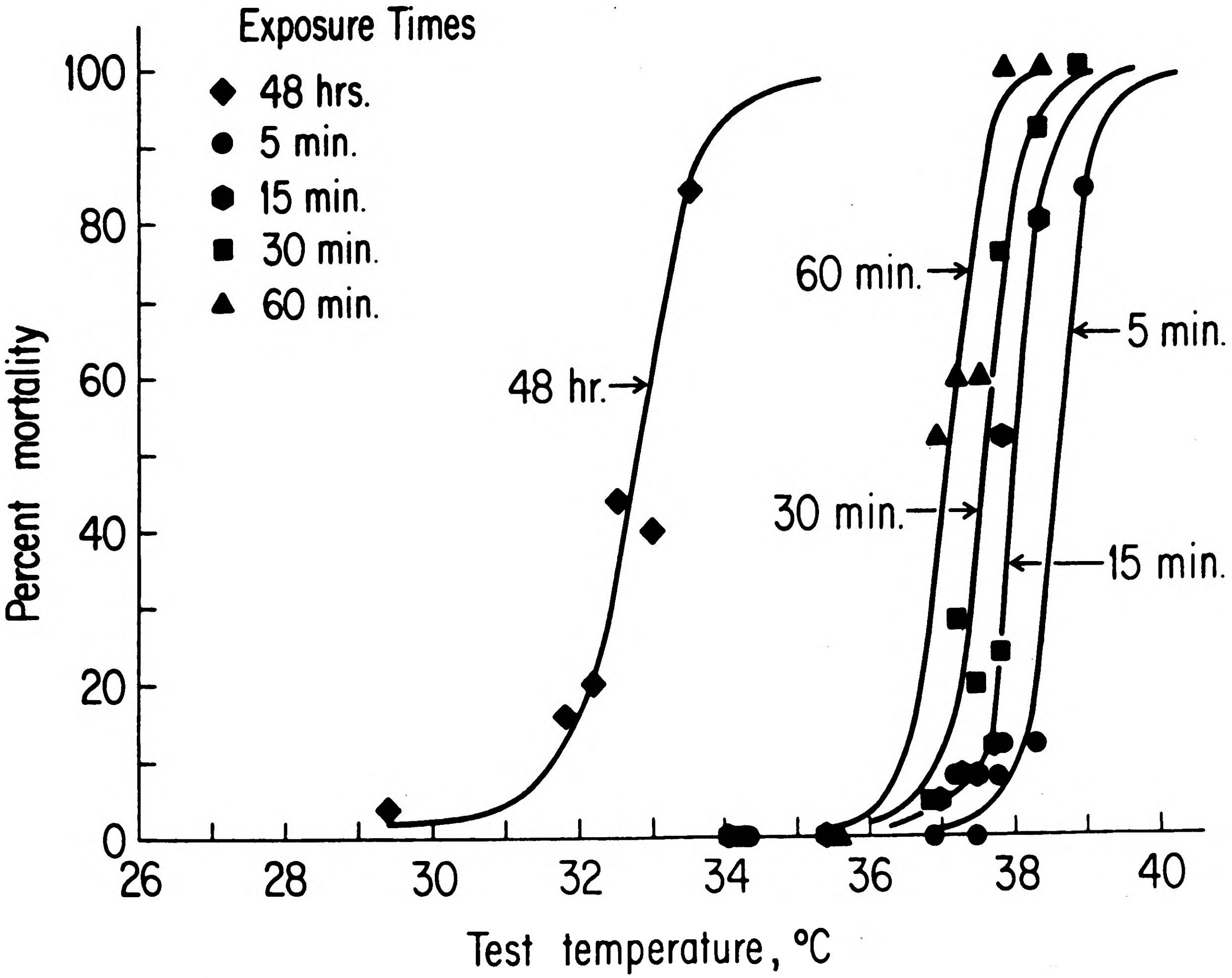


Figure 3. Temperature tolerance of <u>Gammarus</u> sp. at an ambient temperature of 24.7 to 25.8°C. (From Ginn et al, In Press)

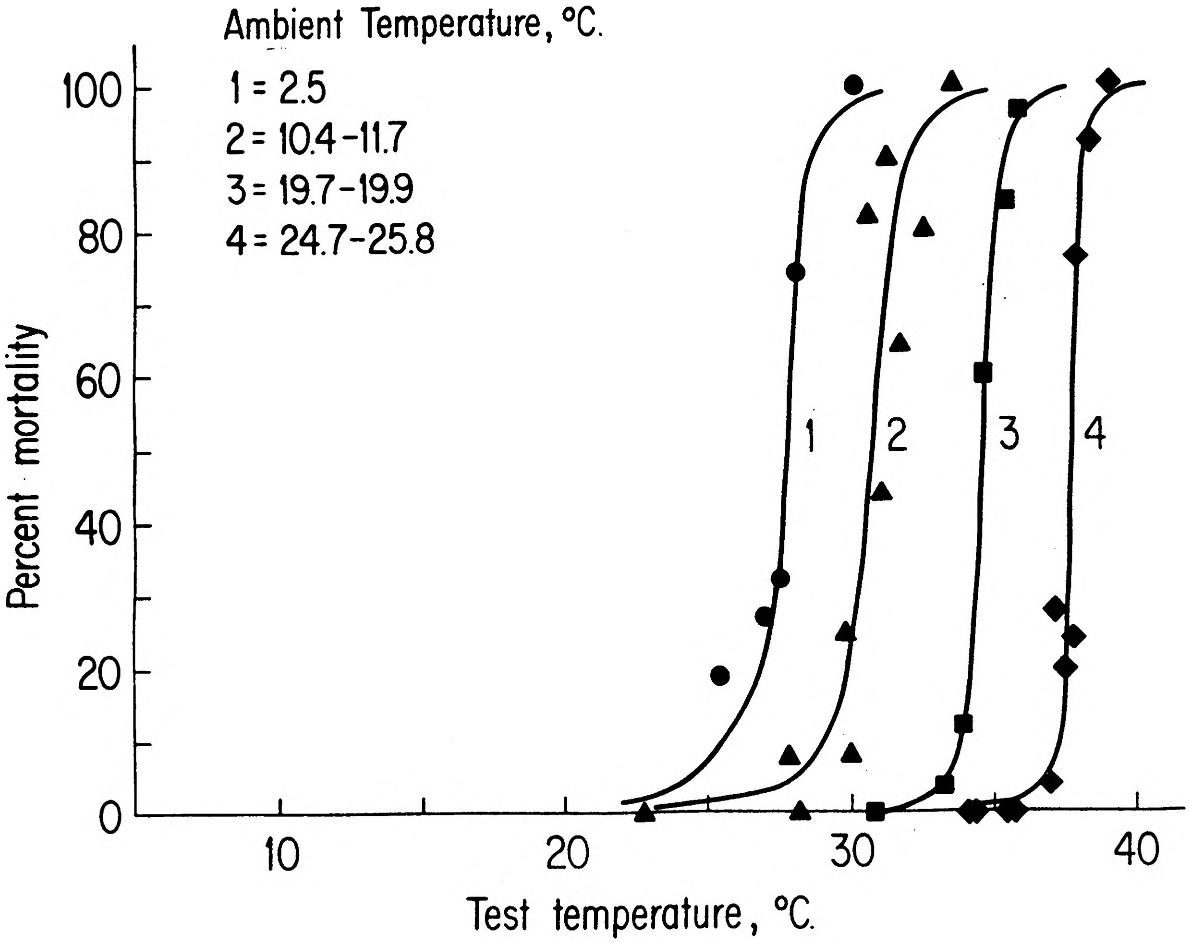


Figure 4. 30 minute temperature tolerance of Gammarus sp. (From Ginn et al, In Press).

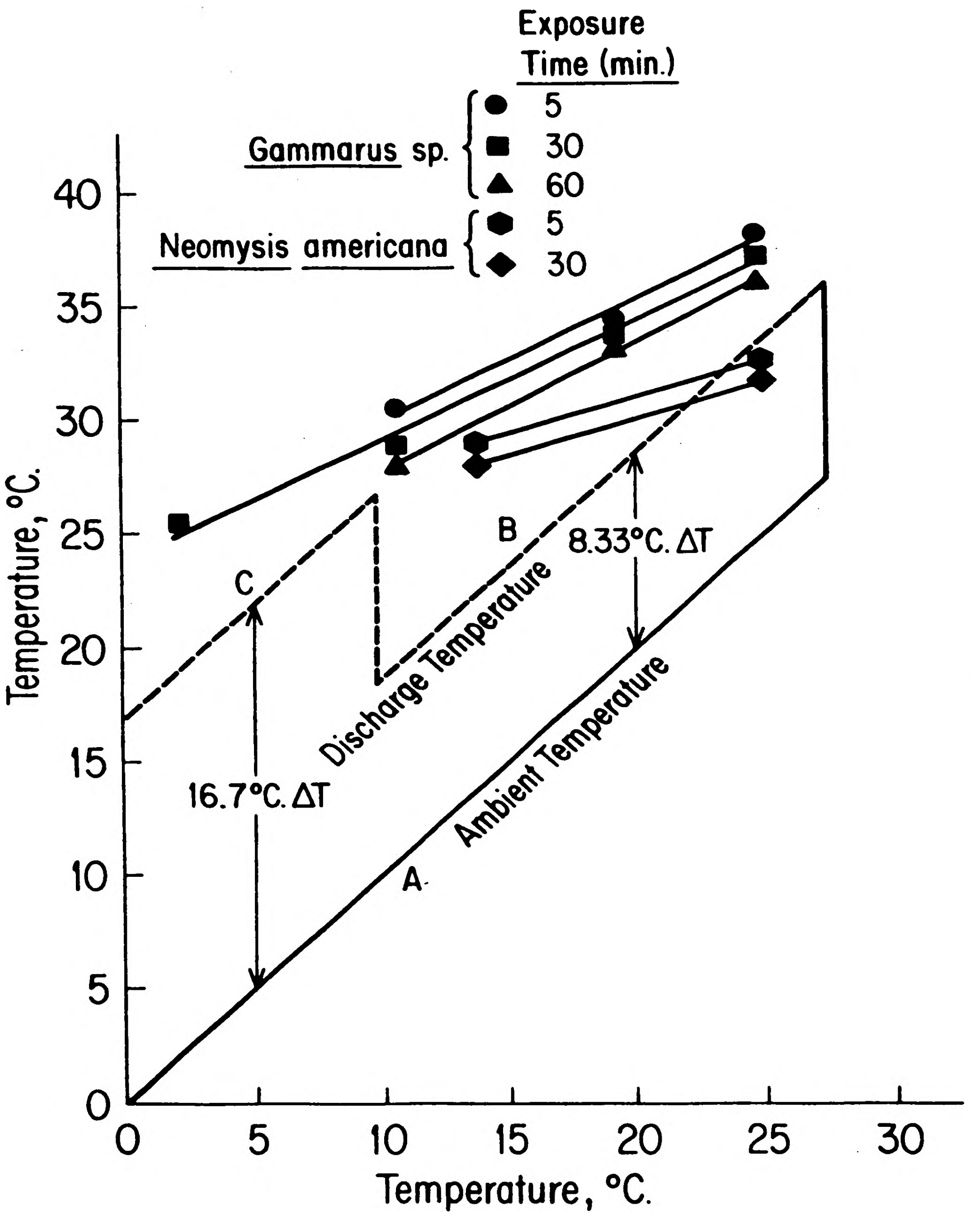


Figure 5. 95% tolerance limits for *Gammarus* sp. and *Neomysis americana*. Projected power plant ΔT's during full flow (line B) and reduced flow (line C) operations are superimposed over the ambient temperature range (line A).