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AN EMPIRICAL TRANSPORT MODEL FOR EVALUATING ENTRAINMENT OF AQUATIC ORGANISMS BY POWER PLANTS

by

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53

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EXECUTIVE SUMMARY

One of the more important potential aquatic impacts of steam electric power plants is the mortality of organisms that are contained in the water that is drawn through the plant for condenser cooling purposes. Organisms that are small enough to pass through the plant's intake screening system are said to be entrained, and many of these organisms may be killed by exposure to mechanical, chemical, or thermal stresses during plant passage. Of particular concern are the early life stages of populations of fish and shellfish that inhabit the adjacent water body or use the area as a spawning or nursery habitat.

A first step in assessing the impact of entrainment mortality is to estimate the conditional entrainment mortality rate, which is the fraction of the population which would be killed due to entrainment in the absence of any other source of mortality. Mathematical models for evaluating the conditional entrainment mortality rate have been proposed by numerous authors. Although some of these models simulate the movement of organisms through the use of hydrodynamic equations, few of the models specify movement patterns based directly on field data. This report describes a generalized mathematical model that incorporates empirically derived organism distribution and movement characteristic to estimate the conditional entrainment mortality rate. The generalized model is formulated as follows:

$$m_T = 1 - \frac{\sum_{s=1}^{S} N_0 R_s \left\{ \prod_{j=0}^{J} \left[\sum_{k=1}^{K} D_{s+j,jk} e^{-(M_{s+j,jk} + E_{s+j,jk})t} \right] \right\}}{\sum_{s=1}^{S} N_0 R_s \left\{ \prod_{j=0}^{J} \left[\sum_{k=1}^{K} D_{s+j,jk} e^{-(M_{s+j,jk})t} \right] \right\}}$$

where: m_T = total conditional entrainment mortality rate,

N_0 = total number of eggs spawned,

s = week of spawning period,

S = total number of weeks in spawning period,

R_s = proportion of eggs spawned during week s,

j = age 0, 1, 2, . . ., J,

J = oldest entrainable age,

k = region 1, 2, 3, . . ., K,

K = total number of regions within the water body,

$D_{s+j,jk}$ = proportion of total standing crop of age j individuals during week s+j in region k,

$M_{s+j,jk}$ = instantaneous natural mortality rate constant of age j individuals during week s+j in region k (units: per day),

$E_{s+j,jk}$ = instantaneous entrainment mortality rate constant of age j individuals during week s+j in region k (units: per day), and

t = duration (in days) of week s+j.

In this formulation, the numerator of the term on the right side of the equation is the total probability of survival for the population when exposed to both natural and entrainment mortality; the denominator is the probability of survival from natural causes only. Both rates of mortality are time-, space-, and age-specific. The model can be simplified by making various assumptions. For example, if natural mortality is assumed to be a function only of age, then the generalized equation can be simplified to:

$$m_T = 1 - \sum_{s=1}^{S} R_s \left\{ \prod_{j=0}^{J} \left[\sum_{k=1}^{K} D_{s+j,jk} e^{-(E_{s+j,jk})t} \right] \right\}$$

Note that with the simplifying assumption, estimates of age, spatial, and temporal variations in natural mortality are not required for estimation of the conditional entrainment mortality rate.

Obtaining the input data needed for the model involves the following: specifying geographic regions within the water body to define the distribution and movement of organisms while they are vulnerable to entrainment; obtaining estimates of physical factors (water volume and power plant intake flow in each region); determining entrainment susceptibility in each region for the various life stages present as a function of calendar time; determining the length of time that organisms will be vulnerable to entrainment; and calculating the distribution of life stages among the regions of the water body as a function of calendar time.

The effect of organism movement patterns is incorporated by the variable D in the model. Given sufficient data, the actual spatial and temporal distributions of the various ages of the organisms, as determined through field sampling, can be used to define D. The value of this approach is that it relies on observed movement patterns rather than complex simulations of incompletely understood mechanisms of organism distribution, which are often unable to adequately replicate distributions observed in the field. A disadvantage of this approach is that it requires an extensive and detailed set of observations throughout the period of occurrence of the entrainable life stages of the population in question.

If sufficient observational detail is lacking to define the values of D as a function of both organism age and calendar time, then field data can be processed to provide a seasonally-averaged distribution as a function of organism age or life stage. The adequacy of this and other simplifications can be studied by sensitivity analyses which allow the user to ascertain the relative importance and probable direction of error that might be introduced by the simplification processes.

The two most important limitations of the application of the model are related to the acquisition and processing of field data. The first lies in the inability of current technology to separate the processes of mortality and movement of entrainable organisms. If natural mortality varies spatially, then changes in observed distributions of organisms