- Conclusions for Nontidal Freshwater Power Plants

In general, entrainment and impingement impacts are small at freshwater facilities, and discharge effects are localized. No long-term cumulative impacts have been identified from operation of these facilities.

E. Aquatic Impact Assessment for Hydroelectric Facilities

Status of License Renewal and Assessment Studies for Conowingo Dam

Conowingo Dam on the Susquehanna River is the largest hydroelectric generating station in Maryland. Significant stocks of resident and anadromous fish species (e.g., channel catfish, white perch, striped bass, river herring) occur downstream of the dam; historically, large spawning runs of anadromous species were found upstream of it (Mansueti and Kolb 1953). Sport fishermen regularly visit the region, and surveys suggest that in past years the area has been one of the most intensively fished locations in Maryland (Pavol and Davis 1982). Changes in regulations, specifically moratoria on the harvest of striped bass in 1975 and shad in 1981, may have resulted in a decline in fishing effort in recent years.

In 1976, the Conowingo hydroelectric facility applied to FERC for license renewal. At that time, a number of interested parties (Maryland DNR, U.S. Fish and Wildlife Service, Pennsylvania Fish Commission, Pennsylvania Department of Environmental Resources, Susquehanna River Basin Commission, Pennsylvania Federation of Sportsmen's Clubs, and the Upper Chesapeake Bay Watershed Association) became involved in the licensing procedure as intervenors. The groups wanted the Philadelphia Electric Company (PECO), operator of the facility, to restore anadromous fish runs upstream of the dam and to implement actions that would alleviate environmental problems downstream of the dam. The major environmental problems downstream of the dam were associated with water level fluctuations resulting from peaking operations. These included the occurrence of low dissolved oxygen concentrations in dam discharges, and virtual cessation of flow when turbines were shut down (Davis 1975; Weisberg and Janicki 1985). Low dissolved oxygen concentrations have deleterious effects on a wide variety of aquatic biota (Davis 1975), and flow fluctuations directly affect the abundances of food organisms important to fish growth and survival (Hynes 1970; Weisberg and Janicki 1985). Loss of freshwater spawning and nursery habitat of anadromous fish due to blockage of migration routes is frequently cited as a major factor contributing to recent population declines of these biota (Walburg and Nichols 1967).

In 1980, FERC issued new operating licenses for Conowingo and the three hydroelectric dams upstream in Pennsylvania. As conditions in each of the new licenses, FERC required that the licensees undertake detailed studies of the causes of oxygen depletion in the project reservoirs and downstream riverine reaches, studies of the effects of project generation on downstream water quality and habitat, and feasibility studies of means to improve the oxygen concentration of the discharge enough to maintain the State discharge standards for dissolved oxygen (DO). The studies for the upstream dams were completed and approved by FERC from 1983 to 1985. At Conowingo, the results of water quality studies were submitted in late 1986, and approved by FERC with major stipulations; the design of fish habitat studies is still a major item of contention, and is being adjudicated by the FERC Administrative Law Judge (see below).

At the time the four new licenses were issued in 1980, FERC also ordered hearings on the feasibility of restoring anadromous fish runs to the entire river basin. These hearings, held in 1981 and 1982, involved the licensees of all four dams and all of the intervenors listed previously. As discussed in detail below, the intervenors soon reached a settlement agreement with the upstream utilities on a demonstration restoration plan. In contrast, the negotiations between PECO and the intervenors are only now approaching settlement.

The following sections discuss the background, the findings to date of the ongoing technical studies and the status of litigation for the three main issues of water flow, downstream habitat water quality and the restoration of anadromous fish.

- Water Flow and Downstream Habitat

Until 1982, Conowingo Dam operated in a peaking mode throughout the year. The intervenors requested a continuous minimum release of water to alleviate habitat modifications downstream of the dam. In response to this request, FERC ordered that, beginning in 1982, a minimum flow of 5,000 cfs be maintained from April 15 through September 15, while field studies designed to aid in the selection of a permanent minimum flow were carried out by PECO. A study evaluating the responses of benthic invertebrates and fish to the interim minimum flows found that benthic abundance increased dramatically under the interim minimum flow and declined rapidly when it was terminated (Weisberg and Janicki 1985). Fish feeding rates were greater and the condition of fish was better during the interim minimum flow period than during the period of sporadic water release (Weisberg and Janicki 1985). Lack of agreement between PECO and the intervenors over the appropriate design for PECO's studies resulted in an additional FERC hearing. This hearing produced an order to implement a plan based on the U.S. Fish and Wildlife Service's Instream Flow Methodology, which estimates the amount of useable fish habitat based on factors such as water depth, velocity and temperature. The study, slated to begin in 1988, is expected to produce flow recommendations within three years.

- Water Quality

Modeling and field studies to identify factors affecting water quality in aquatic habitats downstream of Conowingo Dam and in Conowingo Pond were funded by PECO and the Maryland PPRP. A simulation model of the dissolved oxygen dynamics for aquatic habitats downstream of Conowingo Dam indicated that the dissolved oxygen concentration in these habitats was controlled by the dissolved oxygen concentration in the water released through the turbines (Dwyer and Turner 1982). Processes in the river had little influence on dissolved oxygen levels. Because the dissolved oxygen concentration in the surface water of Conowingo Pond was higher than that in the bottom water during the summer (i.e., the impoundment was vertically stratified), the relative proportions of surface and bottom water withdrawn through the turbines determined dissolved oxygen concentration in water downstream of the dam.

A simulation model of the oxygen dynamics in Conowingo Pond was developed to determine factors controlling oxygen concentration in the impoundment (Summers 1984). An empirical model of the pattern of water withdrawal from the impoundment was also constructed to predict vertical withdrawal patterns under differing dam operating conditions (Dwyer and Turner 1986). The reservoir and withdrawal models were linked and used to predict the dissolved oxygen concentration in water passing through the turbines for a range of alternative minimum flow release schedules (Dwyer and Turner 1986). Results indicated that, due to the strong vertical stratification and near anoxic bottom water in Conowingo Pond during summer, the dissolved oxygen concentration in discharge flows (and thus downstream) could not be increased substantially by continuous minimum flow release schedules (Summers 1984).

The only feasible methods identified to increase the dissolved oxygen concentration of water passing the turbines during minimum flow releases were adding oxygen to the water (either in the impoundment or in the turbines) or reducing (or otherwise controlling) the amount of oxygen-consuming material entering the impoundment from upstream sources (Dwyer and Turner 1986). PECO has submitted a plan to FERC that will utilize turbine venting and other methods to add oxygen to the water being discharged. The new procedures will be completely phased in by 1991.

- Anadromous Fish Restoration

In 1981 FERC held hearings on a separate docket related to restoration of anadromous fish runs upstream of Conowingo Dam, concluding with final briefs in early 1983. The intervenors and the three utilities that operate dams upstream of Conowingo arrived at a settlement on restoration of fish runs. The agreement included an extensive program for releasing hatchery-reared juvenile shad and prespawned adults from other rivers into the upstream tributaries of the Susquehanna River, in hopes that a subsequent return of large numbers of adults to Conowingo (the furthest downstream migratory barrier) would demonstrate the feasibility of a full-scale restoration program. In 1987, PECO collected over 7,000 adult shad at its experimental fish lift at Conowingo Dam, compared with an annual return of a few hundred fish in the late 1970's (see Figure IV-5). Most of these shad were transported by truck to upstream spawning grounds.

The intervenors maintained that the existing Conowingo fish lift, built in the early 1970's as a sampling device, was too inefficient to support an adequate demonstration of the potential for shad restoration. As part of FERC's restoration

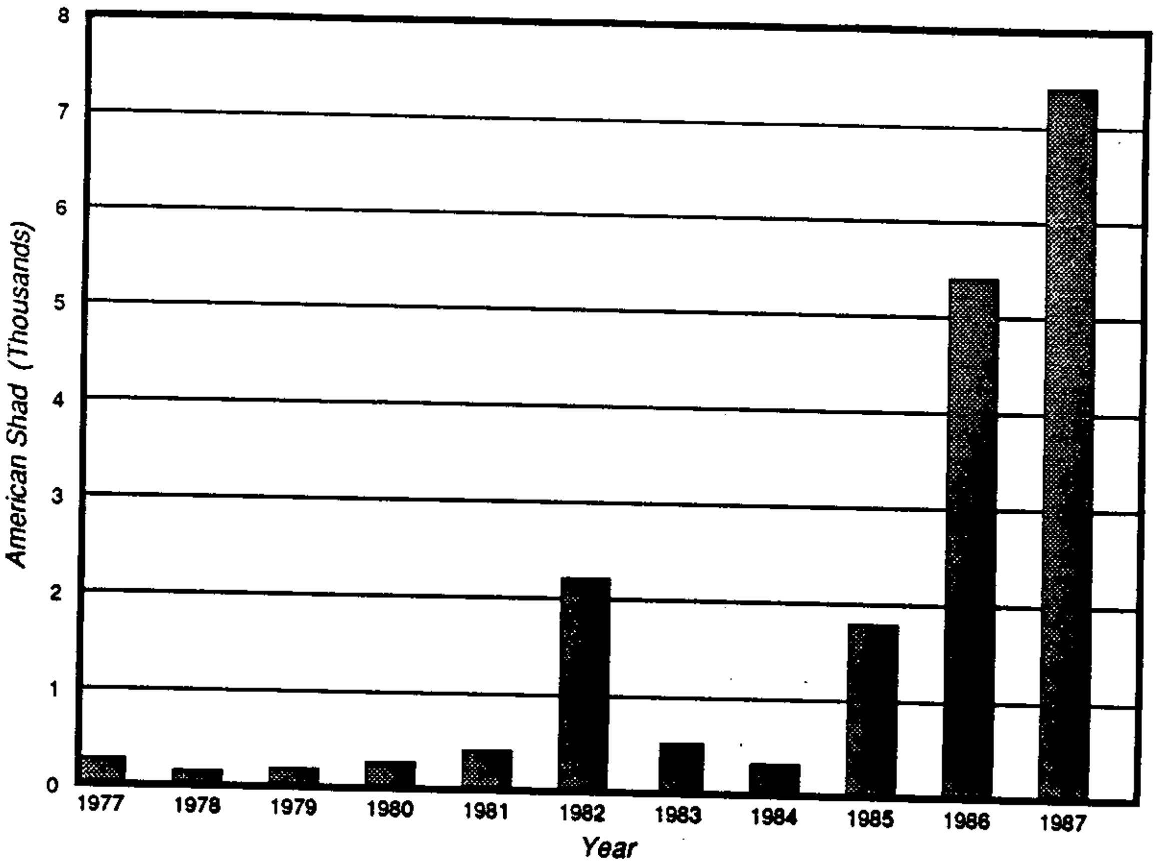

Figure IV-5. **Number of American shad caught at the experimental fish lift at Conowingo Dam, 1977-1987**

order, PECO was required to build a new facility, capable of operating at higher flows (hence earlier in the shad run) and with greater collection efficiency. This facility is now slated to be on line by the spring of 1989.

Status of Assessments for Small-Scale Facilities

Sixteen small-scale projects have been reviewed by the State thus far. Nine of these facilities are now in operation and two are under construction. Three additional projects for which permit applications had been submitted have been abandoned by the developers. A number of environmental issues have been repeatedly raised in the review of these projects.

The first issue, modification of river flow, is difficult because of its importance to both developers and resource agencies. Without alterations in river flow, some projects will be economically infeasible. However, numerous studies (Hildebrand *et al.* 1980; Loar and Sale 1981; Weisberg *et al.* 1985), have shown that the potential negative effects of unmitigated flow alterations on biota are large. As a result of concerns about the effects of flow alterations, the Gilpin Falls and Brighton Dam turbine designs were modified to minimize water level and flow fluctuations downstream of the proposed projects (Bowman and Weisberg 1985). A field study is currently being carried out to assess the effects of the Brighton Dam project on downstream biota. Both Gilpin Falls and the W.J. Dickey projects, as originally proposed, included diversion of a large fraction of streamflow from behind a dam to a generating facility some distance downstream. Under the proposed operational regimes, the diverted stream reaches would have been partially dewatered, leading to possible biotic impacts. This issue was successfully resolved at Gilpin Falls; the W.J. Dickey project was abandoned by the developer while still under FERC review.

The requirement for fish passage is an issue at projects located in areas that might support migratory fish populations. A requirement that "fish passage facilities will be established if anadromous fish are restored to the base of the dam" has been repeatedly included as a license condition in the State's comments to FERC on proposed projects.

A final issue that has arisen is turbine-related fish mortality. In one example, an increase in generating capacity was proposed for Potomac Dam No. 4. During the relicensing process, the possibility of increases in turbine entrainment mortality was identified as a potential adverse impact on recreationally important fish populations near the dam. Allegheny Power System, the operator of the facility, is presently conducting extensive field studies, as required by its FERC license, to determine the potential for such mortality. An assessment of turbine mortality was also required at the Brighton project; field studies are presently being conducted there.

Conclusions

Hydroelectric facilities can affect aquatic life forms in a number of significant ways. Dam operations at the Conowingo hydroelectric facility control water level and flow in downstream aquatic habitats, thereby directly affecting the abundance and type of food organisms important for fish growth and survival. Water quality is also affected: in summer, low dissolved oxygen concentrations from the impoundment released in the discharge water can cause poor water quality downstream of the dam. The physical presence of the dam can be a problem in itself, denying anadromous fish access to spawning areas upstream.

For smaller-scale hydroelectric projects in Maryland, the review process mandating early state resource agency participation has allowed PPRP to work with developers in mitigating potential project impacts prior to plant construction or operation. Where potential impacts could not be fully addressed prior to construction, monitoring programs to measure the degree of impact have been required of the developer or conducted by the State. Field work is being performed at the Brighton Dam and Dam No. 4 projects, both operating small-scale hydroelectric facilities.

F. Biofouling

The Nature of the Problem

The buildup of living organisms on intake structures (e.g., traveling screens, the walls of water boxes), on some intake barriers and in the condenser is a major engineering problem at most estuarine power plants (Diaz-Tous and Miller 1983). These growths can slough off and clog condenser tubes, reducing condenser cooling water flows and causing plant shutdowns. Relatively few species of invertebrates make up the majority of biofouling growth in Chesapeake Bay. Colonial species, mainly bryozoans and hydroids, which are characterized by rapid growth, are the major species that adversely affect power plant operations. Some species of tube building worms, crustaceans and barnacles are also of concern. Their tubes can clog fine-mesh intake screens. They are frequently the initial colonizers of clean surfaces, serving as precursors for other colonial forms (Weisberg *et al.* 1984b). The abundance and kinds of biofouling organisms vary along the salinity gradient, and different groups are of concern in the different salinity zones. Biofouling growth mainly occurs from early spring to late fall; however, it is most rapid from June to September (Weisberg *et al.* 1984b).

Biofouling growth has historically not been a problem at power plants located on Maryland freshwater habitats (ANSP 1981; Mattice 1983). However, the Asiatic clam, *Corbicula fluminea*, has recently invaded freshwater habitats throughout the United States, including Maryland, and has characteristics (e.g., rapid growth, high fecundity, planktonic developmental stages) that can severely impede freshwater power plant and hydroelectric facility operations (Mattice 1983). This clam is a potential threat to operations of steam and hydroelectric power plants in Maryland freshwater habitats.

Use of Chlorine to Control Biofouling

Maryland power plants inject chlorine (a strong oxidizing agent that is widely used as a disinfectant at wastewater treatment facilities) into condenser cooling water to control biofouling (Morgan 1968). Chlorine is generally injected throughout the growing season.

- Biotic Effects of Chlorine Use

Because chlorine is injected into cooling water just after plant entry, it adds a chemical stress to entrainment (Brungs 1976; Bongers *et al.* 1977). Studies at Morgantown and Chalk Point indicate that entrainment mortality was higher during periods of chlorination than at other times (Morgan 1968; Bongers *et al.* 1975; MMES 1985a; ANSP 1983a). Laboratory biotoxicity studies further demonstrate that early life stages of fish and shellfish are adversely affected by chlorine and its decay residuals at very low concentrations (ppb range) (Roberts *et al.* 1975; Liden *et al.* 1980). The allowable chlorine discharge limit at Maryland power plants is 0.2 ppm or less.

Chemical removal of chlorine from effluents (dechlorination) reduces the levels of active oxidant in discharge waters, thereby decreasing its toxicity in the receiving water body (Hall *et al.* 1981). Dechlorination does not reduce entrainment mortality, however, because many entrained biota are exposed to toxic doses of chlorine and are killed before declorination occurs. At present, the amounts of active chlorine oxidant discharged to Maryland receiving waters from power plants are low; therefore, dechlorination of power plant discharges is not necessary and would not be cost-effective (Breisch *et al.* 1984).

- Alternatives to Chlorine

A number of alternatives are available for controlling biofouling, but many have similar environmental consequences or other disadvantages. Economically feasible chemical alternatives to chlorine for power plant application include bromine chloride and ozone (Breisch *et al.* 1984). Both are strong oxidizing agents, and both have environmental consequences similar to those of chlorine (Bongers *et al.* 1977; Mangum and McIlhenny 1974).

A number of mechanical cleaning systems, which physically remove organisms from components of the power plant, are available. The commercially available Amertap system, for instance, removes organisms from condenser tubes. Retrofit of such systems to existing plants is quite expensive, however, and usually only controls biofouling on condenser tubes. They do not control biomass buildup on the walls of water boxes and intake and discharge conduits, which are where the most serious biofouling problems affecting long-term power plant operations occur (Mattice 1983).

Other theoretical alternatives include treating water with ultrasonic vibrations or ultraviolet light to kill organisms before they enter the plant. However, ultrasound has only been shown to control fouling on glass slides in laboratory tests, not at a suitable scale for implementation at operational power plants (Taylor and Richardson 1981). Although ultraviolet light is a suitable alternative to chlorine for wastewater treatment, the much larger volumes of water required for condenser cooling render this technology unsuitable for power plant applications (Breisch *et al.* 1984). Backwashing the internal cooling system with heated water has been used at power plants in other states to control biofouling (Johnson *et al.* 1983). However, this technology has not been seriously considered in Maryland because fouling organisms in Chesapeake Bay can tolerate short exposures to temperatures in excess of 40°C (Nauman and Cory 1969), and because retrofitting of thermal backwash systems into existing facilities would be prohibitively expensive.

An effective technology for the control of biofouling, especially on water boxes, is the use of antifouling coatings. (Gitlitz 1981; Hall *et al.* 1983; Waldock and Thain 1983; Beaumont and Budd 1984). Organotin-based antifouling paints are licensed and extensively used to control growth on boats; while they are not licensed for use on power plant structures, EPA is allowing a few utilities to field test them in Florida and New York (Waxman 1984). Preliminary data indicate these coatings are effective for power plant applications, but their long and short-term environmental consequences are suspected to be adverse. Toxic decay products are known to affect adversely the growth and reproduction of oysters and other biota at very low concentrations (ppb range) (Waldock and Thain 1983; Beaumont and Budd 1984). Concern about environmental impacts of tributyl-tin (TBT) has led Maryland and Virginia to pass legislation prohibiting the use of TBT for biofouling control.

Extensive studies are currently being funded by the Electric Power Research Institute (EPRI) to investigate the effectiveness of various types of nontoxic "slick-paints," which are too smooth to permit attachment of biota. The Chalk Point SES is one major EPRI study site. While preliminary findings suggest that some of these nontoxic paints can be very effective, final results are not yet available.

Biofouling has previously been identified as the major problem affecting the long-term operations of wedge-wire screens, used to control entrainment at many Maryland power plants (Weisberg *et al.* 1984a, 1984b). At Vienna, the most suitable method found to control biofouling was mechanical cleaning and backflushing with air (DP&L 1982). Thirty-day field tests at Chalk Point also demonstrated that backflushing with air was a cost-effective way for controlling biofouling (Weisberg *et al.* 1984b).

Conclusions

Because of the disadvantages or uncertainties involved with other antifouling methods, chlorine injection will continue to be used to control biofouling of internal power plant structures in Maryland in the near future. Other chemical additives have environmental consequences similar to those of chlorine, and most other biofouling control technologies are either expensive or are not sufficiently developed for implementation. Spawning and nursery habitats of RIS should be protected and ecosystem integrity preserved as long as regulatory discharge limits for chlorine are maintained. Nontoxic means of controlling biofouling are being evaluated and developed for power plant applications. These materials may prove to be a viable solution to a major problem common to power plants.

G. Best Available Technology and Operating Practices

Numerous technologies, including both intake technologies and modifications of operating practices, have been developed for reducing entrainment and impingement impacts (Cannon *et al.* 1979; Weisberg *et al.* 1984a; MMES 1985a).

Intake Technologies

Intake technologies can be classified into three categories: behavioral barriers, collection, and physical barriers. Physical barriers have proven most successful to date.

- Behavioral Barriers

Behavioral barriers (e.g., air bubble curtains, sound) are designed to cause fish to actively avoid intake flows. These barriers are not effective at reducing impingement of non-schooling fish. They are partially effective at reducing impingement of some schooling fish, but even for these species they are ineffective at reducing entrainment and impingement of early life stages and most older fish (ASCE 1982; Cannon *et al.* 1979). Early life stages generally lack sufficient swimming ability to overcome intake flows. Most fish simply do not respond to the stimuli provided.

- Collection

Collection of organisms after impingement is only partially effective at reducing impingement losses. Some of the organisms collected, particularly early life stages and juveniles, are sensitive to handling and abrasion and suffer high post-impingement mortality (Tatham *et al.* 1977).

- Physical Barriers

Physical barriers, such as intake screens or nets, prevent withdrawal of organisms. They are very effective in preventing entrainment of early life stages of fish and in preventing impingement of adults and juveniles. However, biofouling of the barrier is generally a problem when the mesh size of physical barriers is sufficiently small to exclude fish eggs and larvae (Weisberg *et al.* 1984a).

Two promising intake control technologies for Maryland applications are barrier nets and wedge-wire screens. Barrier nets, which reduce impingement levels by denying fish access to intake areas, are discussed in Section D. They generally are economical to install and maintain, particulary for retrofitting to older plants, and they effectively reduce impingement levels in both estuarine and freshwater habitats (Haymes and Patrick 1984; MMES 1985a). Physical site limitations may prevent their retrofit to some Maryland power plants, however (Wietz 1982; Barton 1986b).

Wedge-wire screens are cylindrical wire drums that are constructed of wire mesh over frameworks of various other materials. They are usually placed with their axis perpendicular to the natural currents. In this way, intake velocities through the screen are low relative to natural currents around them (Otto *et al.* 1981; Hanson 1977). Impingement on the face of the screens is low because intake velocities are weak relative to the swimming ability of most fish and crabs. Natural currents rapidly wash away organisms that accumulate near or on wedge-wire screens into by-pass flows (Hanson 1977). Because wedge-wire screens are generally constructed with fine mesh spacings (1-3 mm), entrainment of early life stages through them is low.

Field and laboratory tests of wedge-wire screens have been conducted for a variety of organisms, including striped bass, white perch, bay anchovy, naked goby, isopods, mysid shrimp and small crustaceans (Hanson *et al.* 1977; Otto *et al.* 1981; Weisberg *et al.* 1984a). Results of these tests indicated that these screens reduced entrainment of ichthyoplankton and large invertebrates by 50 to 100% but did not reduce the number of zooplankton entrained (Weisberg *et al.* 1984a). The effectiveness of wedge-wire screens was strongly dependent upon fish size. The screens would not exclude fish larvae below 5 mm in length, but almost totally excluded larvae 10 mm in length and larger. Screen slot size (1, 2 or 3 mm), through-screen intake velocity (9.5, 20 or 40 cm/s) and screen diameter had measurable, but small, effects on the number of fish entrained (Weisberg *et al.* 1984a). Essentially no fish or crabs were impinged on wedge-wire screens during the field tests (Weisberg *et al.* 1984a). Some fish larvae may avoid the complex flow patterns that exist near the surface of wedge-wire screens; however, most appear to be physically excluded by the fine mesh wire spacing (Weisberg *et al.* 1984a).

Wedge-wire screens are moderately expensive to retrofit into operational power plants or install into new plants. However, they are more cost-effective and can approach the effectiveness of closed-cycle cooling (MMES 1985a).

Operating Practices

Because of relatively low capital costs, modification of plant operations is frequently the most cost-effective approach to biofouling control. Three power plant operating practices that have been evaluated in Maryland are intake screen wash cycles, use of auxiliary tempering pumps and continuous chlorination.

- Intake Screen Wash Cycles

Most Maryland power plants rotate intake screens every 8 hr to clean them of impinged organisms and debris (Bongers *et al.* 1975; MMEC 1980; EA 1981c; MMES 1985a). When intake screens are rotated more frequently (e.g., once per hour), impingement counts increase but so does the survival rate of impinged organisms (EA 1979b, 1981a, 1981c; MMES 1985a). Estimation of annual impingement loss has generally led to the conclusion that the 8-hr screen wash cycle losses were less than those associated with shorter screen wash cycles. However, numerous factors contribute to the disappearance of organisms from intake screens, including predation by crabs and large fish, decomposition and organisms falling off the screens. The greater the length of time between screen rotations, the higher the probability that organisms will disappear. Some Maryland utilities are now performing studies to estimate the magnitude of loss due to decay, falling off and predation, which will help to optimize screen wash cycle times.

- Auxiliary Tempering Pumps

As previously discussed, auxiliary tempering pumps were used at Chalk Point to temper thermal and chemical power plant effects in the discharge canal and nearfield area by pumping additional water into the discharge (MMES 1985a). However, studies by both PEPCO (Loos 1987) and PPRP (Cadman and Holland 1986) showed that operation of the pumps had deleterious rather than beneficial environmental effects. Turning off the pumps would reduce entrainment and impingement losses of biota (Loos 1987; Cadman and Holland 1986) and would not significantly increase nearfield mortalities due to higher excess temperatures, expected to be about 0.4° C higher than with the pumps in operation (Cadman and Holland 1986). PEPCO has now discontinued use of the pumps.

- Continuous vs. Periodic Chlorination

As discussed in Section F, many Maryland power plants use continuous chlorination to control biofouling of internal plant structures (Bongers *et al.* 1975; MMES 1985a). However, biofouling growth at some power plants can be controlled by periodic chlorine application resulting in reductions in the amount of chlorine discharged to the environment and minimization of the cost of chlorine applications. Maryland utilities are therefore required to conduct studies that demonstrate the need for continuous chlorination. Studies at Chalk Point indicate that intermittent chlorination is not effective during the peak fouling season (PEPCO 1987).

Conclusions

Two intake control technologies that are applicable to Maryland, barrier nets and wedge-wire screens, have been identified and field tested. Both are effective and appear to be applicable throughout Maryland. PPRP has recommended that an operational barrier net be a part of the operating permit for the Chalk Point SES.

H. Long-Term Effects of Power Generation on Maryland's Benthic Resources

PPRP has used benthic monitoring as an integral part of its monitoring program since 1972 (Holland *et al.* 1979). In 1984, PPRP combined its estuarine benthic monitoring with that of the Maryland Department of Health and Mental Hygiene - Office of Environmental Programs (DHMH-OEP), which is now the Maryland Department of the Environment (MDE) (Holland *et al.* 1986). The joint monitoring program, which samples throughout the Maryland portion of the Chesapeake Bay, is an important element of Maryland's effort to determine the state of the Bay and to track the effectiveness of Baywide pollution abatement and water quality management actions (Magnien *et al.* 1987).

As a major tributary of the Chesapeake Bay, the Potomac River is an important Maryland resource, and its freshwater reaches are of substantial ecological and economic importance to the state. Accordingly, in 1983 PPRP established a benthic monitoring program in the riverine portion of the Potomac River (Vannote and Sweeney 1985). Sampling is concentrated in areas potentially affected by the R.P. Smith and Dickerson power plants.

The PPRP long-term benthic monitoring programs are designed around the concept that the composition of benthic communities is largely determined by ambient sediment and water quality. Therefore, the variety, abundance and productivity of benthic organisms is a good indicator and integrator of water and sediment quality responses to power plant operations. Benthic organisms are good indicators for other reasons. Because they generally complete their life cycles within specific regions of the Bay or rivers, their responses to power plant operations and pollution abatement activities are region-specific and may be quantified and evaluated. Since benthos are an important intermediate link in the food web, benthic responses to power plant operations are likely to be representative of the responses of other living resources.

The PPRP studies compare and contrast spatial and temporal characteristics of benthic population and community properties in thermally-affected areas with those of reference areas to assess power plant effects (Holland *et al.* 1985b). A similar scheme used to assess the effectiveness of cleanup activities is to spatially and temporally contrast benthic community properties for regions of concern before and after specific management actions have occurred (Holland *et al.* 1986). The regional and temporal nature of the sampling design allows "average" conditions to be estimated and responses associated with power plant operations or management actions to be measured.

Benthic sampling locations in estuarine waters encompass the range of salinity and sediment types that occur in Maryland, throughout the Bay and in all its major tributaries (Magnien *et al.* 1987). The abundance and productivity of benthic populations and physical and chemical properties of the water and sediments that are known to affect estuarine benthos are measured at each sampling location. Sampling occurs throughout the year, most intensively during periods of highest abundance and rapid growth.

Benthic sampling locations in the freshwater reaches of the Potomac River span the Piedmont and the Ridge and Valley regions of Maryland (Vannote and broad spectrum of physical and chemical water column characteristics, resource parameters (e.g., chlorophyll-a, concentration of periphyton) and substrate parameters (e.g., number of cobble-sized rocks available) are sampled (Vannote and Sweeney 1985). Sampling is concentrated during periods of the year when freshwater benthos are most abundant.

Power Plant Effects on Estuarine Benthos

Large numbers of planktonic life stages of benthic organisms are entrained by Maryland power plants (ANSP 1977; MMEC 1980). Many of the entrained benthos die, especially during summer when chlorine is used to control biofouling. However, entrainment losses to planktonic life stages of benthic organisms do not adversely affect nearfield or regional benthic populations. Factors other than entrainment (e.g., substrate type) control benthic abundances in the vicinity of power plants (Holland *et al.* 1979, 1985a; Holland and Hiegel 1981; Heck *et al.* 1981; MMES 1985a).

Power plant discharges often contain measurable amounts of chlorine and copper, which are toxic at extremely low levels to benthic organisms (Bongers *et al.* 1975; Brungs 1976; ANSP 1983a). However, the consequences of such discharges to environmental quality prove to be minimal. Only at Chalk Point, where releases of chlorine and copper have been large relative to the dilution capacity of the receiving water body, did releases of chlorine and copper have any potential long-term cumulative impacts (MMES 1985a). Copper formerly released from Chalk Point was bioaccumulated by oysters (Roosenburg 1969), and possibly a few other biota, in the immediate discharge region. However, sediments did not accumulate copper (MMEC 1980; MMES 1985a), and it neither passed up the food web nor affected the growth or abundance of biota that accumulated it (Abbe and Hart 1974). The minimal effects of copper discharge at Chalk Point have recently been eliminated completely with the installation of titanium condenser tubes to replace the copper nickel tubes.

Laboratory studies indicate that early life stages of benthic organisms are adversely affected by chlorine at very low concentrations (Brungs 1976; Liden 1980). However, no nearfield depletions of benthic populations have been observed in the vicinity of power plant discharges following extended periods of chlorine use (MMES 1985a), and the concentrations of the most toxic forms of chlorine in power plant discharges are within acceptable limits (Sugam and Helz 1977; Helz 1981). This is because chlorine decays rapidly to relatively nontoxic forms in estuarine waters.

The construction and operation of high-velocity discharge systems at Morgantown and Calvert Cliffs have altered sediment characteristics in their immediate discharge regions (Holland *et al.* 1985b). As a result, a portion of the nearfield environment is a marginal habitat for burrowing benthos. Fouling organisms are, however, generally more abundant in scoured areas than in adjacent soft-bottom habitats (MMEC 1980). Since fouling organisms have approximately the same resource value as burrowing organisms, no net loss in the amount of food available to fish and crabs has resulted. Power plants with low velocity discharge systems (e.g., Crane and Chalk Point) neither strongly influence nearfield sediment characteristics nor adversely affect nearfield habitat characteristics (EA 1981c; MMES 1985a).

A few heat-tolerant benthic species are more abundant and have higher biomass and production in thermally-affected areas near Maryland power plants than at unaffected reference areas unaffected (ANSP 1983a; MMES 1985a; Holland *et al.* 1985b). Some benthic species begin reproduction earlier in the year at thermally-impacted locations than at reference locations (Holland *et al.* 1985a). Power plant discharges, however, have not resulted in the exclusion of any species or caused out-of-season reproductive failure. In general, thermal discharge at Maryland power plants does not exceed thermal tolerances of benthic organisms except within the discharge canals of the Chalk Point, Crane and Morgantown facilities (ANSP 1977; TI 1981; MMES 1985a).

Intake water at both Calvert Cliffs and Morgantown is withdrawn from deep offshore layers, causing their discharges into the nearby oligohaline-mesohaline zone to have higher salinity and lower dissolved oxygen concentration than ambient water (Holland *et al.* 1985b). However, because plant effluents at Calvert Cliffs and Morgantown are discharged rapidly and thus quickly mixed with ambient water, and because both plants discharge into wide portions of the water bodies on which they are located, changes in water quality are not detectable beyond the immediate discharge region (Bongers *et al.* 1975; MMEC 1980; MMES 1985a). The small nearfield declines in dissolved oxygen concentration resulting from plant operations at Calvert Cliffs and Morgantown do not adversely affect nearfield benthic assemblages; nor do plant-related salinity alterations.

Long-Term Trends and Regional Distributions of Estuarine Benthic Communities

Factors other than power plants have significant impacts on benthic communities. Over the 14 years of PPRP's long-term benthic monitoring program in the Chesapeake Bay, benthic populations have fluctuated greatly. They also fluctuate seasonally, as shown in Figure IV-6. Most of the observed long-term changes in abundance are associated with the effects of long term increases in salinity on reproductive success of dominant species (Holland *et al.* 1988). The estuarine salinity gradient is also a major factor controlling regional distributions of the Bay's benthic biota. In general, changes in benthic distribution associated with power plant operations are small and localized compared to the impacts of long-term or regional variations in salinity.

During summer, salinity and temperature differences between surface and bottom waters retard vertical mixing, and the available dissolved oxygen in deeper waters of the Bay is consumed by natural metabolic processes (Magnien *et al.* 1987). Summer low dissolved oxygen conditions have been recorded in deeper (> 10 m) water habitats of Chesapeake Bay since the 1950's (Holland *et al.* 1988). PPRP's long-term benthic monitoring data indicate that the duration and severity of summer hypoxia/anoxia have increased in recent years (Holland *et al.* 1988). Much of the recent increases in the duration and severity of summer anoxia are associated with increases in nutrient loadings and excessive algal production. Changes in agricultural practices and development of the Bay's watersheds are major causes for increased nutrient inputs to the Bay watershed that have been identified (EPA 1983).

Power Plant Effects on Freshwater Benthic Organisms

Potential benthic responses to power plant operations in the riverine portion of the Potomac River include some reduction in abundance and frequency of occurrence of many dominant species, some diminution in the rarer species and occasionally

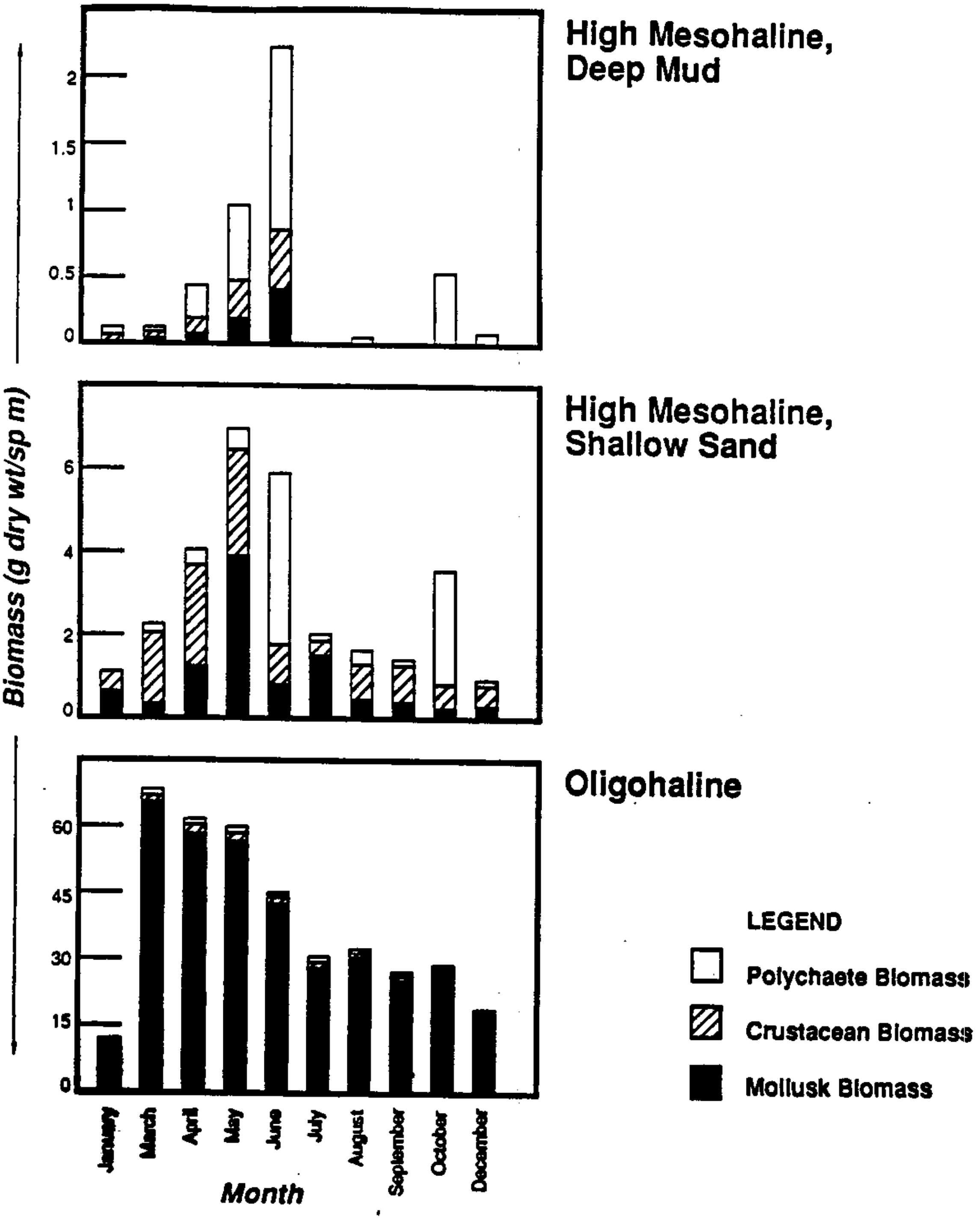

Figure IV-6. Annual cycle of benthic organism biomass in three representative habitats found in Chesapeake Bay (Note: Biomass scale is different on each graph) an increase in the relative abundance of one or more heat-tolerant species. Power plant effects on freshwater benthic organisms are persistent throughout the summer and fall, when water temperatures are high and dominant species are most abundant (Shaughnessy 1987). Increased emigration from the vicinity of plant discharge may be the major reason for diminished benthic abundances in thermally affected areas. In general, however, power plant effects on river water quality and the physicochemical environment are small relative to natural changes, particularly those associated with tributary inputs, and natural year-to-year changes (Shaughnessy 1987).

Conclusions

PPRP's long-term benthic monitoring studies have demonstrated a number of important facts. Benthic organisms are an important component of the Bay ecosystem, particularly in their role as food for fish and crabs. Thus they must be considered when assessing man's impacts on the environment. Monitoring benthic organisms is also appropriate because they are sensitive indicators of water quality that integrate within a food web over time and over a number of environmental variables. Also, benthic responses to power plant-related changes in environmental conditions can be accurately tracked, because natural sources of variation are known and can be quantified and separated from changes due to power plant operations. For those reasons, they are good indicators of the spatial extent of power plant impacts and long-term efforts to improve the water and sediment quality of the Chesapeake Bay.

The impact of low-dissolved-oxygen waters on bottom habitats is difficult to measure directly, but is clearly evident in benthic communities. However, in terms of this and other water quality parameters, power plant operations generally influence benthic abundance and biomass less than water quality changes associated with natural processes. Power plant effects (long-term and short-term) on benthic organisms are small, probably because plant-related alterations to water and sediment quality are small.

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