UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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| In the Matter of | ) | |
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| PHILADELPHIA ELECTRIC COMPANY | ) | Docket Nos. 50-352 |
| | ) | 50-353 |
| (Limerick Generating Station, | ) | |
| Units 1 and 2) | ) | |

# TESTIMONY OF DR. MICHAEL T. MASNIK CONCERNING THE IMPACT OF THE RELOCATION OF THE POINT PLEASANT PUMPING STATION ON AMERICAN SHAD AND SHORTNOSE STURGEON

Q1. Would you please state your name and position with the NRC?

A1. My name is Michael T. Masnik. I am a Senior Fisheries Biologist of the Aquatic Resources Section of the Environmental Engineering Branch, Division of Engineering, Office of Nuclear Reactor Regulation, United States Nuclear Regulatory Commission.

Q2. Have you prepared a statement of your professional qualifications and the responsibilities of your present position?

A2. Yes, a copy of my professional qualifications statement is attached to this testimony.

Q3. Can you describe your familiarity with shortnose sturgeon in general and any specific expertise with the species as it pertains to the Delaware River?

A3. I have performed two assessments of the potential impact of power plant intakes on shortnose sturgeon since 1980 and prior to my involvement with the proposed Point Pleasant Pumping Station. One dealt with the loss of shortnose sturgeon at the Maine Yankee Nuclear Plant near Bath, Maine, and the other at the Salem and Hope Creek Nuclear Generating Stations located on the Delaware River. I coauthored the assessment dealing with the Delaware River which was published by the Nuclear Regulatory Commission as NUREG-0671.

Q4. Can you provide some indication of your familiarity with power plant intake structures?

A4. I have either inspected, sampled at, or conducted a formal review of 34 intake structures. Of these 34, five have proposed or installed passive intakes. The following is a list of the plants:

Operating Fossil Plants Inspected

1. Carbo APCo
2. Glen Lynn APCo
3. Eddystone PECo
4. Chester PECo
5. Delaware PECo
6. Schuylkill PECo

Operating Nuclear Plants Inspected

1. Arkansas 1, 2
2. Browns Ferry 1, 2, 3
3. Brunswick 1, 2
4. Calvert Cliffs 1, 2
5. Ft. St. Vrain
6. Hatch 1, 2
7. Maine Yankee
8. Millstone 1, 2
9. Oyster Creek 1
10. Pilgrim 1
11. Salem 1, 2
12. Sequoyah 1
13. St. Lucie 1
14. Turkey Point 3, 4

Nuclear Plants For Which I Conducted An Intake Review

1. Arkansas 2
2. Catawba 1, 2
3. Clinch River*
4. Grand Gulf 1, 2*
5. Green County
6. Forked River
7. Marble Hill 1, 2
8. McGuire 1, 2
9. Phipps Bend 1, 2
10. Skagit/Hanford 1, 2*
11. St. Lucie 2
12. Summer 1
13. WPPSS 1, 2, 4*
14. WPPSS 3, 5*

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*Indicates passive intake structures

Q5. Would you please state the purpose of your testimony?

A5. The purpose of this testimony is to respond to portions of Contentions V-15 and V-16a (in part) admitted by the Atomic Safety and Licensing Board's Order of June 1, 1982. The contention states that:

> "The intake will be relocated such that it will have significant adverse impact on American shad and shortnosed sturgeon. The relocation will adversely affect a major fish resource and boating and recreation area due to draw-down of the pool."

Specifically, this testimony addresses the consequences of operation of the proposed Point Pleasant Pumping Station on the American shad and shortnose sturgeon fisheries resources of the Delaware River.

Q6. Will you outline the scope of your analysis of the environmental consequences to fisheries resources due to operation of the proposed Point Pleasant Pumping Station?

A6. The approach taken in this analysis consists of the following:

a) Review the location, design, and operating characteristics of the proposed intake structure.

b) Review the scientific literature pertaining to the use of wedge-wire screening for intakes at electrical generating stations.

c) Review the American shad and shortnose sturgeon fisheries resources of the Delaware River in the vicinity of the proposed intake structure.

d) Assess the potential for impact to these two fisheries resources due to the operation of the proposed intake.

Q7. Briefly describe the location, design and operating characteristics of the proposed intake structure as it relates to your testimony.

A7. The following description of the intake relies on the information in Brundage (1982). The site of the proposed Point Pleasant Pumping Station is located along and in the Delaware River near Point Pleasant, Pennsylvania, at river mile (rm) 157.2. The intake structure located in the river will be an assembly of 12 cylindrical screens supported off the river bottom. They will be arranged in two parallel lines of six screens each, oriented along the direction of flow. The screens will be approximately 245 ft from the Pennsylvania shore in about 10 ft of water. Each screen will be 40 in diameter and 40 in long and will be made of helically welded wedge-shaped wire wound circumferentially around internal supports spaced about 6 in apart. The slot opening between the wedge-wire will be 2 mm. The leading and trailing screens (relative to river flow) will be protected by conical end pieces. Each screen will be a minimum of about 2 ft above the river bottom. At the maximum withdraw rate (95 mgd or 147 cfs) the maximum velocity through the slot opening between adjacent wedge-wires will be 0.5 fps. The screen is designed such that nearly uniform through slot water velocities are experienced over the entire screen surface. The low through slot velocity relative to river velocity and the cylindrical design which allows water to be drawn in from all sides, result in a rapid decrease in approach velocity as the distance from the screen increases. At a distance of 1.0 ft from the screen surface, the inward flow component is calculated at 0.071 fps (Applicant's Responses To "Interrogatories Of Del-Aware Unlimited, Inc. Addressed To Applicant Philadelphia Electric Company" August 20, 1982).

1. Shortnose Sturgeon

Q8. Describe the basis of your conclusion and scope of your assessment of the impact of the operation of the Point Pleasant Pumping Station intake on the shortnose sturgeon.

A8. Based on a review of the known distribution of shortnose sturgeon, Acipenser brevirostrum LeSueur, in the Delaware River, the species' life history and behavior, the location of the proposed Point Pleasant Pumping Station and the design and operating characteristics of the proposed intake, I conclude that operation of the intake will not jeopardize the continued existence of this species in the Delaware River. This conclusion is based on an analysis of the available life history data, site specific information and operational characteristics of the intake. The results of my analysis are consistent with the conclusions contained in the assessment by Mr. H. Brundage (Brundage, 1982) and the Endangered Species Act Section 7 Consultation - Biological Opinion (July 19, 1982) prepared by National Marine Fisheries Service (NMFS) for the U.S. Army Corps of Engineers. NMFS has statutory jurisdiction and possesses the necessary expertise in implementing the Endangered Species Act for this species.

I performed an assessment to determine whether the operation of the proposed intake structure could affect the shortnose sturgeon. I examined the following potential sources of mortality to the species from the operation of the intake: entrainment of larvae; impingement of juveniles; denial of use of critical habitat; and, alteration of turbidity immediately downstream of the intake.

A. Entrainment

Q9. Provide your bases and conclusions concerning the impact on shortnose sturgeon due to entrainment through the intake.

A9. It is not likely that eggs and larvae of shortnose sturgeon would be entrained through the wedge-wire screen and would be lost from the Delaware River population. Spawning of shortnose sturgeon has not been reported at the Point Pleasant site although, based on an examination of the river bottom of the site, spawning habitat may be present. The site is located at rm 157.2. The most upstream record of shortnose sturegon is for rm 148 at Lambertville, NJ. The only observation of possible spawning is at Scudders Falls rm 137 (Hoff, 1965).

Shortnose sturgeon eggs are demersal and adhesive and are usually spawned over rubble, cobble or gravel substrates. Within approximately one minute of fertilization the eggs develop their strongly adhesive characteristic and adhere to any available suitable substrate. The eggs are approximately 3.0-3.2 mm in diameter and would probably not be susceptible to entrainment through the 2 mm slots of the wedge-wire screen. Due to the lack of observed spawning in the vicinity of the site, and the adhesiveness, negative bouyancy and size of eggs, entrainment of shortnose sturgeon eggs is highly unlikely and poses no threat to continued existence of this species in the Delaware River.

When first hatched shortnose sturgeon larvae could pass through the wedge-wire intake screens. Once the larvae attain a certain critical size they would be physically excluded from entrainment. Brundage (1982) calculated the critical size of the larvae that would preclude passage through the 2 mm slot width as approximately 20.5 mm total length (TL). A larva reaches this size in approximately 18.5 days after hatching. Observations of shortnose sturgeon larvae have shown that from the time of hatching to 16 days of age the larvae are exclusively bottom oriented and occupy the interstitial spaces in the substrate. This bottom orientation is known to continue as long as 43 days after hatching. (Washburn and Gillis Associates, 1981 in Brundage 1982). The Point Pleasant intake screens will be placed 2 ft above the bottom.

Based on the lack of evidence of spawning in the area of the proposed intake, the intense bottom orientation of the newly hatched larvae, and the design and placement of the intake screens, the Staff has concluded that no impact to the shortnose sturgeon population inhabiting the Delaware River due to larval entrainment will occur. This conclusion would probably not be altered even if spawning was known to occur at the site.

### B. Impingement

Q10. Provide the bases and conclusions concerning the impact on shortnose sturgeon due to impingement on the intake screens.

A10. Operation of the proposed intake will not result in impingement of healthy juvenile or adult shortnose sturgeon on the wedge-wire screening. The maximum calculated velocity through the screen openings (.5 fps or less) is sufficiently low to allow shortnose sturgeon to escape impingement. McCleave et al. (1977) reported that adult shortnose sturgeon exhibited cruising speeds between .3 to 1.1 fps based on radio-tagging studies. Adults will have a substantially greater maximum escape speed. Juvenile shortnose sturgeon 15-35 cm in length were found by Dadswell (in Masnik and Wilson, 1980) to exhibit a maximum escape speed of 1 to 2.2 fps.

Studies (Browne et al., 1981; Hanson et al., undated; Lifton, 1979) conducted at installations of wedge-wire screen intakes with through slot velocities of .5 fps found virtually no impingement of any species of fish. Based on these studies, healthy shortnose sturgeon would not be susceptible to impingement.

Shortnose sturgeon are not impinged in significant numbers at existing cooling water intakes. In the Hudson River, where a larger population of shortnose sturgeon is known than that in the Delaware River only 39 adult or juvenile fish were taken at six power stations between 1972 and 1979 (Hoff and Klauda, 1979). Only three specimens were reported taken prior to 1979 from industrial intakes along the Delaware River (Masnik and Wilson, 1980). Of these three, two were taken at a power plant where the intake flow at the time was about 2500 cfs, a flow of almost 17 times greater than that proposed for the Point Pleasant intake. The power plant had a design through-screen velocity of 1.0 fps or twice the through slot velocity proposed for Point Pleasant. Based on the low incidence of impingement reporting at existing intakes and the apparent low susceptibility of the species to impingement the Staff does not anticipate any impact to the shortnose sturgeon in the Delaware River due to impingement.

## C. Critical Habitat

Q11. Describe the impact of the operation of the Point Pleasant intake, if any, on the shortnose sturgeon's habitat in the vicinity of the site.

A11. The loss of river bottom occupied by the intake will not jeopardize the continued existence of this species in the Delaware River. The areas of critical habitat for the shortnose sturgeon in the Delaware River have not been identified. The actual intake structure will occupy about .05 acres of river bottom. Within a 0.25 mi stretch of river in the vicinity of the proposed intake, assuming an average river widt of 530 ft, approximately 16 acres of river bottom are available.

D. Turbidity

Q12. Provide the bases and conclusions concerning the impact on shortnose sturgeon due to increased turbidity immediately downsteam of the Point Pleasant intake after backflusing.

A12. Increased turbidity due to resuspension of settled solids associated with backflushing of the intake has been suggested as a potential source of impact to shortnose sturgeon. Backflushing will be done between one to three times each week to remove debris from the outside of the screens. Some of the silt below the screens could be resuspended during this process. This may cause an increase in resuspended solids immediately downstream of the intake. This increase could either be tolerated or avoided by all but eggs and the smallest larvae. No significant impact on any of the life stages of shortnose sturgeon due to increases in resuspension of solids due to backflushing is expected. There may be localized redeposition of sediment downstream of the intake, however, this area would be insignificant relative to the amount of river bottom available to the species.

2. American Shad

Q13. Provide the results of your assessment of the impact of the operation of the Point Pleasant Pumping Station on the American shad.

A13. Based on a review of the present distribution of American shad, Alosa sapidissima (Wilson), in the Delaware River, the life history and behavior of the early developmental stages of the species, the location of the proposed Point Pleasant Pumping Station and the design and operating characteristics of the proposed intake, I conclude that operation of the intake will not jeopardize the American shad population in the Delaware River.

American shad spend most of their lives at sea, returning as adults from offshore waters to upstream freshwater spawning grounds. In the Delaware River most of the spawning occurs from mid-April through June, with the peak in May in the reach of the River between Delaware River Water Gap (rm 212) and Port Jervis (rm 252), New York (Chittenden, 1969). Further upriver in the East Branch, spawning may occur somewhat later as a result of slower warming of the waters. American shad will spawn in tidal or non-tidal fresh water or a combination of both, and in the upper Delaware River in long, moderately deep pools separated by riffles and broad flats over substrates of sand, gravel, cobble and bedrock (Barker, 1965 in PSE&G, 1982). Historically, spawning of American shad in the Delaware River was more widespread and included the majority of tidal and non-tidal freshwater areas. Decreasing water quality at the turn of the century limited the return of adult shad ready to spawn (Chittenden, 1969). A high biological oxygen demand exists in the lower reaches of the Delaware River (Masnik and Wilson, 1980). It is thought that once the dissolved oxygen block is established in the vicinity of Philadelphia, PA, adult shad can no longer ascend the river.

At present, no spawning of American shad has been observed at the Point Pleasant site; however, based on the habitat present at the site and the anticipated improvement in water quality in the lower river, future spawning at the site may occur.

Spawning culminates with the broadcasting of the eggs throughout the water column. After fertilization, the eggs are spherical and 2.1-3.8 mm in diameter. Although the eggs are initially adhesive, adhering to suitable substrate, they later become non-adhesive, demersal, and tend to sink to the bottom. The period of incubation is dependent on water temperature and can vary from 2 to 17 days. The eggs are quite tolerant of turbidity. Auld and Schubel (1978) in PSE&G (1982) reported no significant effect on egg hatching at suspended solid concentrations as high as 1,000 mg/l.

American shad larvae hatch at about 5.7-10.0 mm total length (TL). Jones et al. (1978) reported larval size range of 9.0 mm to 27.00 TL. Duration of the larval phase is 21-28 days. Data from the Connecticut River indicated an excellent fit to the Laird-Gompertz growth equation which correlates age of larvae with TL. Using that equation, the TLs for larvae at 5, 10, 15, and 17 days are calculated to be 11.2, 15.3, 18.8, and 20.0 mm, respectively.

Chittenden (1969) reported that larvae exhibited the following behavior upon hatching and subsequent to hatching: "continually, they actively rose toward the surface and then passively sank head-first". Evidently this behavior results in rapid movement downstream from the site of spawning. It is not known if larvae preferentially seek out a particular river habitat.

Transformation to the juvenile phase occurs above 19.1 mm TL, generally between 25-28 mm TL. Growth is rapid with rates between 1.9-7.2 mm/wk. Juveniles move downriver in late summer and fall. Lupine (1982) found that the juvenile shad catch-pwer-unit-effort at Byram Pool across and downstream of the Point Pleasant site peaked in late September in 1980 and late August in 1981. Miller et al. (1975) in PSE&G (1982) reported in the fall of 1973 juveniles were first taken near Philadelphia, Pennsylvania (rm 101) in late October and juvenile populations at that location peaked in November.

The Staff examined the operational characteristics of the Point Pleasant Pumping Station to determine its potential impact on various life stages of American shad in the Delaware River. Possible sources of impact examined were: 1) entrainment of eggs and larvae; 2) impingement of juveniles and adults; 3) loss of habitat critical to the continued existence of the species; 4) alteration of turbidity immediately downstream of the site; and 5) the effect of drawdown of the pool due to station operation. Each of these potential mechanisms for impact will be discussed in turn.

A. Entrainment

Q14. Provide your bases and conlusions concerning the impact on American shad due to entrainment through the intake.

A14. Shad eggs and larvae small enough to pass through the 2 mm slots would be entrained into the pump system and be ultimately lost from the Delaware fishery. If sufficient eggs and larvae were lost from the system, population levels of juveniles and adults could be depressed. Factors influencing the number of eggs and larvae entrained include the withdrawal rate of the intake, their size relative to the size of the 2 mm slots, the behavior of the larvae, and the flow regime in the vicinity of the intake.

The maximum withdrawal rate of the Point Pleasant Pumping Station is 95 mg/d (147 cfs). The mean monthly discharges at the Trenton gauge between 1970-1979 for April, May, June and July are 23,036, 16,231, 11,874 and 8,558 cfs (Brundage, 1982). The minimum mean monthly discharge at the Trenton gauge for the same years for the months of April, May, June and July are 18,120, 11,280, 4,454, 3,723 cfs, respectively (Brundage, 1982). The withdrawal at Point Pleasant will therefore result in the removal of about .6%, .9%, 1.2%, 1.7% of the mean monthly discharge at the Trenton gauge from the months April through July, respectively. It will remove about 0.8%, 1.3%, 3.9% of the minimum mean monthly discharge for the same months. Withdrawal of the Limerick portion (71 cfs) of the flow will be reduced to 27 cfs for flow augmentation of the East Branch of the Perkiomen Creek when flow in the Delaware River drops to 3,000 cfs at the Trenton gauge. Therefore, the worst case condition would be 147 cfs from the minimum allowable flow of 3,000 cfs or 4.9%. The Trenton gauge flow would have to drop to less than 2,100 cfs befor a greater percentage of the flow would be removed under the reduced pumping scheme. (NWRA withdrawal plus flow augmentation to the East Branch of Perkiomen Creek).

If shad eggs and larvae were uniformly distributed in the water column and their removal from the water column were strictly on the basis of volume, then the loss based on the above April through July flow rates would always be less than 5% during the spawning season and for average conditions would be less than 2%. This is a conservative estimate since additional factors elaborated in the following discussion tend to reduce this percentage.

Fertilized eggs described above are demersal, non-adhesive, and 2.1-3.8 mm in diameter. The through slot width of 2 mm is less than that of the water hardened eggs. Although some eggs might be extruded through the slots, many will simply roll along the surface and escape entrainment. Using a different species of eggs but similar screen and through slot velocity, Hanson (1979) found that only about half the eggs within the zone of influence were entrained per pass if the flow past the screen was 0.5 fps. Significant reduction in the number of eggs entrained occurred when the speed of the current sweeping the intake increased.

The Staff concludes, that loss of shad eggs at the proposed pumping station would not be significant, since less than 5% and more typically 2% of the flow would be entrained, and that the design of the intake would further reduce the loss of eggs by approximately one half. The duration of exposure of eggs in the vicinity of the Point Pleasant diversion is impossible to estimate since spawning immediately upstream of the intake is not presently known. Studies by Chittenden (1969) found that after spawning shad eggs sink rapidly even in moderate current, and as a result would not travel far downstream before reaching the bottom. Even if spawning is ultimately established in the stretch of river just upstream of the proposed intake, no significant impact is anticipated since the spawning just upstream of the proposed site would be a small fraction of the total spawning within the Delaware River and the intake itself would take only a small fraction of the available eggs in the drift past the site.

Larvae present in the water column would also be exposed to entrainment. Although no specific wedge-wire screen studies to determine the susceptibility of American shad larvae to entrainment through the screens have been conducted, it can be conservatively estimated, based on studies (Brown et al., 1981) done on the bay anchovy, *Anchoa mitchelli*, and atherinids, that the maximum entrainable size for the 2 mm slots is about 20 mm TL. Therefore larvae from the time of hatching till they attain 20 mm would probably be susceptible to entrainment. Using the Laird-Gompertz growth equation, the larvae probably reach 20 mm TL in about 17 days. Given the short period of potential entrainment larvae hatched greater than 17 days travel time upriver would not be susceptible to entrainment because of their size.

The volumetric estimate of entrainment losses could be significantly altered due to the behavior and habitat requirements of the larvae before they attain the 20 mm TL. Even during the initial 17 days, entrainment would not be a simple function of larval density in the water column. Studies by Zeitoun et al. (1981) indicate that the cylindrical wedge-wire screens substantially reduce entrainment of fish larvae well below that which could be accounted for by physical exclusion alone. There is some evidence in the literature that may be used to quantify entrainment resistance. Two separate studies, one on Lake Michigan (Zeitoun et al., 1981) and one on Barnegate Bay near Toms River, New Jersey (Browne, et al. 1981), using cylindrical 2 mm mesh wedge-wire screens in actual field trials, found that the number of organisms entrained through the screens was about one eleventh of the number expected based on ambient population levels as determined by plankton tows. Based on the size distribution of organisms entrained through the screens and captured in the plankton net, exclusion by physical denial is insufficient to explain the difference in numbers. Therefore, behavioral responses must contribute significantly to the reduced entrainment. If this eleven-fold reduction were applied to the 2% and 5% volumetric figures, a loss rate of less than .2% or .5% would result. A loss of this magnitude would be virtually undetectable and would not significantly affect the population.

Hanson (1979) found that the river flow velocity across the surface of the wedge-wire screen can influence the rate of entrainment. Studies by Hanson (1979) demonstrated a substantial reduction in percent entrainment and impingement of eggs once current velocity past the screen equalled or exceeded 1.0 fps. A similar reduction probably occurs for larvae. Based on velocity profiles presented in Brundage (1982) the river velocity in the vicinity of the proposed intake during low flow conditions (3,000 cfs) and at 4,000 cfs (measured at Trenton gauge) would exceed 1.0 fps.

There is some controversy concerning the existence of an eddy current on the Pennsylvania side of the river in the vicinity of the site. The size, configuration, location and persistence of this eddy is not known. The velocity measurements contained in the Brundage (1982) report provide some indication that such an eddy exists.

The Staff theorized that if this eddy could form in the immediate vicinity of the intake structure it could result in the continuous reintroduction of the same population of shad larvae to the screen surface. Thus, over time such a phenomenon would result in a significant loss of larvae from the eddy.

As water is withdrawn from the eddy by the intake additional water would flow from the non-eddy portion of the Delaware River to replenish water in the existing eddy. Water flowing into the eddy would introduce additional eggs and larvae into the eddy water body replenishing the population of shad eggs and larvae. The number of eggs entrained per unit time would not differ from the losses calculated from a simple volumetic ratio. This is attributable to two factors: (1) a constant volume of water is removed regardless of the location of the eddy, and (2) eggs do not actively seek out the eddy and thus would not be at a higher concentration within the eddy. However, the probability of entraining an individual egg caught in the eddy would be significantly greater than the mean probability of entraining any eggs spawned upriver.

The staff concludes that American shad egg entrainment losses under assumed conditions of eddy influence on the intake would not be significantly greater than under conditions where the intake is not influenced by the eddy.

A similar argument could be put forward with respect to the larvae, however, larvae have some motility and could be attracted to or avoid the eddy. It preferential movement toward the eddy occurs then the number of larvae entrained in the eddy situation increases over the non-eddy situation.

The precise magnitude of increased entrainment would be impossible to determine at this time and probably could only be determined empirically. Larvae would have to detect the presence of the eddy and actively move toward it. It is unlikely that larvae on the opposite side of the river would be able to detect this flow regime and be affected by it. Limited existing data on larval behavior indicate that the larvae actively swim toward the surface then slowly sink toward the bottom only to swim toward the surface again. This behavior pattern appears to have evolved in order to maintain the organisms in the flowing part of the river to allow for downstream movement as opposed to a behavior pattern that results in movement toward the bottom or the shallows where nursery areas exist. Such a behavior pattern would tend to suggest that the larvae would not preferentially seek out the areas of reduced velocity which would exist in the vicinity of an eddy.

The Staff concludes that the existence of an eddy in the vicinity of the intake would not result in larval entrainment significantly greater than would be expected by simple volumetric proportion. Only a portion of the cross section of the river would be affected by the area of reduced velocity and the behavior pattern of the larvae does not indicate strong preference for areas of slack water.

Based on the above analysis, the Staff concludes that the loss of egg and larval American shad due to entrainment into the Point Pleasant Pumping Station will be insignificant and will not jeopardize the continued existence or anticipated future gains in population of this species in the Delaware River.

B. Impingement

Q14. Provide the bases and your conclusions concerning the impact on American shad due to impingement on intake screens.

A14. Once larval shad grow beyond 20 mm TL they are susceptible to impingement on the surface of the wedge-wire intake screen. Given outmigration of juveniles from the upper freshwater reaches of the Delaware River and the lack of spawning downstream of the Point Pleasant site, the entire juvenile shad population must move past the site. This outmigration occurs during the middle and late summer and early fall of the year. Peak densities of American shad juveniles in 1980 and 1981 near the Point Pleasant site occurred in late September and late August repectively (Lupine, 1982).

Population levels of adult shad could be depressed if a sufficient number of juveniles were lost from the system by impingement.

It is also conceivable that adult shad returning in the spring to spawn could be impinged on the intake. However, due to the high mean swim speed of adults in freshwater (approximately 2 ft/sec) relative to the through-slot velocity of .5 ft/sec, no impingement of adults is anticipated.

Significant numbers of impinged fish have not been found on any installed or field tested operating wedge-wire screens. Visual observations on test screens located in Barnegat Bay, New Jersey, during 1979 and 1980 found very limited impingement (Browne et al., 1981). Hanson et al. (undated) found in flume studies that flow past the intake screen resulted in few impingements and those were of short duration. These only occurred at through screen flow rates higher than those planned for the proposed Point Pleasant Pumping Station. Lifton (1979), using a 2 mm slot width wedge-wire screen and a .5 ft/sec through slot velocity in a field test facility in the St. Johns River in Florida, found no impingement in 104 collections with a sample duration time of 30 to 90 minutes each.

Based on the results of the above studies, it is concluded that the loss of juvenile and adult shad by impingement due to operation of the Point Pleasant Pumping Station will be insignificant and will not jeopardize the continued existence or anticipated future gains in population of this species in the Delaware River.

### C. Critical Habitat

Q15. Describe the impact of the operation of the Point Pleasant intake, if any, on shad habitat in the vicinity of the site.

A15. Habitat critical to the existence of American shad in the Delaware River does not appear to exist at the Point Pleasant site. Based on water quality analyses, hydrology, bathymetry, substrate studies and biotic sampling, the Point Pleasant site does not constitute a unique habitat for any life stages of American shad in the Delaware system. The actual intake structure will occupy only about .05 acres of river bottom. Within a 0.25 mi stretch of river in the vicinity of the proposed intake, assuming an average river width of 530 ft, approximately 16 acres of river bottom are available. The loss of .05 acres of river bottom occupied by the intake structure will not jeopardize the continued existence of this species.

### D. Turbidity

Q16. Describe the potential impact on American shad of the operation of the intake due to increased turbidity immediately downstream of the Point Pleasant intake after backflushing.

A16. Backflushing of the intake could result in resuspension of material deposited under the intake structure and result in some increase in turbidity downstream. Increased turbidity due to resuspension of solids, if enough material is resuspended, could impact water quality immediately downstream of the site. The projected frequency of backwashing of the intake is 1 to 3 times per week. The backwash will be of short duration and would result in the possible resuspension of whatever material deposited under the intake structure since the last backwash. Backwashing will be accomplished using compressed air which may not have much effect on material deposited among the rip rap under the intake. The amount of material would be minimal since backwashing would be done at a least once a week thereby minimizing the amount of material deposited. The turbidity plume would have a small cross sectional area and a significant portion of it may be entrained into the intake flow. The intake structure itself occupies less than 1% of the Delaware River water cross section at the proposed site.

Auld and Schubel (1978) in PSE&G (1982) reported survival of American shad larvae 4-12 hrs old in suspended solid concentrations of 50, 500 and 1,000 mg/l as 93, 64 and 66% respectively. Based on the tolerance of American shad eggs and larvae to relatively high levels of suspended solids, the current range of total suspended solids in the Delaware River (0 - 145 mg/l), and the minor addition of resuspended solids that may result due to the operation of the intake, the Staff does not predict any adverse impact on American shad.

## E. Pool Drawdown

Q17. Describe the potential impact on fisheries resources of pool drawdown in the vicinity of the intake.

A17. Based on an analysis provided by Mr. Wescott, the water level in the immediate vicinity of the intake structure would be lowered by only less than 1.0 in. This would be barely perceptible to the eye and would have no effect on the overall water level at Point Pleasant in Byram Pool. In the Staff's opinion, such a reduction would not adversely affect the shad or any other fishery in the Delaware River.

Q.18 The contention states that the relocation of the intake will adversely affect a major fish resource. What effect will relocation have on the fisheries resources in the vicinity of the proposed intake?

A.18 Relocation of the intake from the formerly proposed shoreline position to the present, approximate mid-river, position would not result in any adverse effects on American shad or shortnose sturgeon populations inhabiting the Delaware River. This conclusion is based on the analyses provided in A8 and through A15.

## Literature cited:

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# PROFESSIONAL QUALIFICATIONS
Michael T. Masnik
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I am currently employed as Senior Fisheries Biologist in the Office of Nuclear Reactor Regulation, Division of Engineering, in the Environmental Engineering Branch, USNRC for the last 3 years and before that I have been investigating fishery science for 10 years. As a member of the Aquatic Resources Section of this branch, I have responsibility for the review of applicants' Environmental Reports at both Construction (CP) and Operating License (OL) stages for completeness and environmental acceptability of proposed projects as they may affect natural ecological resources, commercial and sports fisheries resources, and other impacts on the aquatic environment. It is also my responsibility to provide written evaluation of aquatic resources for inclusion during preparation of both Final Environmental Statement (FES) - CP's and FES - OL's. I also act in the capacity of a consultant to other NRC components and provide analyses of aquatic problems through technical assistance requests.

Review of the applicant's environmental technical specifications at the operating license stage and subsequent appraisals of changes to such specifications are also part of my responsibilities. My work also involves the preparation of standard review plans, regulatory guides, and staff position papers dealing with aquatic resources. I provide written input to research proposals under consideration by the Commission dealing with aquatic problems and have served as a Commission representative during the formulation of the Second Memorandum of Understanding between EPA and NRC and have provided written input to both the EPA 316A and 316B guidance manuals.

In the past several years, as a member of the Aquatic Resources Section, I have written the aquatic resources related sections for the Edwin I. Hatch Nuclear Station Unit 2 (FES-OL) and the Perryman Early Site Review; reviewed and provided written input for the aquatic sections of FES-CP stages for the following plants: Marble Hill Nuclear Generating Station Units 1 and 2; Phipps Bend Nuclear Station; and the Yellow Creek Nuclear Plant Units 1 and 2; and Clinch River Breeder Reactor Project; provided draft input to a NRC generic study on environmental impacts of the LMFBR program; reviewed and provided written comments on the second draft of the EPA 316B demonstration guidance manual; prepared a biological assessment for submission to the NMFS on the impact of construction and operation of the Salem and Hope Creek Nuclear Stations on the endangered shortnose sturgeon in the Delaware River; provided and was questioned on testimony dealing with the impact of the operation of the Oyster Creek Nuclear Plant Unit 1 on the biota of the receiving waters and the Pilgrim Station Alternate Site Study; represented the USNRC in the area of ecological resources in the CEQ Interagency Working Group for Environmental Data and Monitoring; chaired a section of the Fourth National Workshop on Entrainment and Impingement as well as reviewed and provided comments on numerous solicited and unsolicited grant proposals submitted to the NRC for original research dealing with aquatic resources. In the last several months, I have provided written input for the aquatic sections of the FES-OL for the Catawba, Clinch River and St.Lucie Nuclear Plants. I have investigated biofouling of essential service water systems by molluscs at the following nuclear plants: Arkansas Nuclear One, Brunswick, Pilgrim, Sequoyah and Salem, and have written a number of NRC technical reports on the subject.

I have a Bachelor of Science in Conservation from Cornell University (1969), a Master of Science in Zoology from Virginia Polytechnic Institute and State University (1971), and a Doctor of Philosophy in Zoology from Virginia Polytechnic Institute and State University (1975).

While at Virginia Polytechnic Institute and State University, I undertook research in a variety of areas, specializing in zoogeography and distribution of freshwater fishes. Other areas of research which resulted in published papers include thermal studies on fishes, recovery of damaged aquatic ecosystems, and development of sampling methodology for fishes and macroinvertebrates. My formal education program has encompassed and emphasized studies in Zoology, Ecology, Ichthyology, Evolutionary Biology, and computer techniques for data handling and analysis.

I was a member of the scientific staff of the 1970 Duke University Caribbean Cruise involved in oceanographic investigations and have served as a consultant, through Virginia Polytechnic Institute and State University, for American Electric Power Company, Koppers Company, Inc., U.S. Army Corps of Engineers, and Tennessee Valley Authority.

During the summers of 1970 and 1971 I was employed as a field biologist by Ichthyological Associates, an ecological consulting firm under contract with Philadelphia Electric Company and Public Service Electric and Gas Company, to perform routine sampling on the Delaware estuary. My duties included routine fish sampling, plankton and benthos sampling, and inplant monitoring of impingement.

I am currently a member of the American Fisheries Society, American Association for the Advancement of Science and the Association of Southeastern Biologists, Society of Sigma Xi, and the Virginia Academy of Science.

I have authored or co-authored some 19 publications.

Michael T. Masnik

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# PRACTICALITY OF PROFILE-WIRE SCREEN IN REDUCING ENTRAINMENT AND IMPINGEMENT

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## Abstract

Experimental studies indicated that 1.01-mm slot profile-wire well screen operated at an intake velocity of 15.24 cm/s virtually eliminated impingement of fishes larger than 15 mm fork length (FL). Intake velocities as high as 53.34 cm/s produced low impingement. Tests of fish less than 40 mm FL held near a functioning intake (15.24 cm/s) for as long as 3 hr yielded no impingement or stress. Many striped bass between 8 and 17 mm FL were capable of resisting impingement at more than 30.48 cm/s velocity for longer than 30 min; larger specimens (12-17 mm) showed excellent ability to escape when impinged. The screen excluded virtually all striped bass eggs from the cooling water. Preliminary egg mortality studies indicate that at least 95% survival can be expected at an approach velocity of 15.24 cm/s and impingement durations up to 2 min.

Fouling studies showed that screens were highly resistant to clogging, essentially self-cleaning in a current, and easily backwashed. *In-situ* studies in the Chesapeake and Delaware Canal have shown that a 61.0- × 76.2-cm, 1.01-mm-slot screen is capable of providing its designed capacity for weeks without backwashing or cleaning. Biofouling proved to be the greatest operational problem. Entrainment samples from the *in-situ* intake have shown significant reductions in organisms/$m^3$ of filtered versus ambient water.

## INTRODUCTION

The potential of profile-wire well screens as surface water intakes is evaluated in this report. Studies were initially conducted to determine the expected entrainment and impingement (involuntary adherance of a fish to the screen for more than 0.5 sec) of striped bass eggs, larvae, and young by a 1-mm-slot well screen intake. Subsequent experiments were expanded to include the study of other fishes, mortality of striped bass eggs due to impingement, clogging rates from biological and detrital fouling, *in-situ* long-term operation, and cleaning techniques. The studies are on-going and some have not progressed sufficiently to allow analyses. Laboratory studies are discussed in Part I and results of *in-situ* testing are discussed in Part II.

## PART I
## LABORATORY STUDIES

### MATERIALS AND METHODS

#### Test Facilities

Most experiments were conducted in a 9.14- x 4.57-m oval flume (Fig. 1). The aluminum and plywood channel was 0.84 m wide and 1.22 m deep. A 1.22- x 2.44- x 1.22-m sump attached to the flume's inner wall served as the site for the model intake. Water was pumped from the sump,

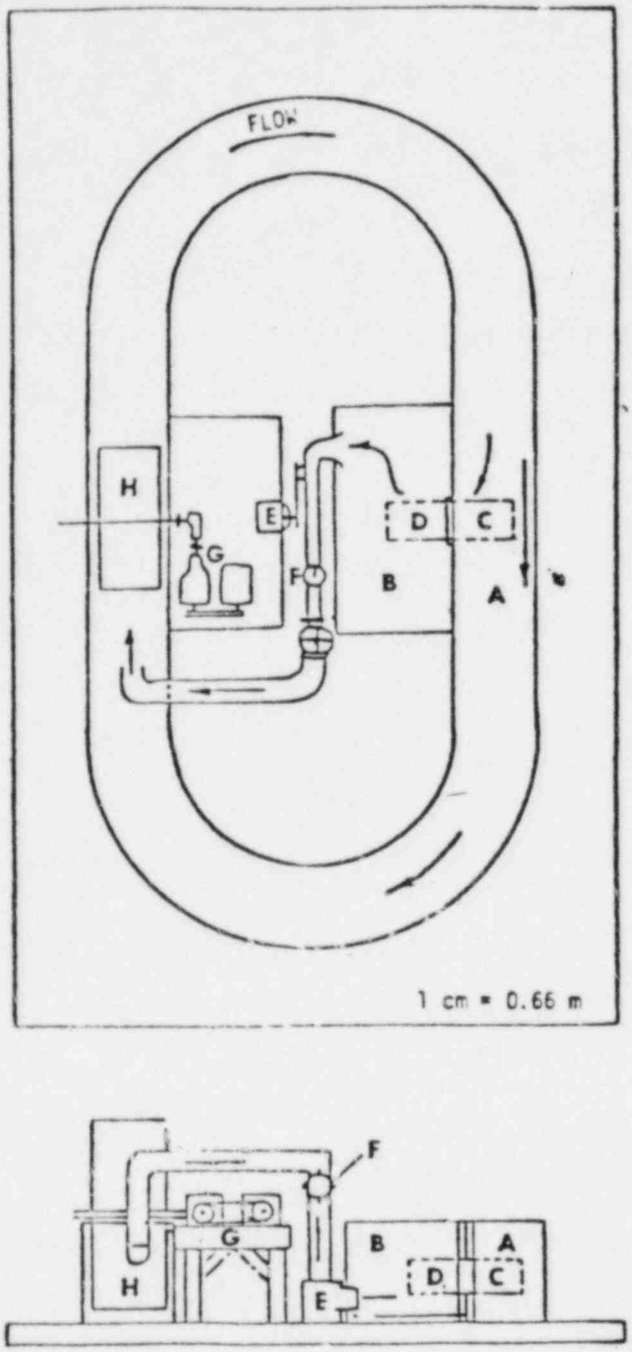

Fig. 1.

Schematic of Large Experimental Flume. A = channel, B = sump, C = standard screen placement, D = inverted screen placement, E = intake pump, F = water volume meter, G = paddle wheel drive, and H = paddle wheel.

initiating a gravity flow from the flume channel through the test screen. The maximum sustainable pump rate was 1.91 $m^3$/min. Pump rate was measured with a turbine-type meter and controlled by butterfly and gate valves. Discharge reentered the flume opposite the sump box. The total volume of the facility at maximum depth (1.02 m) was 20.71 $m^3$.

A 2.11-m diameter paddle wheel generated flume currents as high as 79.9 cm/s. The wheel was driven by an electric motor through a variable-speed hydraulic transmission coupled to a 20:1 right-angle gear reduction box. Water velocities were measured with an electromagnetic current meter.

Egg mortality studies were conducted in a 3.05- x 1.52-m oval flume (Fig. 2). The aluminum and plywood channel was 30.5 cm wide and 43.2 cm deep. A 91.4-cm-diameter six-blade paddle wheel generated current. The wheel was driven by a variable-speed motor coupled to a variable-speed hydraulic transmission. The total volume of the flume was 0.90 $m^3$.

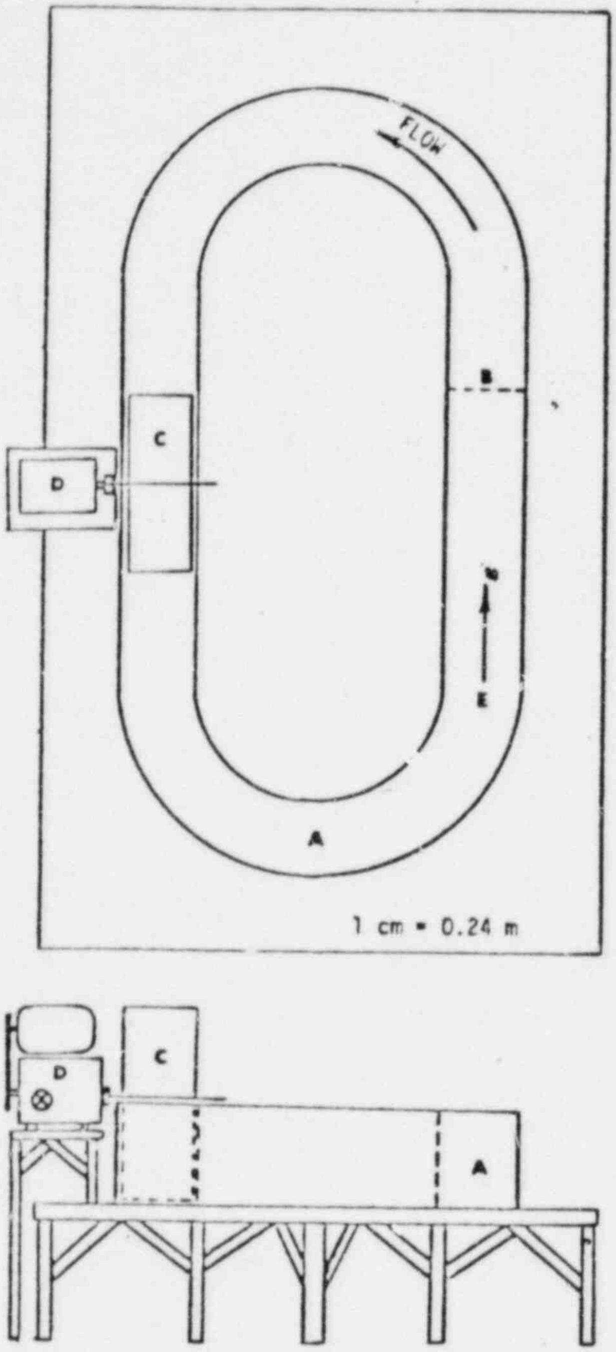

Fig. 2.

Schematic of Small Experimental Flume. A = channel, B = screen placement, C = paddle wheel, D = paddle wheel drive, and E = egg release point.

Screens

Eight different screens were tested; shapes and measurements of the screens are presented in Figure 3. The screen modifications are designated by a three-letter code, and are described in Table 1. Mushroom and panel screens were always tested in unmodified form.

Cylindrical screens were mounted in a threaded collar located on the channel-sump common wall opposite the viewing port. Standard screens were positioned horizontally across the flume channel at about midwater; the inverted screen was located within the sump (Fig. 1).

Panel screens were used in the egg mortality studies. The screens were placed in the small flume channel perpendicular to the flow, 2.54 cm downstream of the viewing port (Fig. 2).

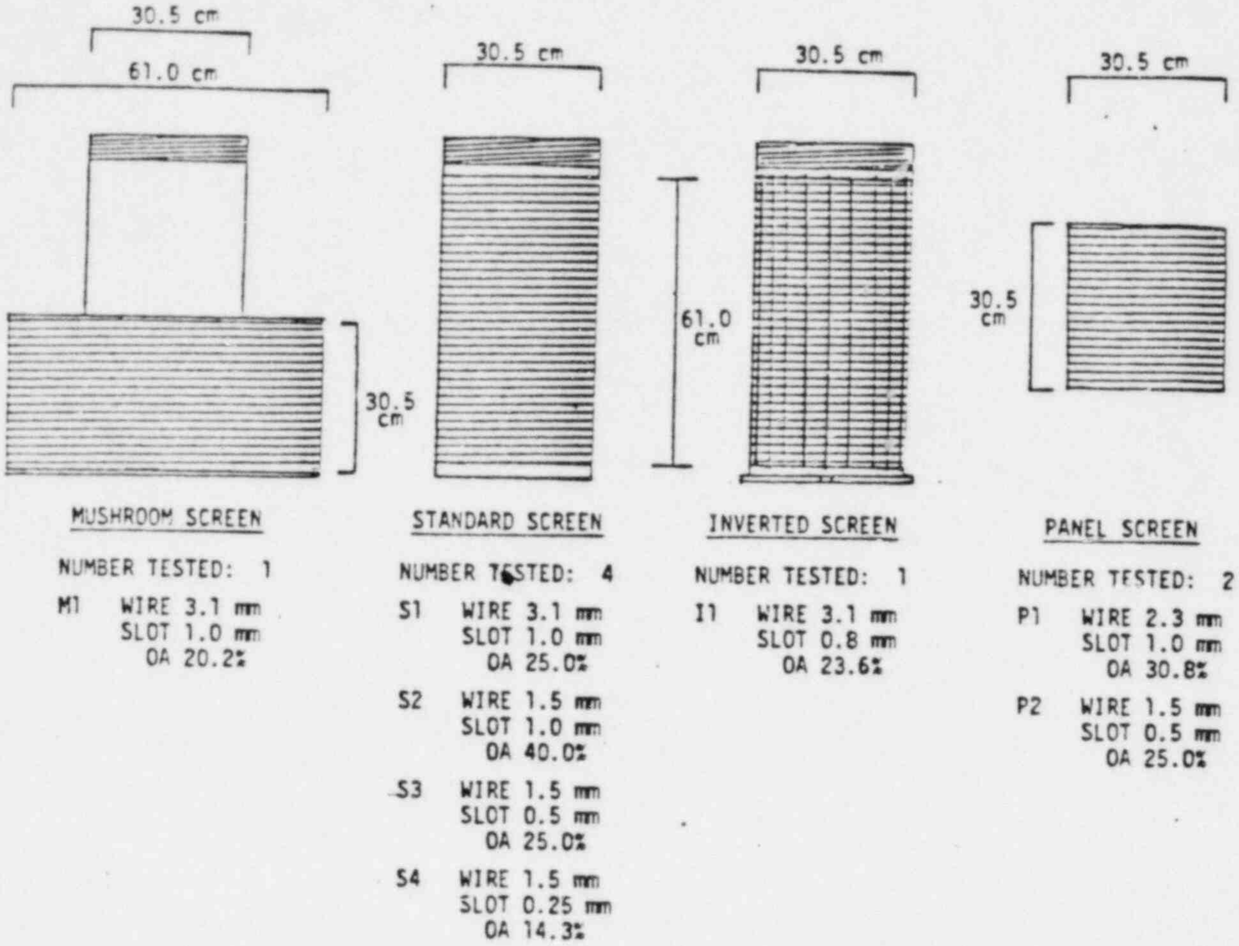

Fig. 3. Schematic of the Different Screen Configurations Tested

## Test Cages

Cages were constructed to keep test specimens in the proximity of the intake during experimental runs in static mode (channel velocity = 0). The standard screen test cage was 73.7 x 57.2 x 72.4 cm and extended the entire width of the channel. The front panel was plexiglass; the sides and bottom were 0.5-mm-mesh nytex. The bottom was custom-fit to expose the test specimens to only the top half of the screen. The bottom portion of the screen (outside the cage) was frequently covered with sheet polyethylene or duct tape to reduce the open area and increase the maximum intake velocity.

The cage for the inverted screen was 78.7 x 68.6 x 76.2 cm. The bottom and side walls were 0.5-mm nytex. The front panel was plexiglass and could be moved to within 41.9 cm of the intake.

Cages were removed from the flume and specimens were allowed to swim freely during tests in the dynamic mode (channel velocity > 0).

## Egg-Screen Interaction

Egg impingement studies were conducted in the large flume. Tests were designed to evaluate egg-screen interaction at various channel velocities. Approximately 300 preserved striped bass eggs, 2-3 mm in diameter, were released 3.05 m upstream of Screen S3A, operated at a mean intake velocity of 15.24 cm/s. Three tests of one trial each were run at channel velocities of 15.24, 22.86, and 38.10 cm/s. Egg-screen interactions were filmed and the percentage impinged noted. Screen S2A was exposed to 15,000 preserved eggs at an intake velocity of 15.24 cm/s to determine effect of various channel velocities (15.24-79.25 cm/s) on impingement. Changes in location and number of impinged eggs were monitored for each of the four velocities tested.

Table 1. Description of Screen[a] Configurations Tested

| Screen Designation | Description |
|---|---|
| M1A | Mushroom screen.[b] A 61.0-cm-diameter by 30.5-cm-long screened cylinder was attached to a 30.5-cm-diameter by 30.5-cm-long extension. A 1.0-mm slot width and 3.1-mm wire width yielded 25% open area (OA). Tested in air backwash studies. |
| S1A | Standard screen.[c] 30.5-cm diameter by 61.0-cm length; 1.0-mm slot, 3.1-mm wire (25% OA). Lower half of screen was taped to expose a 61.0-cm length of top half. Tested in early (1976) fish impingement studies. |
| S1B | Same screen as above with lower half covered and each end taped to expose only 50.8 cm of top half. Tested in larval and fish performance studies in 1977. |
| S1C | Same screen as above except full screen exposed. Tested in detrital clogging studies. |
| S2A | Standard screen. 30.5-cm diameter by 61.0-cm length; 1.0-mm slot, 1.5-mm wire (40% OA). Taped to expose total circumference, 53.3 cm in length. Tested primarily in detritial clogging and egg impingement studies. |
| S2B | Same screen as above but taped to expose only 48.3 cm of top half. Tested in larval performance studies. |
| S3A | Standard screen. 30.5-cm diameter by 61.0-cm length; 0.5-mm slot, 1.5-mm wire (25% OA). Tested in detrital clogging studies. |
| S4A | Standard screen. 30.5-cm diameter by 61.0-cm length; 0.25-mm slot, 1.5-mm wire (14.3% OA). Tested in detrital clogging studies. |
| I1A | Inverted screen.[d] 30.2-cm diameter by 61.0-cm length; 0.8-mm slot, 3.1-mm wire (23.6% OA). Taped to expose 30.5-cm-long full circumferential screening area. Tested in early (1976) fish impingement studies. |
| I1B | Same screen as above with total area exposed. Tested in early (1976) fish impingement studies. |
| P1A | Panel screen. 30.5 × 30.5 cm flat; 1.0-mm slot and 2.3-mm wire (30.8% OA). Tested in egg mortality studies. |
| P2A | Panel screen. 30.5 × 30.5 cm flat; 0.5-mm slot and 1.5-mm wire (25% OA). Tested in egg mortality studies. |

[a] All screens had solid endplates.

[b] A mushroom screen is a cylindrical screen with a non-slotted smaller-diameter neck to equalize intake velocity through all open areas of the screen.

[c] A standard screen is a cylinder constructed by winding a wedge-shaped wire around equally spaced support rods. The resultant slots are equally spaced along the cylinder, and widen inwardly. Water enters the slotted portion of the screen and discharges through the mouth.

[d] An inverted screen is an inside-out standard screen, i.e. external support rods and slot width increase outwardly. Water enters the open screen mouth and is discharged through the slotted portion of the cylinder (see Fig. 5).

The effectiveness of an air bubble curtain in reducing impingement was investigated at channel velocities of 15.24 and 60.96 cm/s. Compressed air was released through a 30.48-cm-long perforated nozzle at 0.70 kg/cm$^2$. The nozzle was positioned to allow the bubbles to strike the leading side of the screen.

Entrainment of striped bass eggs was also evaluated. Approximately 500 ml of preserved eggs (2-3 mm diameter) were dispersed in the large flume at a channel velocity of 30.5 cm/s. Intake was initiated through the 30.5-cm-diameter unscreened mounting orifice at 1.89 m$^3$/min for 10 min. Entrained eggs were collected with a 0.5-mm-mesh net mounted on the screen discharge pipe. The volume of entrained eggs was measured.

Screen S2A was installed and the procedure described above was repeated. In addition, eggs still free in the flume were removed and those impinged on the screen were recovered in an 81.3- x 152.4-cm, 0.5-mm-mesh net. The volume of impinged eggs was measured and used to determine the percentage impinged. Total number of eggs exposed per 10-min duration was calculated and the percentage entrained was determined.

Egg Mortality

Striped bass eggs were obtained from an on-site hatchery. All eggs were incubated in an antiseptic solution of 50,000 IU/L penicillin-G and 50 mg/L streptomycin sulfate. Fertilization took place 15 or more hours before testing. Eggs from a single brood were used in each test. Natural die-off rates were monitored with long-term controls held in an aerated antiseptic solution. Controls were held until tests of that brood were complete. The number of dead eggs in each control was recorded every 30 min. Each test consisted of a 30-, a 60-, and a 120-sec impingement trial with one replicate and one control for each duration. All eggs used in tests and controls were preserved for later examination.

Impingement trials and replicates proceeded in the following manner. Eggs were released at mid-depth into a 15.24-cm/s current 1.22 m upstream of the test screen. After impingement for the desired duration, the current was stopped and the eggs were siphoned from the screen into a gallon jar partially filled with antiseptic solution. Samples were inspected at 5, 20, 45, and 60 min for the first two tests; thereafter inspection was made at 5, 30, and 60 min. Samples were preserved after 60 min.

Trial controls were held in flume water for the appropriate time period, then siphoned into a holding jar filled with the antiseptic solution. Mortality was monitored for 60 min and the samples were preserved.

Preserved samples were examined with a stereo zoom dissecting scope. The smallest and largest eggs in each sample were measured to the nearest 0.1 mm. Developmental stage and live/dead ratios were determined. Eggs were termed dead if they contained abnormal or disintegrating embryonic material, an emulsified oil globule, or translucent perivitelline space.

Striped Bass Larvae

Swimming ability and avoidance behavior of striped bass larvae exposed to a functioning screen were studied in static mode. Larvae were obtained from the on-site hatchery. Two stocks of larvae, 4 and 5 days old, were held in separate 75-L aquaria and fed brine shrimp. Daily tests of each stock were made for 16 (4-day old) and 14 (5-day old) days.

Larvae in groups of 50 or less were acclimated to flume temperature for as long as 3 hr, and released into the standard screen test cage. After a 2-min acclimation to the cage, a preset intake velocity (3.96-15.24 cm/s) was initiated through Screen S2B. Swimming ability and behavior of larvae were noted until all were entrained. Specimens were recovered in a 0.5-mm-mesh net placed over the screen discharge pipe. Total lengths of the largest, smallest, and dead specimens were recorded.

After untested stocks were depleted, survivors of previous tests (20-21 days old) were transferred to a 1.89-m$^3$ tank supplied with unfiltered pond water. Since these fish were capable of prolonged resistance to entrainment, tests were terminated after 30 min exposure. After four tests, Screen S1B was substituted for Screen S2B for higher intake velocities. Impingement, entrainment, behavior, and swimming ability were noted. Also noted was fish-min--the sum of products of the number of fish and the time exposed to any event. Tests of larvae were discontinued when specimens reached 33 days of age (up to 17 mm FL). An additional 34 specimens obtained from hatchery holding facilities also were tested.

## Fish Impingement

Test specimens. Specimens were collected by seine from the Bohemia River, Chesapeake and Delaware Canal, Delaware River, and nearby freshwater ponds. Striped bass were also supplied by the on-site hatchery.

Initially, test specimens were transported and held in insulated, aerated containers. Subsequently, two 1.83- x 0.61- x 0.30-m plywood boxes were used as holding facilities. Flume water was continuously pumped through a sand filter into the holding boxes and drained through standpipes back to the flume. Some smaller test specimens (< 20 mm FL) were held in a 1.89-$m^3$ tank and a 1.61-$m^3$ swimming pool. These facilities were supplied with water from a nearby hatchery rearing pond. Except for striped bass, specimens were not fed prior to testing.

Specimens acquired from brackish waters were acclimated (4-16 hr depending on salinity) to flume water in insulated, aerated containers prior to testing. Flume salinity was raised to 4 ppt during the summer of 1977 to minimize holding and acclimation mortality. This enabled weaker and more sensitive species as well as migrant marine fishes to be tested with minimal osmotic stress. Flume water was treated periodically with copper sulfate (1 ppm) as a disease preventative.

Experimental procedure - static mode. Early experiments (1976) in the static mode (zero flume current) were conducted with standard and inverted screens (Fig. 4). Water depth was maintained at 0.76 m. Specimens were placed in the test cage and allowed to acclimate for 5-20 min; weak or damaged individuals were replaced. The pump was started at a preset rate and the effects of the intake were noted. Intake velocity was increased approximately 6.1 cm/s at 10-min intervals until the maximum rate was reached. Starting intake velocity ranged between 0 and 39.6 cm/s. Fish were continually monitored for behavior, impingement, and entrainment. Upon termination of a test, all specimens except striped bass were measured; dead and injured specimens were counted. Only the smallest and largest of the uninjured striped bass were measured.

Only standard screens were tested in 1977. Water depth was maintained at 0.89 m. Test specimens held in flume water were allowed to adjust to the cage for 10 min before testing; fish held in other facilities were acclimated for as long as 60 min. The pump was started at a preset rate and run for 30 min. Intake velocities of 15.24, 30.48, and 45.72 cm/s were tested. Specimens were continuously monitored for impingement and behavior. All specimens were measured after testing.

Far-field effects of the screen were investigated by increasing the size of the test area to 1.83 m of flume channel centered around Screen S4A. Intake velocity was maintained at 30.48 cm/s for 10 min, then increased to 38.1 cm/s for 15 min. After 25 min, partitions were removed and fish were allowed to swim freely about the flume for 13 min. A 30.48-cm/s channel current was then initiated and maintained for 20 min. Velocity was increased to 41.15 cm/s for an additional 8 min before the test was terminated.

Tests were documented with 35-mm still or 16-mm motion pictures.

Experimental procedure - dynamic mode. Both the inverted and standard screens were tested in dynamic mode (current in the flume) during 1976. Water depth was maintained at 1.02 m. Fish were acclimated for 15-25 min in a water-filled plastic bag suspended in the channel 3.05 m upstream of the screen. Current of the desired velocity was generated in the flume and the intake pump was started. Specimens were released and their behavior noted, especially on the first pass by the screen. Flume velocity was increased at 10-min intervals until maximum velocity (0.80 m/s) was reached; intake velocity was constant. After 10-min at maximum velocity, current in the flume was reduced to zero. Fish were exposed to the functioning intake for an additional 5 min. The far-field effect experiment described earlier was the only test conducted in the dynamic mode during 1977.

The susceptibility of each species to a functioning screen was determined by the formula

$$SI = \frac{IO-ES}{IO} + 1 \quad \frac{FM}{TFM} \tag{1}$$

where SI is the susceptibility index, IO is the number of impingement (standard) or entrapment (inverted) occurrences, ES is the number of escapes, FM is fish-min impinged or entrapped, and TFM is total fish-min exposed. The index ranges from 0 to 2 and is sensitive to differences in behavior and swimming ability.

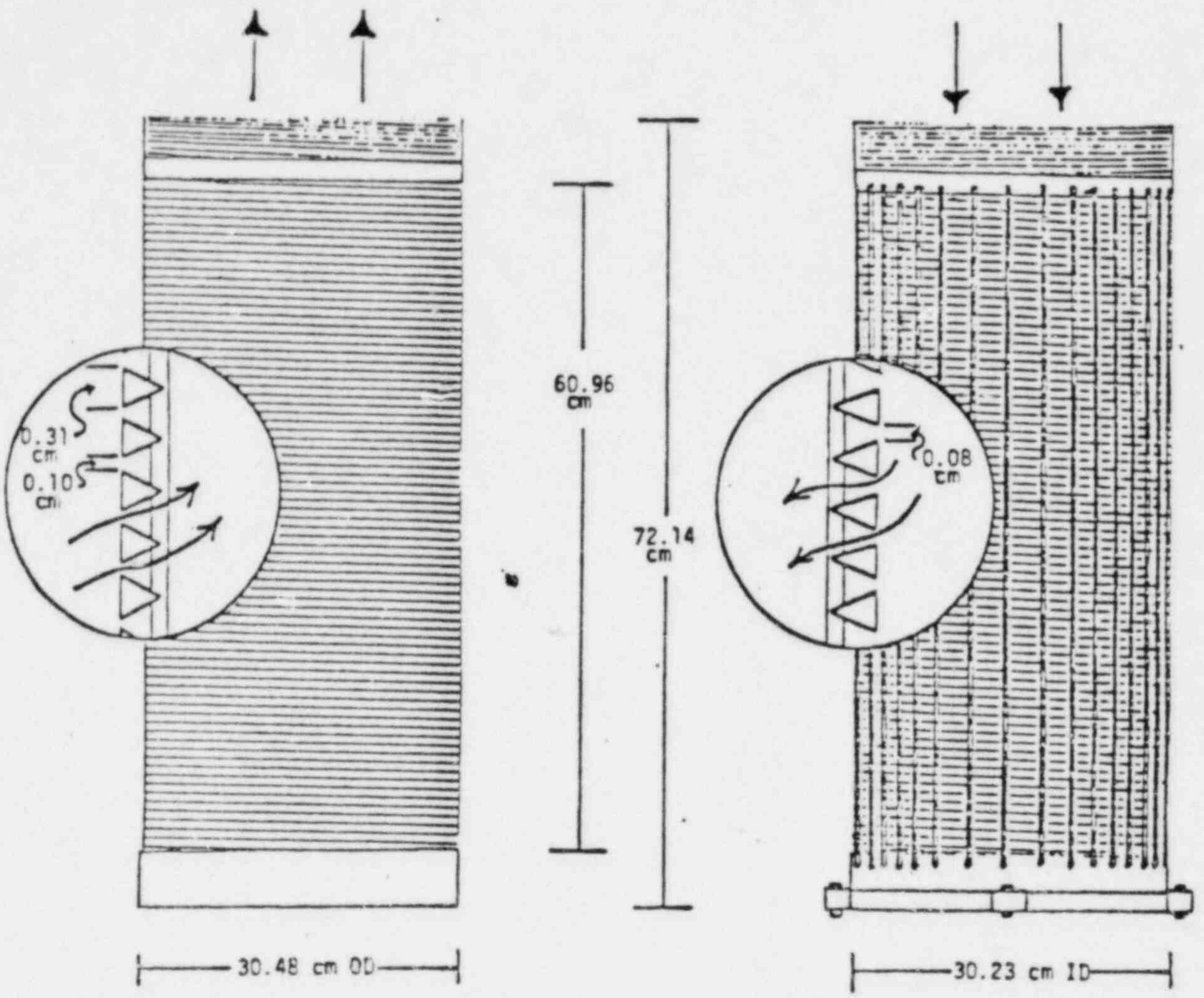

Fig. 4. Comparison of Structure and Flow Pattern for the Standard and Inverted Screens. Measurements are in centimeters.

Detrital Fouling

Detrital fouling of standard screens was studied in the large flume. The effects and interrelationships of flume current, intake velocity, detrital load, and screen slot size were examined. Effectiveness of hydraulic backwash, compressed air backwash, and continuous cleaning with air bubbles was also investigated. The concentrations of detritus tested were much higher than the normal Canal concentration (approximately 9.46 $cm^3/m^3$). The four types of detrital material used were peat moss (at 77.39 times the normal concentration), material removed from traveling screens at the Salem Nuclear Generating Station (at 38.70-77.39 times normal), detritus from Chesapeake and Delaware Canal ichthyoplankton samples (at 6.22-22.11 times normal), and detritus collected in a nearby tidal creek (at 11.06-77.39 times normal). The tidal creek detritus was denoted as Canal I. Detritus was renewed periodically because particle size was eventually reduced by pump and cleaning activities.

Tests were run at flume levels of 0.78-0.89 m. Flume volume was generally held constant for each series of experiments. The effects of intake velocity (6.10, 7.62, 12.19, and 15.24 cm/s), channel velocity (7.62-60.96 cm/s), and detrital load (1.06-13.25 L) on screen performance were evaluated.

A selected wet volume of detrital material was introduced and dispersed in the flume before testing started. Channel current was set and maintained at a predetermined velocity. The screen was backwashed and/or brushed clean immediately prior to test initiation. Time-to-clog (TTC), head differential versus time, and visual observations were recorded for each run. Screens were considered clogged at a differential head of 30.48 cm. Tests were usually terminated in 4 hr if substantial head was not generated. An additional 0.47 L of detritus was added 10 min after startup if the volume of detritus required to clog the screen equaled a substantial part of the test load.

Hydraulic backwash was often used to clean the screen. A 2.31-$m^3$/min pump supplied a reverse flow of 1.89 $m^3$/min through the test screen. Although not strictly documented, backwash efficiency was observed and noted.

An air bubble curtain identical to that used in egg impingement studies was evaluated fouling reduction. The nozzle was placed so that bubbles swept the leading surface of the screen. Time-to-clog and other observations were compared to tests conducted under similar conditions but without the bubbler.

Air/Hydraulic Backwash

Cleaning effectiveness of air/hydraulic backwash was investigated on Screens M1A and S1C. Each test consisted of determination of TTC after thorough manual cleaning and after air/hydraulic backwash. Manual cleaning with a stiff bristle push broom was considered the basic cleaning technique. Compressed air was accumulated in a 0.06-$m^3$ vessel equipped with a 10.2-cm butterfly valve. Backwashing was accomplished by closing the 30.48-cm intake butterfly valve and instantaneously releasing air into the screen through a 1.83-m length of 10.2-cm PVC pipe.

## RESULTS AND DISCUSSION

### DYNAMICS

The initial phase of the study consisted of refining the experimental apparatus and determining the hydrodynamic characteristics of the test screens. The flow characteristics of a profile-wire screen result from its shape and construction. This type of screen is fabricated by helically winding and welding V-shaped profile wire to evenly spaced support rods. This construction results in a smooth external surface with a continuous slot which enlarges inwardly. The physical separation between the center plane of the support rods and wire wrap results in an increased effective open area at low intake velocity (Lee Cook, Johnson Division, UOP, Inc., personal communication). Screen length should be no more than twice the diameter. Two dimensional analogs for a 30.5- x 61.0-cm screen indicate that intake velocity at the proximal slots may be as much as 32 times the calculated mean for this screen (Paul Fournier, Johnson Division, UOP, Inc., personal communication). A more uniform flow distribution can be obtained by reducing the length-to-diameter ratio or by reducing the diameter of the screen discharge pipe and extending it some distance into the screen.

The angle and velocity of approach should decrease from the proximal end of the cylindrical screen (that portion attached to the sump-flume common wall) to the distal end (the unattached end) (Fig. 5). Current measurement and behavior of test specimens confirmed this. Measured approach velocity was always less than calculated intake velocity (Table 2). Actual intake velocity could not be measured for comparison with calculated values since the available current meters could not operate at the screen surface. Theoretically, approach velocity at one wire width from the screen surface is equal to the product of intake velocity and open area to total surface area ratio. Approach velocity, then, decreases as a function of the square of the radius. Approach velocity measured 7.62 cm from the screen surface at a pump rate of 1.70 $m^3$/min was 7.62 (distal), 8.53 (midpoint), and 10.36 cm/s (proximal). The calculated mean intake velocity for this pump rate was 46.94 cm/s. Higher approach velocity at the proximal end was verified by egg and detrital impingement patterns.

Visual observation in the dynamic mode indicated that screen influence was restricted to that portion of the water column which would have passed through or within 5 cm of the screen. Impingement or entrainment of small suspended particles was most common along the leading edge of the screen. This was caused by channel current and was enhanced by pumping rate. Particles which approached the screen more obliquely were generally deflected by a boundary current. Deflection was augmented by the cylindrical shape of the screen. The buildup of impinged material was greatest on the proximal third of the upstream edge where intake velocity was highest. Material impinged elsewhere on the screen was not held as tightly and tended to move to the downstream side. Eddy and channel currents in this area produced a washing effect which increased with channel velocity.

Dimensions of the inverted screen have a pronounced effect upon approach velocity within the screen. If the ratio of open area to the cross-sectional area exceeds 1, a field of deceleration theoretically exists, with velocity lowest at the screen surface and greatest at the mouth. If the ratio is 1, velocity is constant within the screen; if the ratio is less than 1, the relationship between approach and intake velocity is similar to that of the standard screen. Measurements taken at 7.62 cm from the screen surface at a calculated intake velocity of 23.16 cm/s showed a velocity gradient from 5.49 cm/s at the sump wall to 18.29 cm/s at the distal end of the screen.

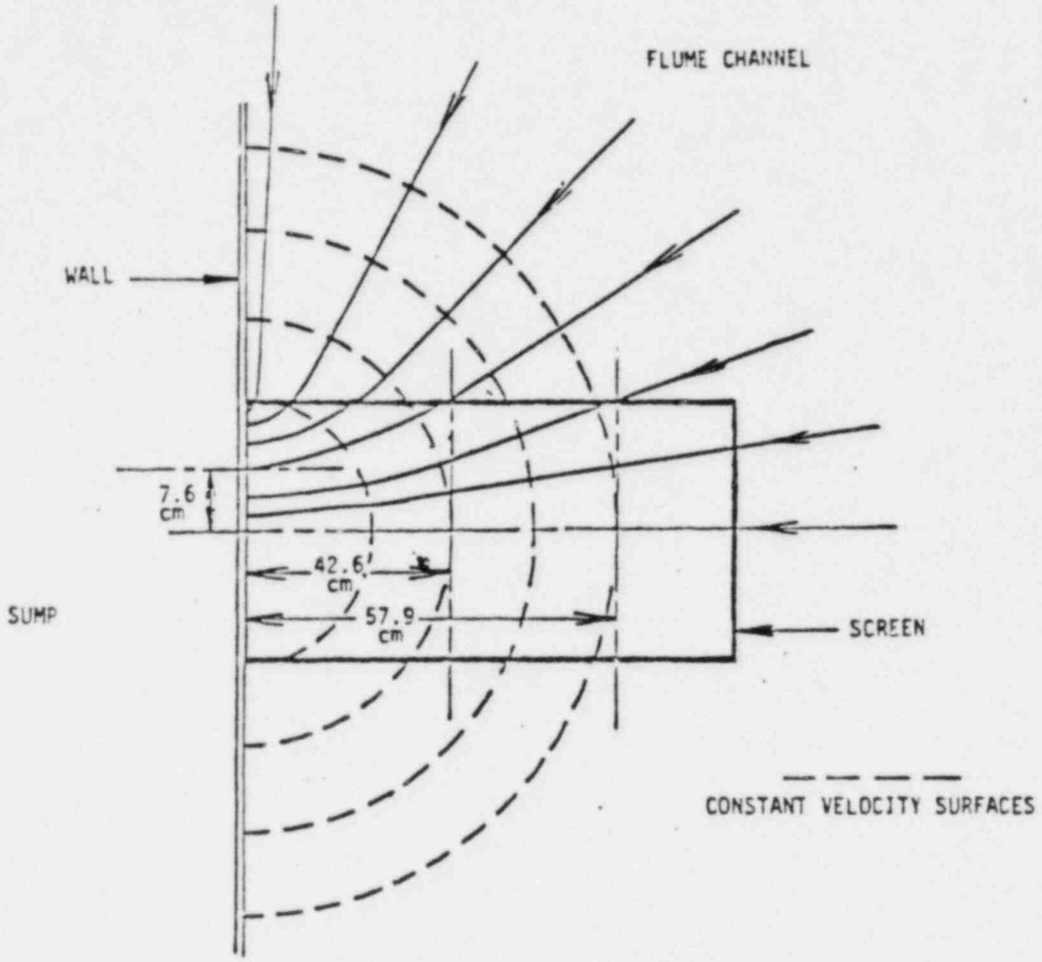

Fig. 5. Schematic Diagram of Flow Patterns Associated with the Standard Screen. Provided by Lee Cook, Johnson Division, UOP Inc. Measurements are in centimeters.

Table 2. Empirically Determined Velocities of Screen S1B

| Pump Rate ($m^3$/min) | Calculated Mean Intake Velocity (cm/s) | Measured Velocity (cm/s) | | |
|---|---|---|---|---|
| | | Proximal Zone[a] | Midpoint Zone[a] | Distal Zone[a] |
| | | Measured 5.08 cm Inside Surface | | |
| 1.21 | 33.22 | 19.81 | - | 12.19 |
| 1.51 | 41.76 | 17.98 | - | 13.72 |
| 1.59 | 43.89 | 18.90 | - | 14.63 |
| 1.74 | 48.16 | 19.81 | - | 14.94 |
| 1.89 | 52.12 | 24.38 | 14.93 | 15.24 |
| | | Measured 7.62 cm Outside Surface | | |
| 0.57 | 15.54 | 3.96 | 3.35 | 2.74 |
| 1.14 | 31.39 | 7.32 | 6.40 | 5.79 |
| 1.70 | 49.94 | 10.36 | 8.53 | 7.62 |

[a] The proximal zone extends from the portion of the screen attached to the sump-flume common wall to the midpoint zone; the distal zone extends from the unattached end of the screen to the midpoint zone.

Observation of the inverted screen in the dynamic mode indicated a small zone of influence adjacent to the screen mouth. Deflection of suspended material began at the upstream edge of the orifice but was negligible more than 15 cm off or 6 cm above or below it. Turbulence generated by the inertia of water entering the screen kept most entrapped material suspended, and prevented long-term impingement. The degree of turbulence was directly related to flume velocity and was severe as long as any water passed through the screen.

The dynamics of the mushroom-shaped screen were not fully investigated. Assumed velocity surfaces and vectors are presented in Figure 6. Observations during detrital runs indicated that the velocity field along the screen surface was fairly uniform. Unlike the standard screen, impingement of material in the dynamic mode was even across the length of the leading edge.

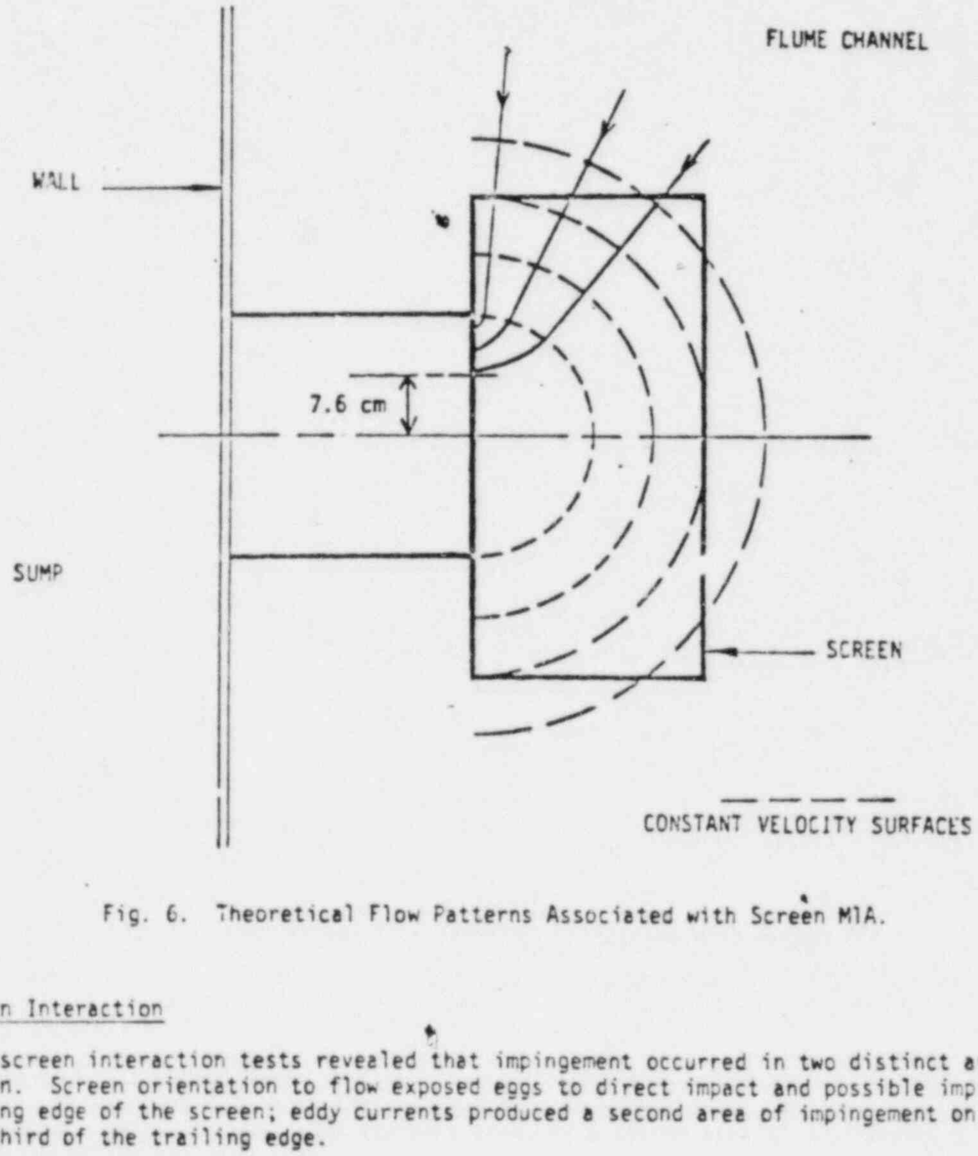

Fig. 6. Theoretical Flow Patterns Associated with Screen M1A.

Egg-Screen Interaction

Egg-screen interaction tests revealed that impingement occurred in two distinct areas on the screen. Screen orientation to flow exposed eggs to direct impact and possible impingement on the leading edge of the screen; eddy currents produced a second area of impingement on the proximal one-third of the trailing edge.

Impingement on the leading edge was a function of channel velocity but was self-limiting above 61.0 cm/s. At velocities greater than 61.0 cm/s, all available surface area was rapidly occupied; thereafter, a slow rate of interchange, approximately 1% per min, accounted for all new impingement. A very low percentage of the eggs exposed was impinged on the leading edge. This was the only portion of the screen where entrainment and wedging in the slots occurred. Entrainment and wedging in slots apparently were caused by pressure generated by channel velocity rather than intake current.

Impingement on the trailing edge was maximum when channel velocity was equal to or less than intake velocity. Eggs in this area were loosely held as evidenced by their movement on the screen surface. As much as 20% of the passing eggs struck the leading edge, but most (95%)

quickly rolled over the screen and accumulated in the proximal portion of the trailing edge. At higher channel velocities only a few eggs were present in this area. Entrainment or wedging in the slots was never observed in this region.

Incorporation of a bubble curtain effectively reduced egg impingement. Eggs did not impinge on areas of the screen struck by the bubbles. The bubble curtain also removed previously impinged eggs. Entrained bubbles were vented in the sump. Results indicated that impingement of eggs can be virtually eliminated by a bubble curtain.

Entrainment was associated primarily with the upstream side of the screen. Less than 0.1% of the exposed eggs were entrained in 2 hr of testing. In tests run without the screen, 40% were entrained through the 30.48-cm mounting orifice during each of two 10-min trials. Only 1% were entrained and 11% impinged during two similar trials with the screen in place (a 97.5% reduction in entrainment).

Impingement and entrainment could also have been reduced or eliminated by reorienting the screen so the slots were perpendicular to the current. This orientation would eliminate hydraulic problems associated with the leading and trailing edges and should, due to inertia, increase filtration efficiency for particles smaller than the slot size.

## Egg Mortality

Twenty-six tests were conducted with 6945 striped bass eggs of six different stocks. Eggs were 18-38 hr old and 1.8-3.2 mm in diameter (after preservation). Developmental stages (Kernehan et al. 1977) tested were late-gastrula (LG), early-embryo (EE), tailbud-free (TBF), and fully-developed-embryo (FDE). Mean mortalities of tests and controls at three different impingement durations are summarized in Table 3 and Figure 7. Statistical analyses for differences in percent mortality (student's t-test after arcsine transformation; Sokal and Rohlf 1969) yielded significant ($P \leq 0.05$) differences between test and control for 30-sec impingement duration (stages combined), LG-EE stages (durations combined), and all data combined. In general, LG-EE eggs suffered greater mortality than other stages in both tests and controls (Fig. 8). The high mortality for the earliest stages tested may reflect greater fragility.

Mortality due to impingement (test-control difference) ranged from 0% to 11.9%. Mean mortality of developmental stages versus impingement duration ranged from 0% to 2.0%. Overall, mean mortality due to impingement was 1.4% (Table 3).

Table 3. Summary of Striped Bass Egg Mortality Due to Impingement on Screen P2A (15.24-cm/s approach velocity)

| Devel. Stage[a] | 30-sec | | | 60-sec | | | 120-sec | | | Long-term Control[b] | Totals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test | Control | Diff. | Test | Control | Diff. | Test | Control | Diff. | | Test | Control[c] | Diff. | All |
| LG-EE | | | | | | | | | | | | | | |
| Trials | 12 | 6 | - | 12 | 6 | - | 12 | 6 | - | 4 | 36 | 18 | - | 58 |
| Dead n | 54 | 22 | - | 40 | 17 | - | 29 | 16 | - | 24 | 123 | 55 | - | 202 |
| % dead | 6.6 | 4.6 | 2.0 | 5.2 | 3.4 | 1.8 | 4.3 | 3.7 | 0.6 | 0.6 | 5.5 | 3.9 | 1.6 | 5.1 |
| Total n | 813 | 478 | - | 763 | 498 | - | 669 | 431 | - | 296 | 2245 | 1407 | - | 3948 |
| TBF | | | | | | | | | | | | | | |
| Trials | 2 | 1 | - | 2 | 1 | - | 2 | 1 | - | 1 | 6 | 3 | - | 10 |
| Dead n | 2 | 0 | - | 0 | 0 | - | 0 | 0 | - | 0 | 2 | 0 | - | 2 |
| % dead | 1.1 | 0.0 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.5 | 0.3 |
| Total n | 188 | 76 | - | 131 | 88 | - | 116 | 62 | - | 118 | 435 | 226 | - | 779 |
| FDE | | | | | | | | | | | | | | |
| Trials | 4 | 2 | - | 3 | 2 | - | 2 | 1 | - | 2 | 9 | 5 | - | 16 |
| Dead n | 2 | 1 | - | 2 | 0 | - | 0 | 0 | - | 3 | 4 | 1 | - | 8 |
| % dead | 0.7 | 0.3 | 0.4 | 0.8 | 0.0 | 0.8 | 0.0 | 0.0 | 0.0 | 0.1 | 0.5 | 0.1 | 0.4 | 0.4 |
| Total n | 283 | 376 | - | 254 | 127 | - | 225 | 302 | - | 651 | 762 | 805 | - | 2218 |
| Totals | | | | | | | | | | | | | | |
| Trials | 18 | 9 | - | 17 | 9 | - | 16 | 8 | - | 7 | 51 | 26 | - | 84 |
| Dead n | 58 | 23 | - | 42 | 17 | - | 29 | 16 | - | 27 | 129 | 56 | - | 212 |
| % dead | 4.5 | 2.5 | 2.0 | 3.7 | 2.4 | 1.3 | 2.9 | 2.0 | 0.9 | 0.1 | 3.7 | 2.3 | 1.4 | 3.1 |
| Total n | 1284 | 930 | - | 1148 | 713 | - | 1010 | 795 | - | 1065 | 3442 | 2438 | - | 6945 |

[a]

| Developmental Stage | Age (hr) | Diameter (mm) | Temperature (°C) |
|---|---|---|---|
| Late gastrula-early embryo (LG-EE) | 18.0-31.0 | 1.8-3.2 | 15.5-22.0 |
| Tailbud-free (TBF) | 21.5-22.0 | 2.1-2.4 | 22.0 |
| Fully developed embryo (FDE) | 36.0-38.0 | 2.0-2.7 | 20.5-21.0 |
| Total | 18.0-38.0 | 1.8-3.2 | 15.5-22.0 |

[b] These eggs were held from 2.0 to 6.5 hr. Percentages are on a per-hour basis for comparison.

[c] Does not include long-term controls.

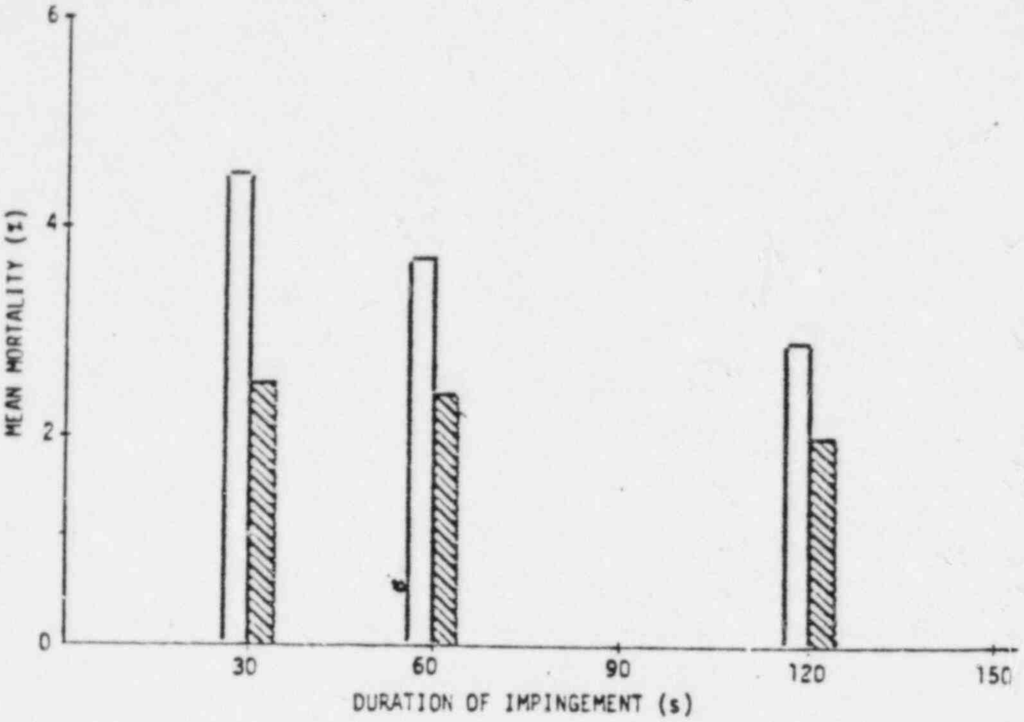

Fig. 7. Mortality of Striped Bass Eggs Due to Impingement on Screen P2A at an Approach Velocity of 15.24 cm/s. Cross-hatched bars indicate controls.

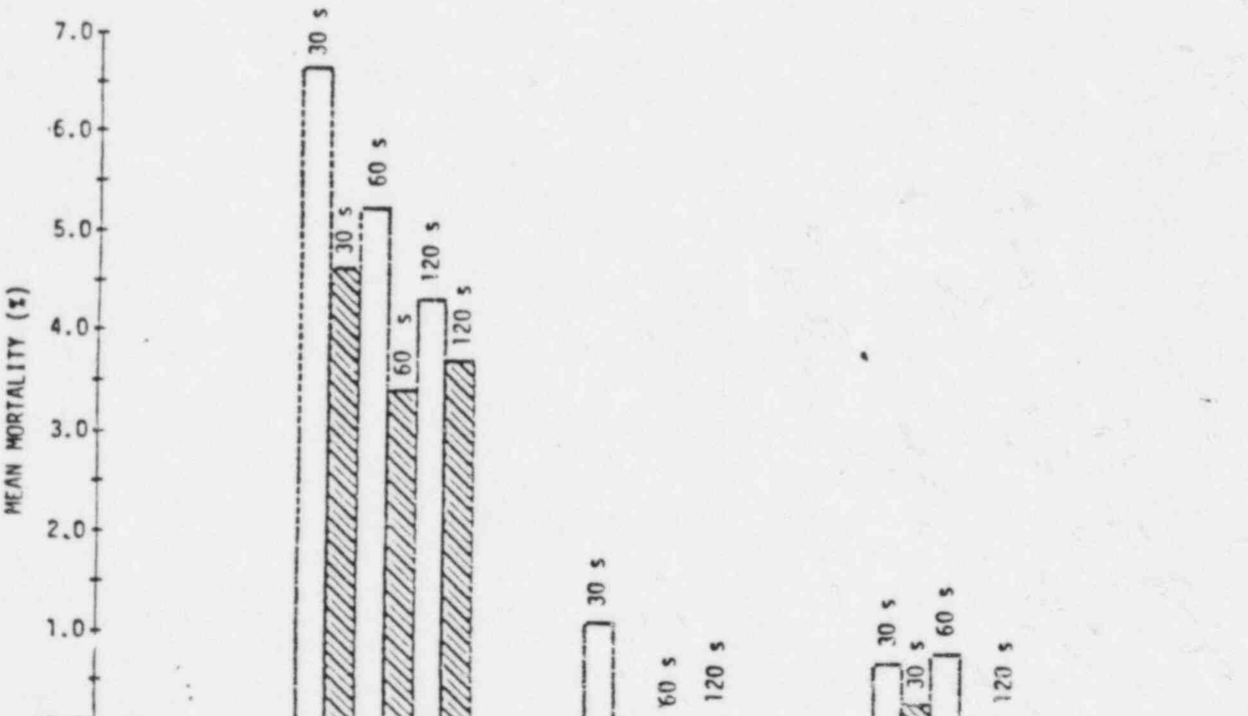

Fig. 8. Mortality of Various Developmental Stages of Striped Bass Eggs Due to Impingement on Screen P2A at an Approach Velocity of 15.24 cm/s. Cross-hatched bars indicate controls.

The low mortality of long-term controls was probably due to reduced handling stress. Visual inspection of eggs during the 60-min post-impingement holding time revealed that most mortality occurred in the first 30 min.

Skinner (1974) reported that mortality of striped bass eggs impinged on 1.6-mm-mesh screen was usually less than 20% at approach velocities less than 27.43 cm/s and less than 30% at 30.48 cm/s; at an approach velocity of 15.24 cm/s, mortality was approximately 8% and 12% at 1 and 2 min, respectively. Comparable mean mortality in this study was 3.7% and 2.9% for 1- and 2-min impingement durations. The differences between studies are probably due to differences in screen construction, slot size (1.6 mm vs. 0.51 mm), procedure, egg stage, or egg origin (wild vs. hatchery-reared in this study).

### Striped Bass Larvae

Fortythree tests were conducted with more than 1,000 hatchery-reared striped bass larvae. Larvae 4-32 days old (5.2-17.0 mm FL) were exposed to mean intake velocities of 3.96-45.72 cm/s at temperatures of 13-24°C.

During one set of experiments, more than 930 larvae (aquaria-held) from age 4 to 20 days (5.2-9.2 mm TL) were tested at mean intake velocities of 3.96-15.24 cm/s and temperatures of 13-19°C (Table 4). Ability to resist entrainment was rated subjectively on a group and individual basis. Performance was rated on general swimming ability, resistance to impingement and entrainment, and burst ability, and then was compared to performance on the previous day.

Table 4. Performance of Hatchery-reared Striped Bass Larvae Exposed to Screen S2B

| n | TL (mm) | Age (days) | $\bar{x}$ Intake Velocity (cm/s) | Estimated % Entrained In First Min | Minutes to 100% Entrained | Relative Resistance to Intake[a] | |
|---|---|---|---|---|---|---|---|
| | | | | | | Group | Individual[b] |
| 50 | 5.2 | 4 | 6.10, 23.77 | 85 | 1.43 | P | F |
| 50 | 6.0-6.5 | 5 | 6.10 | 85 | 1.33 | P | F |
| 50 | 6.0-6.5 | 5 | 8.53 | 100 | 0.75 | P | P |
| 50 | 6.0-6.5 | 5 | 3.96 | 80 | 1.25 | P | F |
| 20 | 5.5-6.3 | 5 | 10.67 | 30 | 3.00 | P | F |
| 50 | 6.3-6.9 | 6 | 10.67 | 80 | 5.00 | F | G |
| 50 | 5.9-6.1 | 6 | 10.67 | 75 | 5.00 | P | P |
| 50 | 5.9-6.1 | 7 | 10.67 | 95 | 1.50 | P | P |
| 25 | 6.3-6.4 | 7 | 10.67 | 75 | 5.00 | P | G |
| 50 | 6.4 | 8 | 10.67 | 75 | 20.00 | F | F |
| 50 | 6.0-6.3 | 8 | 10.67 | 75 | 2.00 | F | F |
| 50 | 6.0-6.2 | 9 | 10.67 | 75 | 10.00 | F | F |
| 25 | 5.4-6.0 | 9 | 10.67 | 90 | 3.00 | P | G |
| 50 | 6.0-6.4 | 10 | 10.67 | 95 | 2.00 | P | G |
| 25 | 5.3-6.3 | 10 | 10.67 | 25 | 3.00 | G | G |
| 25 | 6.2-6.4 | 11 | 10.67 | 60 | 5.00 | F | G |
| 25 | 6.0-6.6 | 11 | 10.67 | 75 | 9.00 | F | G |
| 25 | - | 12 | 10.67 | 75 | 2.00 | F | G |
| 20 | 6.2-6.8 | 12 | 10.67 | 90 | 5.00 | F | F |
| 20 | 6.0-7.3 | 13 | 10.67 | 85 | 10.00 | F | F |
| 20 | 6.0-7.0 | 13 | 10.67 | 80 | 2.50 | F | G |
| 15 | 6.4-7.0 | 14 | 10.67 | 75 | 2.00 | F | G |
| 25 | 7.0-7.9 | 14 | 15.24 | 90 | 1.50 | F | G |
| 35 | 6.5-7.3 | 15 | 10.67 | 50 | 15.00 | G | E |
| 15 | 7.0-7.9 | 15 | 15.24 | 80 | 10.00 | F | F |
| 10 | 6.5-7.3 | 16 | 15.24 | 50 | 3.00 | F | F |
| 9 | 6.3-7.9 | 17 | 15.24 | 50 | 2.00 | F | G |
| 10 | 8.0-9.0 | 18 | 15.24 | 100 | 1.00 | P | F |
| 10 | 6.7-7.4 | 19 | 15.24 | 100 | 1.00 | P | F |
| 15 | 7.8-9.2 | 19 | 15.24 | 35 | 22.00 | G | E |
| 10 | 7.8-8.8 | 20 | 15.24 | 40 | 12.00 | G | E |

[a] P = poor, F = fair, G = good, E = excellent.

[b] Rating of 10% of total.

Avoidance behavior was observed in all experiments. Although most specimens were entrained within 1 min, many exhibited positive rheotaxis and actively resisted entrainment upon contact with the screen; those which did not touch the screen were entrained more or less passively. Most of the larvae were entrained in the proximal half of the screen where intake velocity was greatest. The percentage which actively resisted entrainment increased with age, but all still were entrained. Mean intake velocity was increased to 15.24 cm/s after 11 days in response to improved swimming ability; results were similar to tests at 10.67 cm/s (Table 4).

The extent of escape due to a washing current or movement away from the screen could not be ascertained since all tests were conducted in static mode with a test cage. However, a burst of swimming activity after contact with the screen should greatly decrease the potential to impinge or entrain when a current is present.

Tests were originally designed to monitor the increase in avoidance capability as larvae increased in age and size. However, by test day 10, the performance of the aquaria-held larvae was more or less constant and stunting was suspected. Comparison to specimens of the same age which were fed natural food and held in larger tanks or rearing ponds revealed substantial differences in size and swimming ability. Mansueti (1958) noted that stunting may be due to factors such as overcrowding, lack of proper nutrients, variable effects of metabolites in the aquaria, and hormonal imbalances due to an artificial environment. There was rapid increase in growth rate and swimming ability after aquaria-held larvae were transferred to larger hatchery tanks supplied with natural food.

Larvae (100) reared on a diet of natural food were tested at mean intake velocities of 15.24-45.72 cm/s (Table 5). Ages and total lengths ranged from 10 to 32 days and 8 to 17 mm. Water temperature was 19-24°C. Many of these specimens were survivors of earlier tests. Their larger size and greater swimming ability permitted testing at higher intake velocities; impingements were frequent but usually temporary. The oldest specimens tested (13-17 mm FL) were easily able to resist intake velocities as high as 45.72 cm/s. Most temporary impingements occurred near the top of the screen where intake currents were vertical.

Table 5. Performance of Hatchery-reared Striped Bass Larvae Exposed to Screens S1B and S2B

| n | TL (mm) | Age (days) | $\bar{x}$ Intake Velocity (cm/s) | Estimated % Entrained In First Min | Percent Entrained | Impingement Occurrences | Escapes | Fish-min | Relative Resistance to Intake[a] Group | Relative Resistance to Intake[a] Individual[b] |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 8.0-10.0 | 10-14 | 15.24 | 0 | 100[c] | 3 | 3 | 0.03 | - | E |
| 10 | 9.8-10.9 | 18 | 15.24 | 0 | 30 | 3 | 0 | 24.90 | G | E |
| 10 | 8.6-11.2 | 18 | 30.48 | 30 | 50 | 10 | 7 | 107.89 | P | G |
| 10 | 8.3-12.4 | 19 | 30.48 | 0 | 10 | 11 | [illegible] | 160.14 | P | E |
| 2 | 13.0-16.4 | 19-23 | 15.24[d] | 0 | 0 | 6 | 4 | 53.54 | - | G |
| 7 | 10.3-1[illegible] | 24 | 15.24[d] | 0 | 43 | 3 | 3 | 0.67 | G | G |
| 7 | 8.3-12.1 | 26 | 15.24[d] | 0 | 0 | 0 | 0 | - | E | E |
| 11 | 8.4-13.6 | 29 | 15.24[d] | 0 | 18 | 1 | 0 | 29.25 | G | E |
| 11 | 9.8-14.5 | 30 | 30.48 | 0 | 9 | 20 | 20 | 0.26 | G | E |
| 11 | 12.5-16.1 | 30 | 45.72 | 0 | 0 | 24 | 22 | 45.95 | G | G |
| 10 | 13.0-17.0 | 32 | 30.48 | 0 | 0 | 4 | 4 | 0.07 | E | E |
| 10 | 13.0-17.0 | 32 | 45.72 | 0 | 0 | 8 | 8 | 0.07 | E | E |

[a] P = poor; F = fair; G = good; E = excellent.

[b] Rated 10% of total.

[c] Entrained in 25 min.

[d] Tests using Screen S2B.

There were 93 impingements, 75 escapes, and 16 entrainments (Table 5). Mortality due to impingement was not investigated. Most prolonged impingements entered the screen tail-first and were held by their opercles; the damage incurred was probably fatal. Avoidance (no entrainment or prolonged impingement) ranged from 40% to 100% for 30-min tests. In tests with intake currents of 30.48-45.72 cm/s, 92.9% of the larvae (9.8-17.0 mm FL) swam for 30 min without entrainment or prolonged impingement.

Sazaki et al. (1972) found 5% of striped bass larvae less than 5 mm were able to swim against a current of 6.1 cm/s (not impinge indefinitely) for 2 min. None of the 5.1-7.5 mm larvae could swim against a 12.19-cm/s current for 4 min. Skinner (1974) reported that 90% of 12-15 mm striped bass larvae could swim in a 6.10-cm/s current for 4 min.

Results in this study exhibit similar trends for larvae less than 10 mm. Swimming success (no entrainment or permanent impingement) for larger larvae (8.3-13.6 mm TL) ranged from 57% to 100% for 30-min tests. Nearly 93% of the larvae (9.8-17.0 mm FL) swam for 30 min against a 30.48-45.72 cm/s intake velocity without entrainment or prolonged impingement.

## Fish Impingement

In total, 1780 fish of 21 species were exposed to standard and inverted screens at mean intake velocities as high as 45.70 and 46.63 cm/s, respectively. Only the smallest or weakest specimens tested were instantly overpowered by the maximum velocities. The maximum approach velocity for the inverted screen was 44.50 cm/s; this value is a function of mouth size and pumping rate (1.91 $m^3$/min). Most experiments were conducted in static mode. This represents the worst operating condition for the standard screen because of the constant exposure and absence of washing current to decrease entrainment and impingement. The inverted screen performed poorly in both static and dynamic mode. Water temperature ranged from 3.0 to 27.0°C during the tests.

Intake velocity, fish size, behavior, and screen type were the major factors which influenced the rate of screen interaction. The effect of low temperature on fish-screen interaction was not investigated. Bibko et al. (1974) noted that long-term swimming endurance decreased with decreasing temperature. The 70 striped bass (105-151 mm FL) tested at temperatures less than 10°C displayed no sign of stress or reduced performance.

Frequency of impingement varied between species and in some cases seemed to be more a function of behavior than of swimming ability. Mummichog and banded killifish occasionally appeared to intentionally lie on the screen surface. Some species appeared to "play" with the functioning screen, while others exhibited feeding behavior on and around it. A direct relationship between intake velocity and impingement was assumed but was not always evident.

In total, 1318 specimens of 19 species were tested in static mode with Screens S1A and S1B. Only 20% of the 260 impinged fishes failed to escape. The majority of screen interactions occurred at an intake velocity in excess of 30.48 cm/s or after more than 10 min of exposure. Both values exceed the intake velocity (15.24 cm/s) and exposure time (1 min) for a well-designed intake.

Most of the 34 test mortalities (22 in 1976 and 12 in 1977) resulted from prolonged impingement of weaker or more sensitive species. Handling and osmotic stress were probably the most important factors causing mortalities, since most were in poor condition before testing. Pre-test stress and mortality were greatly reduced after handling techniques were refined and flume salinity was increased to 4 ppt in 1977. Although impingement-induced mortality should be investigated, it is expected to be minimal for fishes larger than 20 mm FL. Specimens impinged for long durations sustained little or no visible physical damage. The only instances of screen-induced injury occurred among striped bass larvae which entered the slot to the level of the opercles.

Sixty-nine specimens of seven species were tested in dynamic mode with Screens S1C and S4A. Channel and mean intake velocity ranged from 0 to 60.96 cm/s and 12.50 to 38.10 cm/s, respectively. The total duration of the three observed impingements was 0.07 min. Results and observation indicate that impingement durations of longer than 5 seconds are unlikely.

The inverted screen was substantially less effective in preventing impingement than was the standard screen. A total 313 specimens of eight species were tested in static mode. Of the 191 entrapments, 88 were impinged for a total of 2498.02 min. The trap-like nature of the screen resulted in only 16 escapes, and produced 54 mortalities.

Poor performance of the inverted screen was further exemplified in dynamic mode. Eighty specimens of five species were tested; 26 entrapments resulted in 20 mortalities and only six escapes. The extreme turbulence within the screen disoriented entrapped specimens and resulted in multiple impingements and extreme physical abuse. Studies of this screen were discontinued in 1976.

Details of the individual species tests are contained in the Appendix.

## Detrital Fouling

The detrital clogging characteristics of profile-wire screens were determined from 102 tests in the large flume. Intake and channel velocity ranged from 6.10 to 15.24 cm/s and 7.62 to 60.96 cm/s, respectively. Results indicate type and concentration of detritus, slot size, open area ratio, intake velocity, and channel velocity all affect the time required to clog the screen. The importance and interrelationship of these factors vary with operating conditions and screening objectives.

Screen clogging patterns were similar in all tests. The leading or upstream side of the screen impinged a 7- to 10-cm band of detritus along the length of the screen because of channel current. As the test progressed, detritus built up and the band spread in the proximal high intake velocity areas. At the same time, a 2.5- to 5.0-cm band formed on the trailing edge. Both bands continued to widen, particularly in proximal areas, until they met on the top and bottom of the screen. Spreading continued on the distal portion until the entire surface was covered.

Attainment of a 30.48-cm differential head was not indicative of zero flow. In most tests, the screen was passing more than 80% (over 50% for all tests) of the initial rate when the head reached 30.48 cm.

Detritus

Initial tests were conducted with peat moss on Screen S1C at an intake velocity of 12.19 cm/s. Time-to-clog ranged from 13 to 315 min (Table 6). Debris from the Salem Nuclear Generating Station (SNGS) screens clogged the screen much more rapidly than peat moss at the same concentration. The SNGS detritus consisted of weeds and large pieces of plant material as well as finer matter similar to peat moss and Canal detritus. Larger debris which impinged on the screen formed a mat that tended to trap finer debris which might have otherwise passed through

Table 6. Results of Detrital Clogging Studies

| Screen | S1C | S1C | S1C | S1C | S1C | S1C | S1C |
|---|---|---|---|---|---|---|---|
| Detrital load (cm³/m³) | 732.15 | 366.07 | 732.15 | 732.15 | 104.59 | 209.00 | 209.18 |
| Ratio to canal normal | 77.39 | 38.70 | 77.39 | 77.39 | 11.06 | 22.10 | 22.11 |
| Intake velocity (cm/s) | 12.19 | 12.19 | 6.10 | 12.19 | 12.19 | 6.10 | 12.19 |
| Number of tests | 15 | 3 | 7 | 15 | 10 | 2 | 4 |
| Origin of detritus | Peat moss | SNGS | SNGS | SNGS | C&D | C&D | C&D |
| Flume Velocity (cm/s) | Mean Time to Clog (min) | | | | | | |
| 7.62 | 30.25 | - | 14.25 | 5.34 | - | - | - |
| 15.24 | 26.33 | 12.82 | 12.31 | 4.94 | >240.00[a] | >240.00[a] | 48.41 |
| 15.24[b] | - | - | - | - | - | - | >240.00[a] |
| 22.86 | 43.06 | - | 14.04 | 4.80 | 200.00 | - | - |
| 30.48 | 77.38[a,c] | 18.17 | 21.39 | 5.77 | >300.00[a] | >240.00[a] | 82.09 |
| 30.48[b] | - | - | - | 35.00 | - | - | - |
| 38.10 | 315.00 | 18.00 | 56.64 | 5.50 | >315.00 | - | 310.61 |
| 45.72 | >240.00[a] | - | 189.00 | 7.83 | >420.00[a] | - | - |
| 53.34 | >110.00[a] | - | - | 10.53 | - | - | - |
| 60.96 | - | - | - | 6.54 | - | - | - |

| Screen | S3A | S3A | S4A | S2A | S2A | S2A | S2A |
|---|---|---|---|---|---|---|---|
| Detrital load (cm³/m³) | 117.67 | 58.83 | 117.67 | 104.59 | 209.18 | 366.07 | 732.15 |
| Ratio to canal normal | 12.44 | 6.22 | 12.44 | 11.06 | 22.11 | 38.70 | 77.39 |
| Intake velocity (cm/s) | 15.24 | 15.24 | 15.24 | 15.24 | 15.24 | 15.24 | 15.24 |
| Number of tests | 9 | 3 | 7 | 5 | 5 | 8 | 8 |
| Origin of detritus | C&D | C&D | C&D | C&D I | C&D I | C&D I | C&D I |
| Flume Velocity (cm/s) | Mean Time to Clog (min) | | | | | | |
| 7.62 | 11.22 | - | 19.15 | 86.17 | 35.45 | 10.02 | 6.48 |
| 7.62[b] | 77.55 | - | - | - | - | - | - |
| 15.24 | 12.75 | 19.72 | - | 44.67 | 20.27 | 7.72 | 4.32 |
| 22.86 | 16.12 | 29.18 | - | - | - | - | - |
| 22.86[b] | 480.00[a] | - | - | - | - | - | - |
| 30.48 | 30.00 | 54.42 | - | 40.20 | 21.92 | 9.29 | 5.24 |
| 38.10 | 79.98 | - | 7.99 | - | - | - | - |
| 45.72 | >180.00[a] | - | - | 101.95 | 32.08 | 16.27 | 8.05 |
| 53.34 | - | - | - | - | - | - | - |
| 60.96 | 410.80 | - | 19.18 | 240.00[a] | 240.00[a] | 46.67 | 18.94 |

[a] One or more tests failed to clog in the allotted time.

[b] Bubble curtain incorporated.

[c] Flume leakage caused concentration to change during test.

the screen. This resulted in a more rapid attainment of a 30.48 cm head. Tests of SNGS detritus indicated that a 50% reduction in detrital concentration (77.39 to 38.70 times normal Canal) resulted in a three-fold increase in TTC (Table 6).

Extensive testing of Canal detritus indicated that concentration had a marked effect on screen performance (Table 6). In general, a 50% reduction in concentration increased TTC by a factor of about 2 for 1.01-mm-slot screens (Fig. 9). Tests of a 0.51-mm-slot screen indicated that a 50% reduction in concentration increased TTC by 1.5 to 1.8 times.

The lowest concentration of Canal detritus tested was 6.22 times normal. Tests at or near normal Canal concentration were precluded because the amount of detritus added could not physically cover and clog the screen. This prevented accurate estimation of TTC under expected operating conditions.

## Slot Size and Open Area Ratio

Slot size and open area ratio also affect TTC. The effect of slot size is related to particle size and filtration efficiency. The increased filtration efficiency with decreased slot width resulted in decreased TTC because more particles impinged. The volume filtered per unit of screen surface area is related to the open area ratio. Screens with high open areas filter more water at any given intake velocity and are therefore exposed to a greater detrital load per unit surface area and time. The resultant change in TTC should be comparable to those which occurred when concentrations were changed.

Screens S3A (0.51-mm slot) and S4A (0.25-mm slot) were tested under the same conditions at a concentration 12 times normal Canal level (Table 6). Screen S3A (25% open area) clogged slightly faster at 7.62 cm/s flume velocity, but Screen S4A (14% open area) clogged 10.0 and 21.4 times faster at 38.10 and 60.96 cm/s channel currents, respectively. This indicates that higher loading associated with large open area may exert less of an effect on TTC than small slot size. Times-to-clog for three slot sizes at different flume velocities are presented in Figure 10.

The importance of open area was evident in tests of 1.01-mm-slot screens. Screen S1C (25% open area) clogged in one of 10 tests at a detrital concentration 11.1 times Canal normal at an intake velocity of 12.19 cm/s. Screen S2A (40% open area) clogged in four of five tests at an intake velocity of 15.24 cm/s under the same conditions. Screen S2A clogged 2.4-3.7 times faster than S1C at a concentration 22.1 times normal (Fig. 11).

## Intake Velocity

The inverse relationship of TTC and intake velocity probably resulted from the change in volume of water filtered and the corresponding change in debris load. A decrease in intake velocity from 12.19 to 6.10 cm/s increased mean TTC an average of 852% in 19 tests of SNGS detritus (Table 6). In tests run at a mean intake velocity of 12.19 cm/s with Canal detritus (22.1 times normal), Screen S1C clogged in 48.41 and 82.09 min at channel velocities of 15.24 and 30.48 cm/s, respectively. Comparable tests at an intake velocity of 6.10 cm/s failed to clog the screen within 4 hr.

## Channel Velocity

An increase in channel velocity generally increased TTC. The only exception was TTC at a velocity of 7.62 cm/s which exceeded that at 15.24 cm/s due to detritus that fell out of suspension. In general there was a distinct increase in self-cleaning characteristics at channel velocities in excess of 38.1 cm/s.

## Bubble Curtain

Incorporation of the bubble curtain eliminated clogging or markedly increased TTC. Conditions which clogged the screen in 48 and 16 min without the bubble system failed to increase the head in 4 and 8 hr, respectively, when the bubble curtain was in operation. A test of Screen S3A at 12 times normal Canal concentration at a channel velocity of 7.62 cm/s resulted in a 573% increase in TTC (Table 6).

## Air/Hydraulic Backwash

The merits of air/hydraulic backwash as an alternative to the standard hydraulic technique was investigated in several experiments. All air pressures tested (0.70, 1.76, and 3.52 kg/m$^2$)

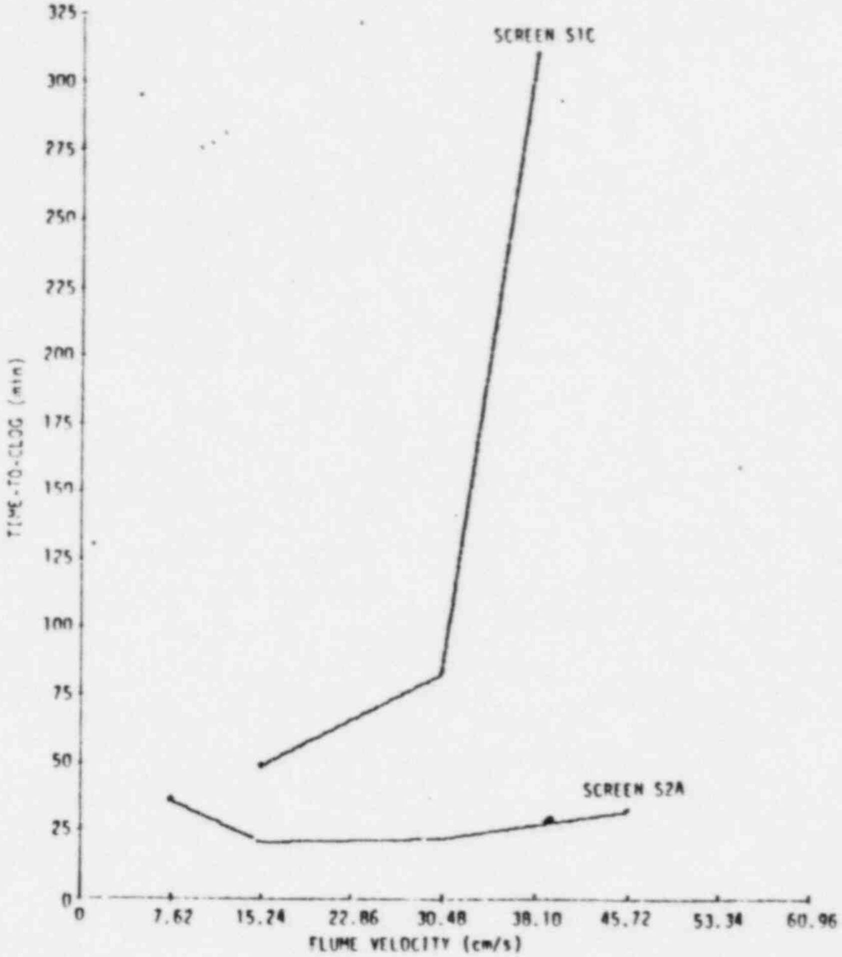

Fig. 9. Time-to-Clog for Screens S1C and S2A at Various Flume Velocities. Detrital concentration was 209 cm$^3$/m$^3$. Intake velocity was 12.19 cm/s for S1C and 15.24 cm/s for S2A.

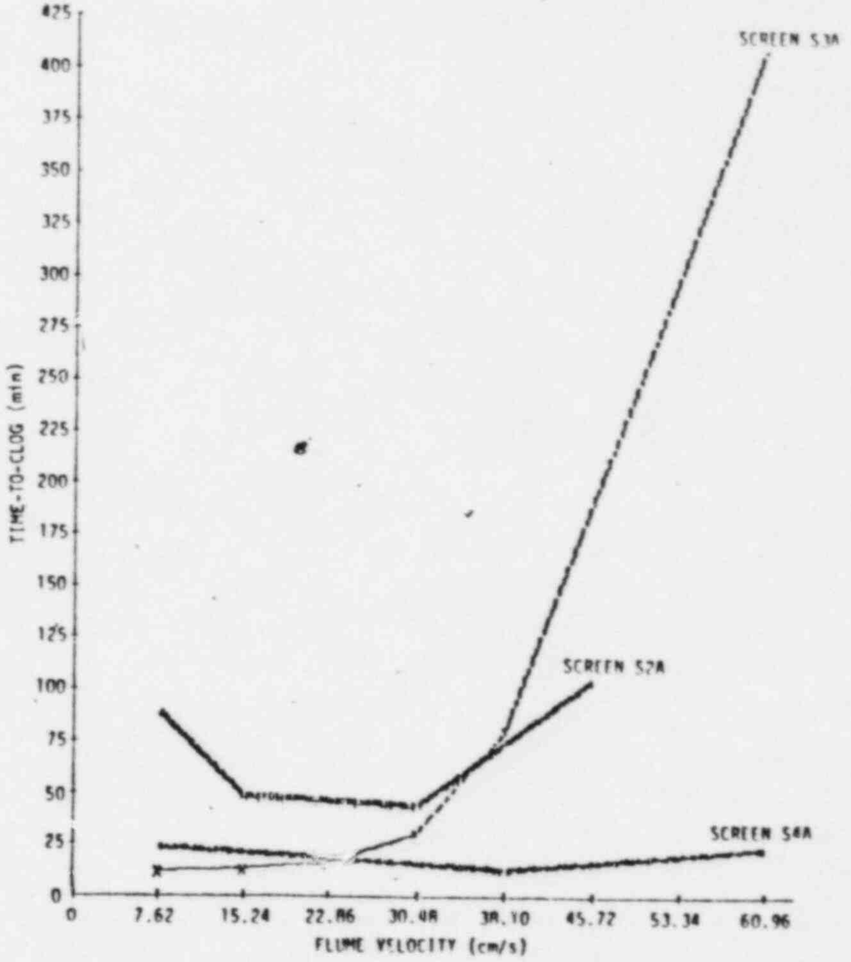

Fig. 10. Time-to-Clog for Screens S2A, S3A, and S4A. Detrital concentration was 195 cm$^3$/m$^3$ for Screen S2A and 118 cm$^3$/m$^3$ for Screens S3A and S4A. Intake velocity was 15.24 cm/s.

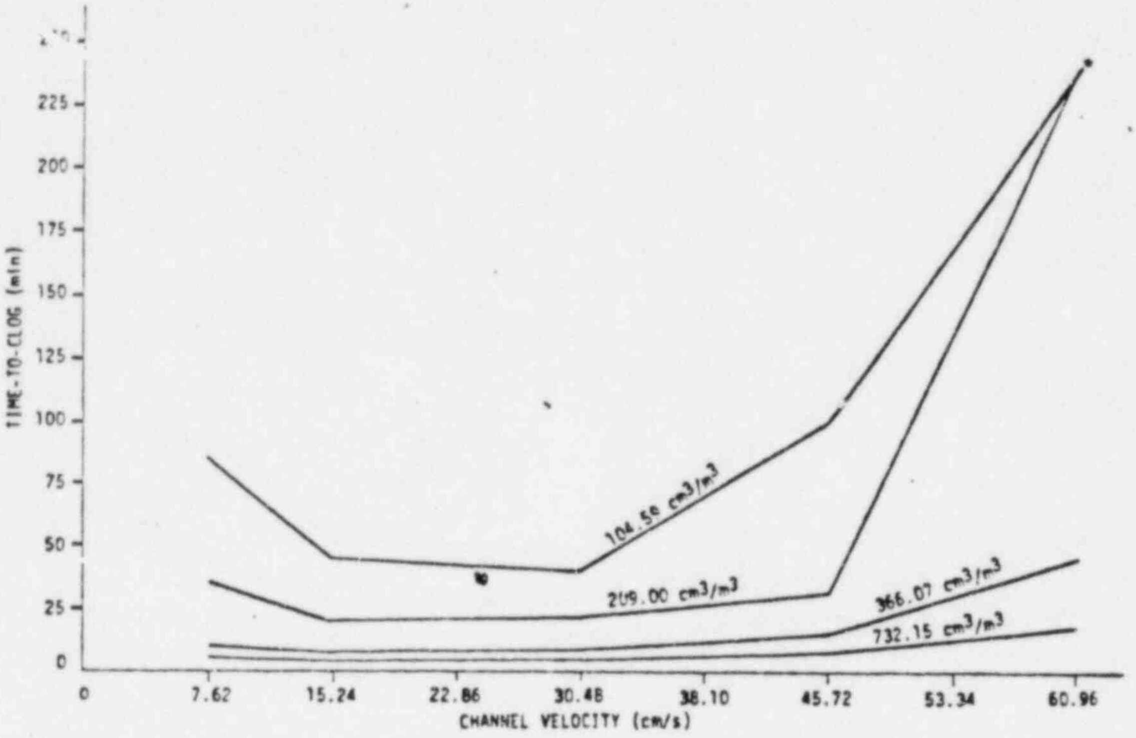

Fig. 11. Time-to-Clog for Screen S2A When Exposed to Various Detrital Concentrations and Flume Velocities. An asterisk (*) indicates termination before a 30.48-cm pressure drop.

appeared adequate for cleaning of a screen fouled by detritus, but subsequent running times were usually shorter than after hydraulic or manual cleaning under similar conditions. Most cleaning appeared to result from the water forced from the screen by the air blast. Bubbles rising to the surface tended to carry a substantial portion of the debris out of the zone of screen influence. Although some detritus reimpinged on the leading edge, most was carried away by the channel current. Head differential consistently returned to the initial level after this type of backwash.

## SUMMARY

1. Intake velocity decreased exponentially from the proximal to the distal end of the standard screen; the reverse was true for the inverted screen.

2. Intake velocity appeared uniform along the surface of the mushroom-shaped screen.

3. Approach velocity for the standard screen was always less than intake velocity, and decreased rapidly with increased distance from the screen. Approach velocity for the inverted screen was a function of screen dimensions.

4. Mean mortality of eggs due to impingement ranged from 0% to 2.0%. Early developmental stages (LG and EE) sustained greater mortality than later stages.

5. Egg impingement was most concentrated in the proximal areas of the screen due to the intake velocity gradient.

6. The number of eggs impinged on the trailing edge was inversely related to channel velocity; on the leading edge it was directly related.

7. The bubble curtain effectively prevented impingement of eggs; it also removed impinged eggs.

8. A 1.01-mm-slot screen prevented 97.5% of potential entrainment.

9. Avoidance behavior was observed in all experiments of aquaria-held larvae (5.2-9.2 mm TL), although all were entrained within 0.75-22.00 min.

10. The larvae (13-17 mm TL) held in 1.61-1.89 $m^3$ tanks were capable of sustained resistance at intake velocities as high as 45.72 cm/s.

11. No screen interactions were observed for alewife, silvery minnow, golden shiner, banded killifish, pumpkinseed, bluegill, and yellow perch.

12. Of the 1318 specimens exposed to standard screens in static mode, there were 260 impingements and 209 escapes.

13. Only three short impingements occurred among the 69 specimens exposed to standard screens in dynamic mode.

14. The majority of impingements occurred at or above an intake velocity of 30.48 cm/s and after more than 10 min of exposure.

15. The five species most susceptible to the standard screen were spottail shiner, bay anchovy, spot, striped bass, and Atlantic menhaden.

16. Exposure of 313 fishes to the inverted screen in static mode resulted in 88 impingements, 16 escapes, and 54 mortalities.

17. Of the 80 specimens tested in dynamic mode, 26 were entrapped; six escaped and 20 were killed.

18. The five species most susceptible to inverted screens were Atlantic menhaden, black crappie, bat anchovy, bluefish, and tidewater silverside.

19. Macroinvertebrates appeared to be highly resistant to damage by the screen.

20. Inverted screens of the type tested were unsatisfactory for protecting fishes.

21. Time-to-clog appears to be inversely related to intake velocity, percent open area, and detrital concentration, and directly related to flume velocity and slot size.

22. The bubble system prevented clogging or markedly increased TTC.

23. Air/hydraulic backwash may have potential as an alternative cleaning technique.

## PART II

## *IN-SITU* FIELD TESTS

### MATERIALS AND METHODS

The *in-situ* field test program was conducted to obtain information on engineering and maintenance requirements of a profile-wire screen intake under actual operating conditions. Biological information was considered of secondary importance and was collected as time and manpower allowed.

Tests were conducted with a 6.93-m-high model intake constructed of corrugated steel pipe (Figs. 12 and 13). The instrumentation and pump chamber was 2.36 m high and 1.83 m in diameter; the sump chamber was 4.57 x 1.52 m. The facility was mounted on I-beam supports and secured to a large pier approximately 1.0 km west of the proposed intake site.

The instrumentation chamber contained two vertical turbine pumps capable of pumping 2.54 $m^3$/min singly, or 4.35 $m^3$/min in tandem. Pumping rate was measured by a magnetic flow tube. Head differential was measured by a differential pressure transmitter. Both parameters were recorded by a strip chart recorder. The system was equipped with a duplex alarm which shut down the pumps when sump water level approached the pump intakes.

The model intake was designed to accept either a single 76.2-cm-diameter screen or two 30.48-cm-diameter screens. To date, only 61.0- x 76.2-cm screens have been tested. Test screens were mounted on stainless steel backing plates which were inserted into vertical tracks on the model intake. The screen was lowered down the tracks until it wedge-fit over a manifold with a single 30.5-cm orifice. The screen protruded horizontally into the Canal perpendicular to the current at a level approximately 30 cm below the surface at mean low water.

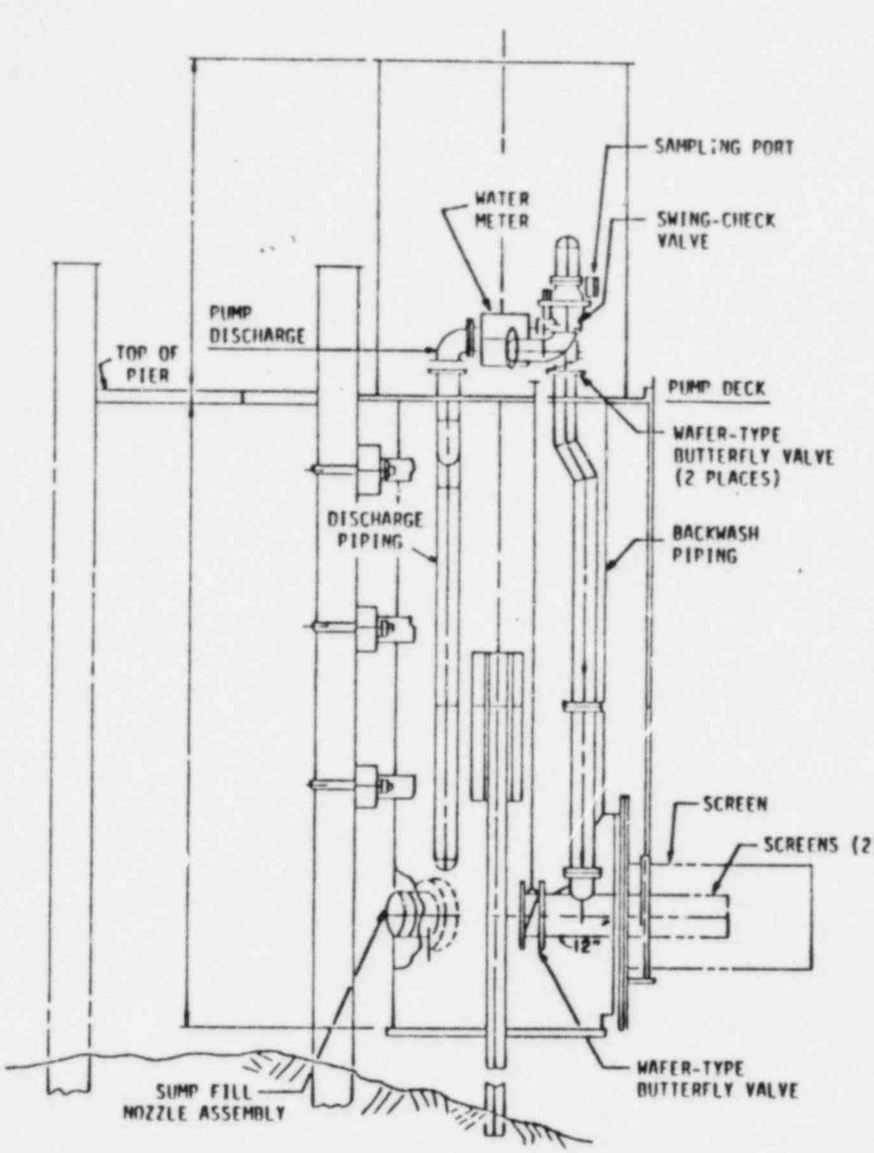

Fig. 12. Schematic of *In-situ* Test Apparatus

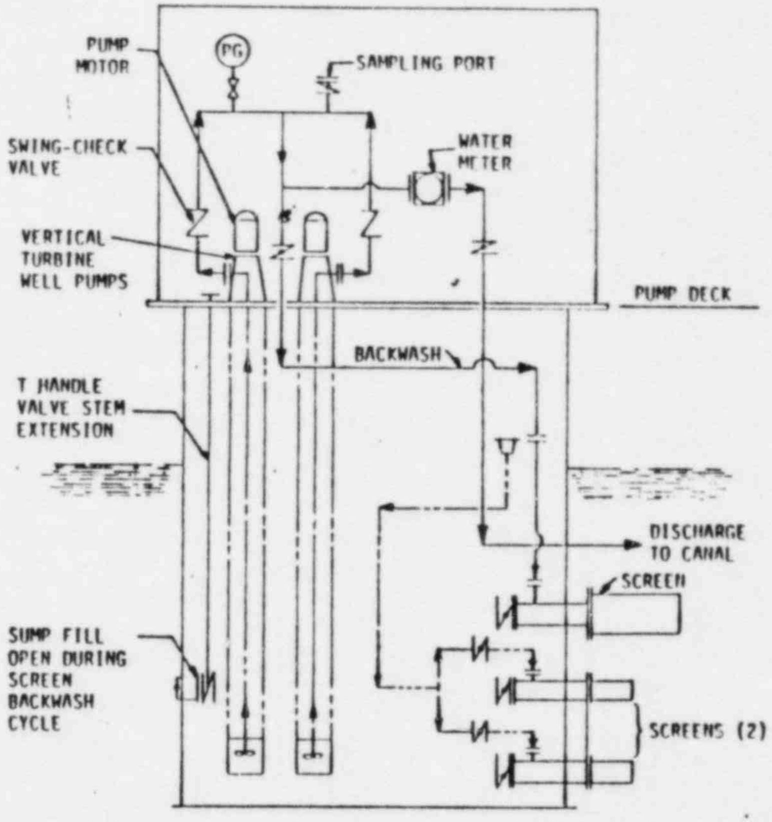

Fig. 13. Schematic of the Flow Path for the *In-situ* Test Apparatus

### Phase I

The operating capacity and characteristics of the model intake were established between 29 March and 11 April 1977. The 40% open area screen (1.01-mm slot, 1.52-mm wire) filtered 4.35 m$^3$/min for approximately 7 hr of each working day. The endplate and 17.8 cm of the sidewall were taped off to achieve an intake velocity of 17.68 cm/s.

### Phase II

After installation of the 1.01-mm-slot, 4.01-mm-wire screen (20.2% open area) on 14 April, the unit operated continuously. Pump rates were 2.5 m$^3$/min (intake velocity = 14.02 cm/s) or 4.35 m$^3$/min (intake velocity = 24.38 cm/s) during Fouling Period I; pump rate was 2.5 m$^3$/min during other fouling periods. Water was pumped from the sump which initiated a gravity flow through the test screen. Discharge reentered the Canal on the opposite side of the test facility. The unit was checked virtually every working day. The parameters recorded included head differential, pump rate, water level, current direction, and estimated current velocity. Pertinent physicochemical parameters were recorded as part of the routine operation. For purposes of the study, the screen was considered clogged upon attainment of a 30.48-cm head.

Backwashing was used to maintain the head within the desired operating range. Both water and air/hydraulic backwashes were used. A water backwash consisted of pumping water through the screen in a reverse direction for approximately 3 min. The air/hydraulic backwash consisted of draining the system and restarting the pump three times. This provided a blast of air through the screen which lasted 10-15 sec per restart. When backwashing failed to maintain the head at less than 30.48 cm for more than 8 hr, the screen was considered fouled and was pulled for manual cleaning. Wire brushes and scrapers only were used in the first cleaning; subsequent cleanings also included high-pressure water (35 kg/cm$^2$).

### Biosampling

The biosampling program was restricted by apparatus design and the engineering objectives of the study. When time permitted, entrainment samples were collected from the 5.08-cm sample port located on the apex of the common pump exhaust (Fig. 12). A 0.5-mm-mesh net was used to collect the entrained organisms. The reliability and validity of the samples could not be determined because total pump output could not be collected for comparison. Ambient conditions were determined from simultaneous surface, midwater, and bottom collections made nearby with volumetrically metered 0.5-m, 0.5-mm-mesh plankton nets.

A series of 24-hr studies was conducted once each month from June through September. Samples were taken every 3 hr in conjunction with ichthyoplankton tows at a nearby station. Additional tests were conducted to compare entrainment in water drawn through the screen with that in water drawn through the "sump-fill" orifice. All samples were preserved with 5% Formalin and stained with "rosé Bengal." Specimens were identified to the lowest practical taxonomic level.

Wilcoxon signed-ranks tests (Steel and Torrie 1960) were performed to determine if significant differences existed between mean ambient and entrained densities of striped bass eggs, prolarvae, postlarvae, young, all striped bass, and all specimens combined.

## RESULTS

### PHASE I

The screen was pulled and examined on several occasions during Phase I. The leading edge showed some detrital buildup, but head differential never exceeded the level required (6.1 cm) to obtain the desired flow rate and intake velocity through a clean screen. This phase of the study confirmed flume tests which indicated that the normal running time for a clean screen to clog under Canal conditions would be in excess of 8 hr.

### Fouling Period I (14 April to 21 June)

The apparatus was placed in continuous operation at an intake velocity of 24.38 cm/s on 14 April. After one day, intake velocity was reduced to 14.02 cm/s (2.5 m$^3$/min) and remained at that rate for 35 days. Head differential was 2.5 cm for the entire period. The pumping rate was then increased to 4.35 m$^3$/min (24.38 cm/s intake velocity) in an attempt to induce clogging. Head differential (6.1 cm) remained constant for 11 additional days. Head increased to between 12 and 15 cm on 29 May and 1 June then returned to normal. Pumping rate was reduced to

2.50 $m^3$/min (14.02 cm/s) on 3 June; head remained at 2.54 cm for seven more days. On 10 June, head began to increase. After backwashing, head was reduced to 2.54 cm but then increased to 91.4 cm in less than 6 hr. Examination showed that the entire screen surface was biofouled (Fig. 14) with a mixture of the hydroid *Garveia franciscana*, algae, the amphipod *Corophium lacustre*, and barnacles (*Balanus* spp.); some entangled detritus was also present. *Garveia* appeared responsible for most, if not all, of the increase in head. Backwashing failed to reduce the head to normal but generally maintained the head at less than 30.48 cm for eight or more hours per backwash until 20 June (Table 7). At that time backwashing only reduced the head to 18.25 cm; it returned to 30.48 cm within 1 hr on 21 June. The screen was then pulled, cleaned with wire brushes, replaced, and backwashed, whereupon head returned to the normal operating level.

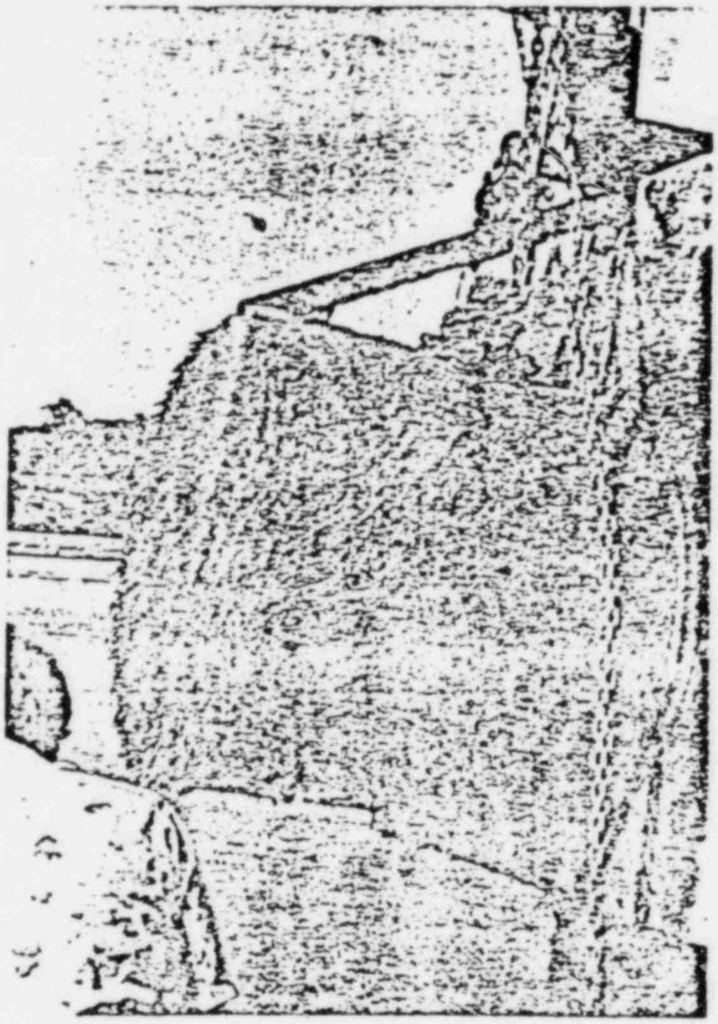

Fig. 14. A Heavily Biofouled *In-situ* Test Screen after 22 Days of Exposure

Fouling Period II (21-30 June)

Head differential remained between 2.5 and 5.0 cm until 26 June when it rose to 17.70 cm (Table 7). The wake of a passing ship reduced it to 7.62 cm, but by 28 June it reached 30.48 cm. A backwash reduced the head to about 10.16 cm, but 24 hr later it again reached 30.48 cm. Backwashing only reduced the head to about 12.70 cm so the screen was pulled for examination. The screen was heavily biofouled and appeared to be in the same condition as observed at the end of Fouling Period I. The rapid decline in screen efficiency compared to that during Fouling Period I indicated that biofouling was a greater operational problem than originally anticipated. High-pressure water (35.15 kg/$cm^2$) was incorporated into the second cleaning procedure in an attempt to remove all biofouling debris from the screen. This technique blasted virtually all

Table 7. Performance of *In-situ* Test Screen 14 April through 4 October 1977

| Date | Time of Backwash | Type of Backwash | Pre-backwash Head Differential (cm) | Post-backwash Head Differential (cm) | % Reduction in Head Differential | Elapsed Time from Backwash to Attainment of Clogging Level (hr) |
|---|---|---|---|---|---|---|
| 14 April | - | Screen installed | - | - | - | - |
| 10 June | 1207 | Water | 5.1 | 2.5 | 50.00 | 9.05 |
| 13 June | 1105 | Water | 48.3 | 11.4 | 76.32 | 12.58 |
| 14 June | 0958 | Water | 42.7 | 6.1 | 85.71 | 20.87 |
| 15 June | 1445 | Water | 33.0 | 6.1 | 81.54 | 16.25 |
| 17 June | 0850 | Water | 58.4 | 17.8 | 69.57 | 17.75 |
| 20 June | 0902 | Water | Off | 19.0 | - | 0.50 |
| 20 June | 1615 | Water | 39.4 | 17.8 | 54.84 | 11.42 |
| 21 June | 0902 | Water | 48.3 | 18.3 | 62.11 | 1.17 |
| 21 June | 1410 | Water | 39.4 | 18.3 | 53.55 | a/ |
| 21 June | 1500 | Water | 19.1 | 18.3 | 4.00 | a/ |
| 21 June | 1515 | Scrubbing | - | - | - | - |
| 21 June | 1605 | Water | Off | 5.1 | - | 174.45 |
| 28 June | 1610 | Water | 30.5 | 11.4 | 62.50 | 32.08 |
| 30 June | 0845 | Water | 30.5 | 12.7 | 58.33 | a/ |
| 30 June | 1030 | Scrubbing | - | - | - | - |
| 5 July | 0920 | Water | 2.5 | 2.5 | 0.00 | 230.67 |
| 6 July | 0845 | Water | 2.5 | 2.5 | 0.00 | 207.25 |
| 7 July | 0910 | Water | Off | 2.5 | - | 182.83 |
| 8 July | 1010 | Water | 2.5 | 2.5 | 0.00 | 157.83 |
| 11 July | 0950 | Water | 25.4 | 6.4 | 75.00 | 86.17 |
| 12 July | 0850 | Water | 17.8 | 10.2 | 42.86 | 63.17 |
| 13 July | 0900 | Water | 22.9 | 11.4 | 50.00 | 39.00 |
| 14 July | 0920 | Water | 25.4 | 11.4 | 55.00 | 14.67 |
| 15 July | 0920 | Water | Off | 17.8 | - | 15.00 |
| 16 July | 0915 | Water | Off | 30.1 | - | 0.00 |
| 18 July | 1120 | Scrubbing | - | - | - | - |
| 19 July | 1040 | Water | 2.5 | 2.5 | 0.00 | 181.50 |
| 20 July | 1105 | Water | 2.5 | 2.5 | 0.00 | 157.08 |
| 25 July | 0930 | Water | 6.4 | 6.4 | 0.00 | 38.67 |
| 26 July | 0950 | Water | 6.1 | 6.1 | 0.00 | 14.33 |
| 27 July | 0930 | Water | 27.9 | 6.4 | 77.27 | 13.25 |
| 27 July | 1345 | Water | 11.4 | 6.1 | 46.67 | 9.00 |
| 28 July | 0905 | Water | 55.9 | 11.4 | 79.55 | 14.42 |
| 28 July | 1035 | Water | 11.4 | 10.2 | 11.11 | 12.92 |
| 29 July | 1615 | Water | 48.8 | 12.7 | 73.96 | 7.75 |
| 1 August | 0925 | Water | Off | 17.8 | - | 1.83 |
| 2 August | 0950 | Water | 25.4 | 20.3 | 33.33 | 1.25 |
| 2 August | 1410 | Scrubbing | - | - | - | - |
| 12 August | 1115 | Water | 6.1 | 3.8 | 37.50 | 18.75 |
| 14 August | 1005 | Water | 43.2 | 8.9 | 79.41 | 46.92 |
| 15 August | 1005 | Water | 17.8 | 7.6 | 57.14 | 22.92 |
| 16 August | 0930 | Water | 30.5 | 11.4 | 62.50 | 55.33 |
| 22 August | 1015 | Water | 54.6 | 17.8 | 67.44 | 2.83 |
| 25 August | 0915 | Water | Off | 24.4 | - | 1.25 |
| 25 August | 1400 | Scrubbing | - | - | - | - |
| 9 September | 1515 | Water | 48.3 | 12.7 | 73.68 | 5.83 |
| 12 September | 1215 | Water | Off | 30.5 | - | 0.00 |
| 13 September | 1615 | Scrubbing | - | - | - | - |
| 22 September | 1530 | Water | 24.1 | 6.1 | 74.74 | 69.75 |
| 25 September | 1105 | Water | 38.1 | 12.7 | 66.67 | 2.17 |
| 26 September | 0925 | Water | 76.2 | 17.8 | 76.67 | 4.58 |
| 26 September | 1640 | Air | 30.5 | 6.1 | 80.00 | 2.33 |
| 27 September | 0850 | Air | 38.1 | 12.7 | 66.67 | 54.42 |
| 27 September | 1550 | Air | 24.1 | 11.4 | 52.63 | 47.58 |
| 28 September | 0855 | Air | 12.7 | 12.7 | 0.00 | 30.50 |
| 28 September | 1550 | Air | 19.1 | 12.7 | 33.33 | 23.58 |
| 29 September | 0855 | Air | 20.3 | 12.7 | 37.50 | 6.33 |
| 29 September | 1545 | Air | 35.6 | 12.7 | 62.29 | 30.25 |
| 30 September | 0905 | Air | 26.7 | 17.8 | 33.33 | 12.92 |
| 30 September | 1540 | Air | 25.4 | 17.8 | 30.00 | 30.33 |
| 3 October | 0825 | Air | 35.6 | 18.3 | 48.57 | 10.08 |
| 3 October | 1550 | Air | 25.4 | 18.3 | 28.00 | 2.67 |
| 4 October | 0820 | Air | 24.4 | 18.3 | 25.00 | a/ |
| 4 October | 1400 | Scrubbing | - | - | - | - |

[a] Clogging level not attained.

material from the inner and outer screen surface and ultimately proved to be more efficient in terms of subsequent running time.

Fouling Period III (30 June to 18 July)

The head differential remained at normal levels for the first nine days of the period (Table 7). Daily backwashing was instituted as a deterrent to biofouling on 5 July. The first increase in head occurred on 9 July. Backwash techniques kept head below 30.48 cm until 15 July when the test facility automatically shut down with a 83.82-cm head. A backwash returned head to 17.75 cm, but the 30.48-cm value was exceeded within 24 hr. By 18 July, head could not be kept less than 30.48 cm for 8 hr, so the screen was pulled and cleaned. Biofouling, primarily by *Garveia*, was again responsible for the decrease in efficiency.

Fouling Period IV (18 July to 2 August)

Routine daily backwashes were again conducted to prevent biofouling. Head remained constant at 2.54 cm through 23 July. It then increased steadily and reached 30.48 cm on 26 July. Backwashing kept head below 30.48 cm for more than 8 hr until 29 July (Table 7). By 2 August dense biofouling necessitated screen cleaning. The fouling agents were the same as in the two previous periods.

Fouling Period V (2-25 August)

Daily backwashing was discontinued during this period and the screen was backwashed only after the head began to increase. The first increase occurred on 11 August. Backwashing generally maintained head below 30.48 cm through 18 August; thereafter it failed to maintain the desired head for the required 8-hr period (Table 7). The facility was shut down from 23 to 25 August for pump maintenance. The screen was pulled and cleaned on 25 August. The abundance and growth of *Garveia* appeared to be lower, but it was still the primary biofouling agent; the density of barnacles was much greater than in previous periods.

Fouling Period VI (25 August to 13 September)

The screen functioned 10 days before head began to increase (Table 7). The apparatus was shut down for 52 hr from 6 to 8 September to replace a defective check valve; clogging levels were attained within 6 hr after resumption of normal operation. Backwashing proved ineffective and the screen was pulled and cleaned on 13 September. *Garveia* was the dominant fouling agent; the set of barnacles was minimal.

Fouling Period VII (13 September to 4 October)

Head differential was constant through 19 September when the first increase occurred (Fig. 15). The increase coincided with a peak in the abundance of ctenophores from 19 to 22 September. On 22 September the screen was pulled and inspected for impinged ctenophores. The small number present appeared to be in the process of being extruded through the screen. Water backwash maintained the head below 30.48 cm until 25 September. Air/hydraulic techniques were then used to maintain acceptable operating levels through 4 October (Table 7) when the screen was manually cleaned.

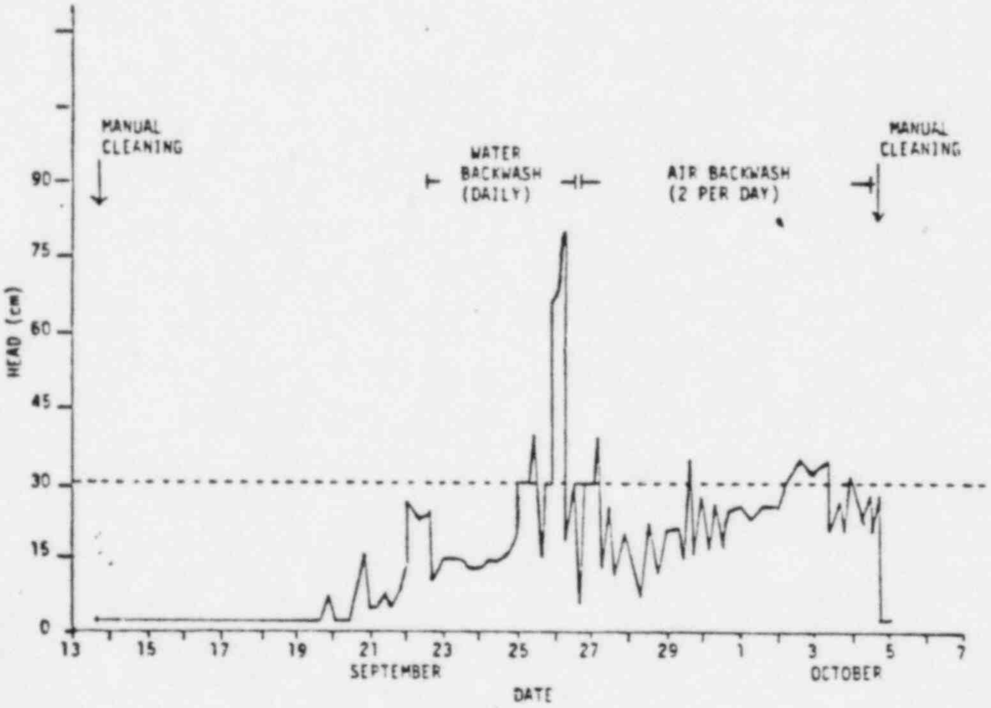

Fig. 15. Fluctuations in Head During a Typical Fouling Period and the Effects of Hydraulic and Air/Hydraulic Backwash

### Subsequent Fouling Periods (4 October to 17 December)

Although not described in detail in this report, studies continued from 4 October through mid-December. The screen showed an unexpected increase in head during mid-October and was pulled for examination. The increased head appeared to be the result of regrowth of incompletely removed organisms rather than reproductive activity. The screen was cleaned, scraped, dried for 24 hr, and reinstalled. It then functioned at 2.54 cm head until early December when it was replaced with a 40%-open-area screen (76.20 x 43.18 cm). This screen operated at normal head until 17 December when the apparatus was decommissioned for the winter.

## DISCUSSION

Clogging by suspended detritus was expected to be the major problem associated with screen operation. Although biofouling was anticipated, it was expected to be of secondary importance. Test results showed the reverse was true. The screen ran for months without cleaning or maintenance when biofouling was minimal. In fact, an unfouled screen was not clogged by increasing the intake velocity from 14.0 to 24.4 cm/s. The only instance when suspended material generated an increased head across a clean to moderately biofouled screen occurred during Fouling Period VII when the abundance of ctenophores was maximum. Although ctenophores failed to reach the abundance observed in previous years, the maximum head generated (12.70 cm), the observed rate of extrusion through the slots, and the ability to satisfactorily backwash the screen indicate that the screen could remain functional at much higher levels of abundance. Detrital fouling is of significance only when the screen is heavily biofouled. Instrumentation always indicated when this type of clogging might occur and the rate was always slow enough to allow ample time for manual cleaning.

Virtually all maintenance was due to biofouling. The biofouling season began in late May and extended through early October. During this period, the average time between cleaning with high-pressure water and an increase in head was eight days. The mean times between the first increase in head and the first clog (30.48-cm head) was four days; the mean time between the first clog and removal for cleaning was seven days (Fig. 16). Average time between cleanings was 19 days. Running times might have been increased if the apparatus had been equipped with an automatic backwash system.

Daily backwashing had no apparent effect on the rate of biofouling and may have adversely affected running time. The mean time between cleaning and the first increase in head for fouling periods which incorporated a daily backwash was seven days. The average time to the first increase in head for fouling periods without daily backwash was eight days. This difference probably resulted from the reduction in slot size caused by the tangling of *Garveia* growing on the inside (Fig. 17) and outside screen surfaces. The reduction in slot size caused by growth is compounded by tangling during backwashing. A delay in backwashing until head reaches 30.48 cm might increase time between manual cleanings.

Air/hydraulic backwashing was not conducted frequently or early enough in the study to definitely determine its overall efficiency. It does, however, appear to be at least as effective as the water technique and substantially faster. Tests during Fouling Period VII showed that the water backwash maintained head at less than 30.48 cm for less than 5 hr, while the air/hydraulic technique had running times of 6.33-54.42 hr (Fig 15).

The incorporation of more effective cleaning techniques such as higher-pressure (70.30 $kg/cm^2$) hot water and/or biocides should substantially increase running time. Experience in Fouling Period II indicates that incomplete cleaning results in rapid regrowth of hydroids and drastic reduction in running time.

Although the maintenance requirements due to biofouling were not particularly severe, they could be reduced significantly. The use of metals with antifouling properties such as copper alloys (Fig. 18) in screen construction would most assuredly reduce the frequency of manual cleaning. In theory, it could reduce cleaning to a yearly or less-frequent interval.

### BIOSAMPLING

Screen efficiency, in terms of reduction in biological impact, was evaluated on the basis of 102 entrainment samples. Only 35 (34.31%) of the samples contained fish. A total of 131 specimens ($n/m^3 = 0.635$) of seven fishes was collected. Eggs (n = 64) and larvae (67) were about equally abundant; no young or adults were collected. The most abundant species were bay anchovy (n = 76), white perch (30), and striped bass (17).

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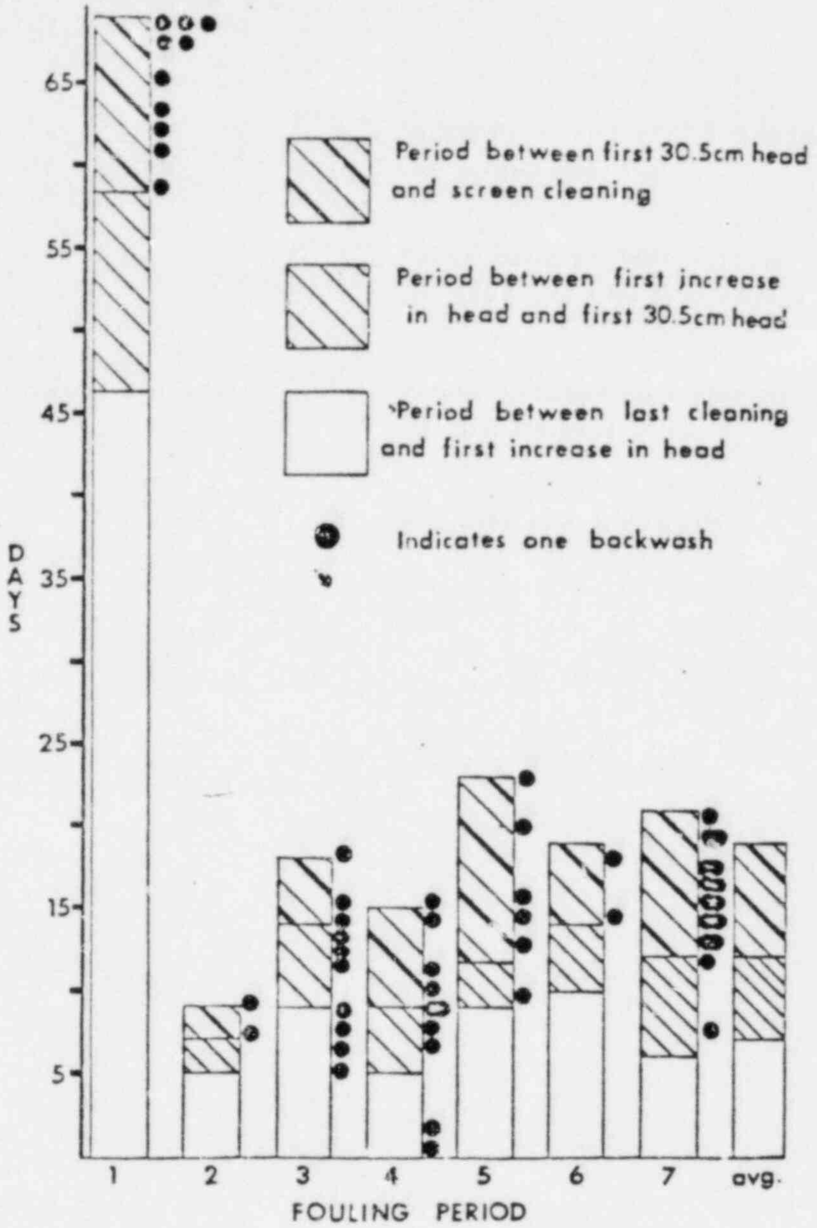

Fig. 16. A Summary of Fouling Periods One through Seven Showing Running Time, Backwashes, and Clogging

Bay anchovy accounted for 50 of the eggs; most of these (88%) were taken in four samples. Abundance was highest in June when 25 bay anchovy eggs were taken in 17.413 $m^3$ (1.435 /$m^3$). Striped bass (n = 12) accounted for 18.75% of the eggs. All were collected in April and May. The remainder of the catch consisted of one white perch and one unidentified egg.

White perch (n = 29) and bay anchovy (31) were the most abundant larvae and accounted for 43.28% and 46.27% of the total, respectively. Only five striped bass larvae were entrained. Other larvae entrained were herring sp. (n = 1), river herring spp. (3), minnow sp. (1), Atlantic silverside (1), temperate bass spp. (3), and unidentified larvae (1). Bay anchovy were taken in June and July; the other fishes were taken during April and May. Abundance of larvae was highest ($n/m^3$ = 1.5853) in April but the largest catch was made in May.

Ichthyoplankton collections were made simultaneously with 62 of the entrainment samples. Sixty-seven specimens ($n/m^3$ = 0.531) were present in entrainment samples (Table 8); ichthyoplankton samples contained 19,301 specimens ($n/m^3$ = 1.675). Statistical analysis revealed significantly lower mean density in entrainment samples for prolarvae, postlarvae, young, and all stages combined as well as for striped bass eggs (Table 9). There were no significant differences for striped bass pro- and postlarvae, but the sample size was small (1 each).

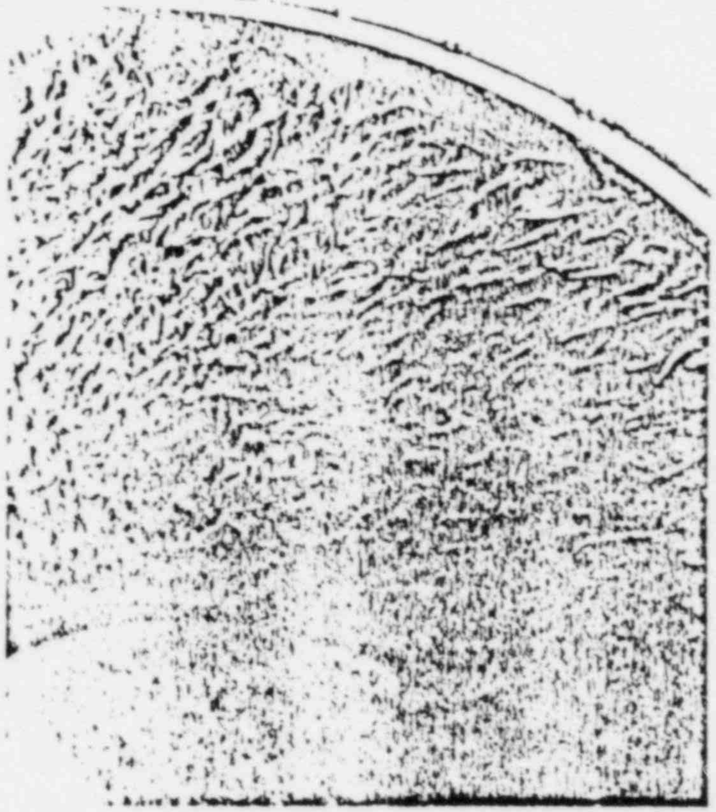

Fig. 17. Biofouling Inside the *In-situ* Test Screens

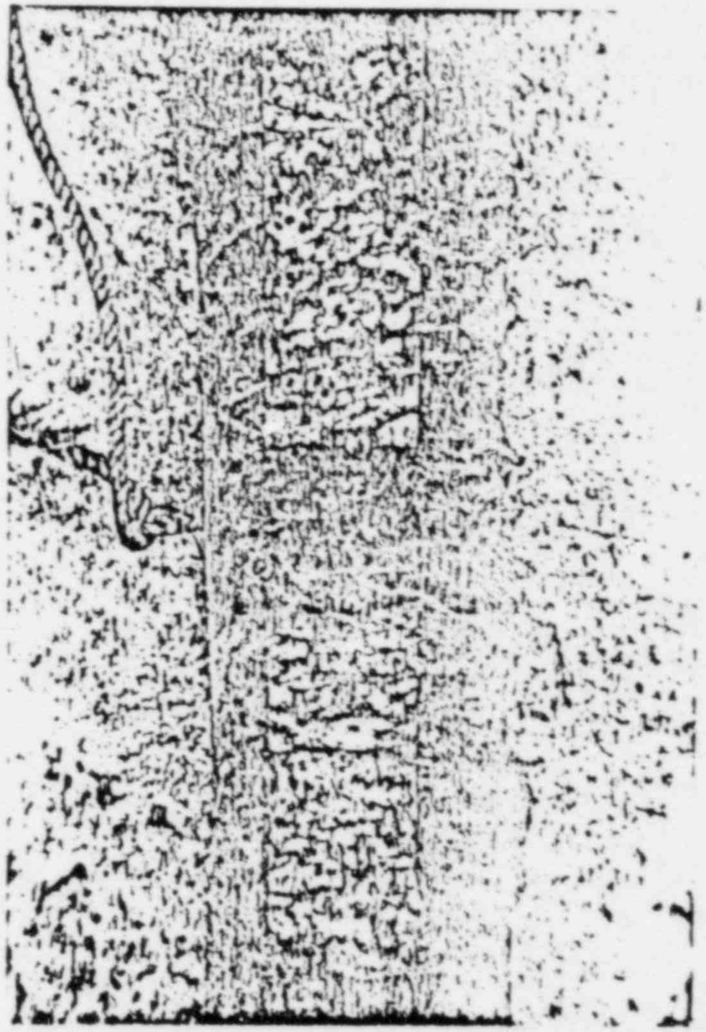

Fig. 18. Reduced Biofouling on 90-10 Copper-Nickel after Two Months of Exposure Adjacent to the *In-situ* Test Apparatus

## Table 8. Comparison of Ambient and Entrained Ichthyoplankton Density for *In-situ* Tests

| Date | Volume (m³) | | Total Specimens/m³ | | Eggs/m³ | | Prolarvae/m³ | | Postlarvae/m³ | | Young/m³ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Net | Screen | Net | Screen | Net | Screen | Net | Screen | Net | Screen | Net | Screen |
| All Species | | | | | | | | | | | | |
| 27 Apr | 165.430 | 1.893 | 0.060 | 0.000 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.018 | 0.000 |
| 29 Apr | 179.289 | 1.893 | 0.284 | 1.585 | 0.128 | 0.528 | 0.061 | 1.057 | 0.061 | 0.000 | 0.033 | 0.000 |
| Apr total | 344.719 | 3.786 | 0.177 | 0.792 | 0.070 | 0.264 | 0.049 | 0.528 | 0.032 | 0.000 | 0.026 | 0.000 |
| 2 May | 145.425 | 1.893 | 12.363 | 0.528 | 1.692 | 0.000 | 4.463 | 0.000 | 6.209 | 0.528 | 0.000 | 0.000 |
| 4 May | 166.980 | 1.893 | 3.222 | 1.585 | 0.527 | 0.000 | 2.545 | 0.528 | 0.144 | 1.057 | 0.006 | 0.000 |
| 5 May | 129.215 | 1.514 | 0.163 | 0.661 | 0.023 | 0.000 | 0.008 | 0.000 | 0.108 | 0.661 | 0.023 | 0.000 |
| 10 May | 166.044 | 1.136 | 0.247 | 0.000 | 0.151 | 0.000 | 0.024 | 0.000 | 0.066 | 0.000 | 0.006 | 0.000 |
| 12 May | 183.896 | 3.407 | 0.038 | 0.294 | 0.016 | 0.294 | 0.011 | 0.000 | 0.005 | 0.000 | 0.005 | 0.000 |
| 16 May | 172.557 | 0.946 | 1.287 | 0.000 | 0.985 | 0.000 | 0.058 | 0.000 | 0.243 | 0.000 | 0.000 | 0.000 |
| 17 May | 165.096 | 0.757 | 2.617 | 3.963 | 1.969 | 0.000 | 0.357 | 0.000 | 0.291 | 3.963 | 0.000 | 0.000 |
| 18 May | 187.145 | 0.757 | 2.405 | 0.000 | 1.715 | 0.000 | 0.321 | 0.000 | 0.369 | 0.000 | 0.000 | 0.000 |
| 19 May | 172.897 | 1.893 | 0.359 | 0.528 | 0.139 | 0.000 | 0.064 | 0.000 | 0.156 | 0.528 | 0.000 | 0.000 |
| 20 May | 164.286 | 0.946 | 0.049 | 0.000 | 0.043 | 0.000 | 0.000 | 0.000 | 0.006 | 0.000 | 0.000 | 0.000 |
| 23 May | 186.949 | 1.893 | 0.091 | 0.528 | 0.059 | 0.528 | 0.000 | 0.000 | 0.021 | 0.000 | 0.011 | 0.000 |
| May total | 1,840.490 | 17.035 | 1.954 | 0.646 | 0.665 | 0.117 | 0.663 | 0.059 | 0.622 | 0.470 | 0.004 | 0.000 |
| 8 Jun | 198.644 | 1.514 | 1.344 | 1.321 | 0.886 | 1.321 | 0.000 | 0.000 | 0.453 | 0.000 | 0.005 | 0.000 |
| 20 Jun | 164.483 | 1.514 | 0.097 | 1.982 | 0.067 | 1.321 | 0.000 | 0.000 | 0.030 | 0.661 | 0.000 | 0.000 |
| 23 Jun[a] | 180.259 | 1.136 | 1.587 | 0.000 | 0.216 | 0.000 | 0.006 | 0.000 | 1.265 | 0.000 | 0.010 | 0.000 |
| 23 Jun[a] | 210.870 | 1.136 | 0.171 | 0.880 | 0.005 | 0.000 | 0.005 | 0.000 | 0.156 | 0.880 | 0.005 | 0.000 |
| 23 Jun[a] | 212.431 | 1.893 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| 23 Jun[a] | 193.024 | 2.271 | 0.026 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.016 | 0.000 | 0.010 | 0.000 |
| 23 Jun[a] | 183.634 | 1.514 | 3.959 | 1.321 | 0.414 | 1.321 | 0.027 | 0.000 | 3.354 | 0.000 | 0.163 | 0.000 |
| 23 Jun[a] | 158.648 | 1.514 | 3.133 | 7.266 | 2.988 | 7.266 | 0.006 | 0.000 | 0.044 | 0.000 | 0.095 | 0.000 |
| 24 Jun[a] | 196.008 | 1.514 | 0.444 | 0.000 | 0.352 | 0.000 | 0.000 | 0.000 | 0.051 | 0.000 | 0.041 | 0.000 |
| 24 Jun[a] | 187.589 | 1.893 | 1.972 | 4.226 | 1.860 | 4.225 | 0.000 | 0.000 | 0.069 | 0.000 | 0.043 | 0.000 |
| 27 Jun | 185.288 | 1.514 | 1.274 | 0.000 | 0.027 | 0.000 | 0.027 | 0.000 | 1.214 | 0.000 | 0.005 | 0.000 |
| June total | 2,070.878 | 17.413 | 1.222 | 1.585 | 0.579 | 1.436 | 0.006 | 0.000 | 0.596 | 0.117 | 0.041 | 0.000 |
| 5 Jul | 166.531 | 1.136 | 1.099 | 0.880 | 0.000 | 0.000 | 0.006 | 0.000 | 1.069 | 0.880 | 0.024 | 0.000 |
| 11 Jul | 187.638 | 1.325 | 44.058 | 12.830 | 1.039 | 12.830 | 0.021 | 0.000 | 42.982 | 0.000 | 0.016 | 0.000 |
| 14 Jul | 187.233 | 3.407 | 0.118 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.118 | 0.000 | 0.000 | 0.000 |
| 21 Jul[a] | 162.828 | 1.514 | 9.605 | 0.000 | 0.049 | 0.000 | 9.525 | 0.000 | 0.012 | 0.000 | 0.018 | 0.000 |
| 21 Jul[a] | 211.127 | 1.703 | 2.444 | 4.110 | 0.000 | 0.000 | 0.000 | 0.000 | 2.169 | 4.110 | 0.275 | 0.000 |
| 21 Jul[a] | 192.546 | 1.893 | 0.706 | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 | 0.675 | 0.000 | 0.026 | 0.000 |
| 21 Jul[a] | 194.069 | 1.703 | 4.833 | 0.000 | 0.000 | 0.000 | 0.015 | 0.000 | 4.638 | 0.000 | 0.180 | 0.000 |
| 21 Jul[a] | 202.292 | 1.514 | 3.060 | 0.661 | 0.044 | 0.000 | 0.064 | 0.000 | 2.857 | 0.661 | 0.094 | 0.000 |
| 22 Jul[a] | 187.452 | 1.514 | 1.302 | 0.000 | 0.005 | 0.000 | 0.000 | 0.000 | 0.886 | 0.000 | 0.411 | 0.000 |
| 22 Jul[a] | 210.508 | 1.703 | 0.451 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.333 | 0.000 | 0.119 | 0.000 |
| 22 Jul[a] | 197.684 | 1.893 | 1.290 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.012 | 0.000 | 0.278 | 0.000 |
| 25 Jul | 181.941 | 3.785 | 0.176 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.170 | 0.000 | 0.005 | 0.000 |
| Jul total | 2,201.849 | 23.090 | 5.641 | 1.126 | 0.093 | 0.736 | 0.689 | 0.000 | 4.733 | 0.390 | 0.125 | 0.000 |
| 1 Aug | 160.440 | 3.785 | 0.156 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.037 | 0.000 | 0.018 | 0.000 |
| 8 Aug | 196.567 | 3.785 | 0.015 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 | 0.010 | 0.000 |
| 18 Aug | 177.421 | 1.136 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.006 | 0.000 | 0.000 | 0.000 |
| 18 Aug | 161.080 | 1.703 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 18 Aug | 179.739 | 1.703 | 0.028 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.028 | 0.000 | 0.000 | 0.000 |
| 18 Aug | 199.264 | 1.703 | 0.602 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.251 | 0.000 | 0.351 | 0.000 |
| 18 Aug | 202.610 | 0.757 | 0.128 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.069 | 0.000 | 0.059 | 0.000 |
| 30 Aug[a] | 173.385 | 1.514 | 0.035 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.035 | 0.000 |
| 30 Aug[a] | 185.266 | 1.893 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 |
| 30 Aug[a] | 188.027 | 1.893 | 0.016 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.016 | 0.000 |
| 30 Aug[a] | 197.696 | 1.514 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 30 Aug[a] | 228.109 | 1.703 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.000 |
| 30 Aug[a] | 160.077 | 1.893 | 0.019 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.019 | 0.000 |
| 31 Aug[a] | 190.591 | 1.893 | 0.131 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 | 0.126 | 0.000 |
| 31 Aug[a] | 211.713 | 1.514 | 0.033 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.033 | 0.000 |
| Aug total | 2,812.005 | 28.389 | 0.080 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.028 | 0.000 | 0.053 | 0.000 |
| 6 Sep | 179.086 | 1.136 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 19 Sep | 181.322 | 1.893 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22 Sep[a] | 209.199 | 2.271 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22 Sep[a] | 207.595 | 3.785 | 0.010 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.010 | 0.000 |
| 22 Sep[a] | 218.123 | 3.785 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22 Sep[a] | 208.575 | 3.785 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22 Sep[a] | 211.681 | 3.785 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 22 Sep[a] | 179.443 | 3.785 | 0.028 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.028 | 0.000 |
| 23 Sep[a] | 205.441 | 3.785 | 0.024 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.024 | 0.000 |
| 23 Sep[a] | 188.21[illegible] | 3.785 | 0.016 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.016 | 0.000 |
| Sep total | 1,988.6[illegible] | 31.795 | 0.008 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 | 0.000 |
| 4 Oct | 183.979 | 4.731 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 |
| Oct total | 183.979 | 4.731 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 |
| Total | 11,522.598 | 126.239 | 1.675 | 0.531 | 0.231 | 0.357 | 0.245 | 0.024 | 1.151 | 0.151 | 0.048 | 0.000 |
| Striped Bass | | | | | | | | | | | | |
| 27 Apr | 165.430 | 1.893 | 0.030 | 0.000 | 0.000 | 0.000 | 0.030 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 29 Apr | 179.289 | 1.893 | 0.151 | 0.528 | 0.112 | 0.000 | 0.039 | 0.528 | 0.000 | 0.000 | 0.000 | 0.000 |
| Apr total | 344.719 | 3.786 | 0.093 | 0.264 | 0.058 | 0.000 | 0.035 | 0.264 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2 May | 145.425 | 1.893 | 6.279 | 0.000 | 1.685 | 0.000 | 4.339 | 0.000 | 2.255 | 0.000 | 0.000 | 0.000 |
| 4 May | 166.980 | 1.893 | 3.054 | 0.000 | 0.443 | 0.000 | 2.533 | 0.000 | 0.078 | 0.000 | 0.000 | 0.000 |
| 5 May | 129.215 | 1.514 | 0.008 | 0.661 | 0.008 | 0.000 | 0.000 | 0.000 | 0.000 | 0.661 | 0.000 | 0.000 |
| 10 May | 166.044 | 1.136 | 0.169 | 0.000 | 0.151 | 0.000 | 0.018 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 12 May | 183.896 | 3.407 | 0.027 | 0.294 | 0.016 | 0.294 | 0.011 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 16 May | 172.557 | 0.946 | 1.032 | 0.000 | 0.985 | 0.000 | 0.035 | 0.000 | 0.012 | 0.000 | 0.000 | 0.000 |
| 17 May | 165.096 | 0.757 | 2.277 | 0.000 | 1.920 | 0.000 | 0.309 | 0.000 | 0.048 | 0.000 | 0.000 | 0.000 |
| 18 May | 187.145 | 0.757 | 1.998 | 0.000 | 1.705 | 0.000 | 0.256 | 0.000 | 0.037 | 0.000 | 0.000 | 0.000 |
| 19 May | 172.897 | 1.893 | 0.249 | 0.000 | 0.139 | 0.000 | 0.064 | 0.000 | 0.046 | 0.000 | 0.000 | 0.000 |
| 20 May | 164.286 | 0.946 | 0.043 | 0.000 | 0.043 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23 May | 186.949 | 1.893 | 0.086 | 0.000 | 0.059 | 0.000 | 0.000 | 0.000 | 0.016 | 0.011 | 0.011 | 0.000 |
| May total | 1,840.490 | 17.035 | 1.490 | 0.117 | 0.650 | 0.059 | 0.638 | 0.000 | 0.201 | 0.059 | 0.001 | 0.000 |
| Striped bass total | 11,522.598 | 126.239 | 0.2407 | 0.024 | 0.106 | 0.008 | 0.103 | 0.008 | 0.032 | 0.008 | 0.0002 | 0.000 |

[a] 24-hr study

Table 9. Results of Statistical Analyses (Wilcoxon Signed-ranks Test) for Entrained Densities versus Ambient Densities

| Species Compared | Stage of Development | Number of Pairs | Sum of Positive Ranks | Sum of Negative Ranks | Level of Significance[a] |
|---|---|---|---|---|---|
| Striped bass | All stages | 13 | 70.0 | 21.0 | NS |
| Striped bass | Eggs | 12 | 71.0 | 7.0 | HS |
| Striped bass | Prolarvae | 10 | 47.0 | 8.0 | NS |
| Striped bass | Postlarvae | 8 | 29.0 | 7.0 | NS |
| Striped bass | Young | 1 | 1.0 | 0.0 | I |
| All species | All stages | 54 | 1072.0 | 413.0 | HS |
| All species | Eggs | 26 | 181.0 | 170.0 | NS |
| All species | Prolarvae | 21 | 213.0 | 18.0 | HS |
| All species | Postlarvae | 42 | 686.0 | 217.0 | HS |
| All species | Young | 43 | 946.0 | 0.0 | HS |

[a] NS = no significant difference ($P < 0.05$), HS = highly significant difference ($P = 0.02$), and I = insufficient number of comparisons.

Data from samples drawn through the screen and from the sump fill orifice were inadequate for statistical comparison. One larva was taken through the sump fill orifice; none were taken through the screen.

The results of entrainment experiments were about as expected based on experiments conducted in the flume. The degree of protection offered striped bass pro- and postlarvae could not be determined because experimentation began after the peak in abundance. The reduction in impact on invertebrates was also not determined. A more extensive biological sampling program will be required before the potential reduction in impact from entrainment can be quantified.

## SUMMARY

1. Biofouling was more important than detrital fouling in clogging of the screens.

2. The major biofouling agent was the hydroid *Garveia*. Other agents included barnacles, algae, and amphipods.

3. The biofouling season lasted from late May through mid-October.

4. The average length of time between manual cleanings during the biofouling period was 19 days. The average length of time between the last screen cleaning and the first clog was 12 days.

5. Detritus accelerated the rate of clogging for a biofouled screen but never clogged a clean screen.

6. Daily backwashing before the first clog may have decreased rather than increased running time.

7. Samples ($n = 102$) of filtered water yielded 131 specimens ($n/m^3 = 0.635$) of seven fishes.

8. Bay anchovy accounted for 78.13% ($n = 50$) of the eggs collected; striped bass ($n = 12$) accounted for 18.75%.

9. The mean density of entrained prolarvae, postlarvae, young, and all stages combined was significantly lower than in simultaneous ichthyoplankton samples. The mean density of striped bass eggs was also significantly lower in entrainment samples.

## ACKNOWLEDGEMENTS

The authors would like to express appreciation to the entire staff of the Delmarva Ecological Study, Ichthyological Associates, Inc., for their contributions during construction of the test apparatus and collections of test materials. Special thanks are extended to Steven E. Allison, who conducted the initial experiments; Michael R. Headrick and his hatchery crew, who supplied striped bass eggs and larvae; and Ronnie J. Kernehan for editorial assistance.

Technical information on screen hydraulics was provided by Lee Cook and Paul Fournier of Johnson Division, UOP, Inc.

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# DATA ON SHORTNOSE STURGEON (<u>ACIPENSER</u> <u>BREVIROSTRUM</u>) COLLECTED INCIDENTALLY FROM 1969 THROUGH JUNE 1979 IN SAMPLING PROGRAMS CONDUCTED FOR THE HUDSON RIVER ECOLOGICAL STUDY*

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PREPARED FOR

MEETING OF SHORTNOSE STURGEON RECOVERY TEAM
30 NOVEMBER 1979
DANVERS, MASSACHUSETTS

*FINANCED BY CONSOLIDATED EDISON COMPANY OF NEW YORK, INC., ORANGE AND ROCKLAND UTILITIES INC., CENTRAL HUDSON GAS AND ELECTRIC CORPORATION, POWER AUTHORITY OF THE STATE OF NEW YORK

# Shortnose Sturgeon Collected From Intake Screens of Consolidated Edison, Orange and Rockland, and Central Hudson, Hudson River Power Plants, 1972 through 30 June 1979

| Date | Plant/Unit | River Mile | Total Length (mm) | Weight (gm) |
|---|---|---|---|---|
| 1972 | | | | |
| 6/ 7 | Danskammer | 64 | --- | 1500 |
| 6/27 | Indian Point/2 | 42 | 174 | 12 |
| 7/ 6 | Danskammer | 64 | --- | 1075 |
| 8/ 3 | Danskammer | 64 | --- | 320 |
| 8/ 6 | Indian Point/1 | 42 | 248 | 36 |
| 8/12 | Indian Point/1 | 42 | 98 | 3 |
| 8/24 | Danskammer | 64 | --- | 910 |
| 7/ 8 | Indian Point/1 | 42 | 234 | 40 |
| 1973 | | | | |
| 1/16 | Bowline | 37 | 625 | 1017 |
| 3/28 | Indian Point/2 | 42 | 310 | 85 |
| 5/17 | Danskammer | 64 | --- | --- |
| 7/20 | Indian Point/2 | 42 | 479 | 407 |
| 9/ 5 | Danskammer | 64 | --- | --- |
| 1974 | | | | |
| 3/20 | Bowline | 37 | 254 | --- |
| 4/ 2 | Roseton | 64 | --- | --- |
| 5/ 5 | Indian Point/2 | 42 | 493 | 532 |
| 6/20 | Indian Point/2 | 42 | 805 | 1702 |
| 8/ 8 | Indian Point/2 | 42 | 707 | 1588 |
| 8/20 | Indian Point/1 | 42 | 122 | 7 |
| 1975 | | | | |
| 6/20 | Indian Point/2 | 42 | --- | 84 |
| 1976 | | | | |
| 2/16 | Indian Point/2 | 42 | 307 | 253 |
| 12/27 | Bowline | 37 | --- | --- |
| 1977 | | | | |
| 1/23 | Indian Point/2 | 42 | --- | 516 |
| 2/23 | Indian Point/2 | 42 | --- | 1800 |
| 4/ 2 | Indian Point/2 | 42 | --- | x 16.8 |
| 4/ 2 | Indian Point/2 | 42 | --- | x 16.8 |
| 4/12 | Danskammer | 64 | 271 | 89 |
| 5/25 | Indian Point/2 | 42 | --- | 73 |
| 9/23 | Indian Point/3 | 42 | --- | 99 |
| 11/16 | Indian Point/2 | 42 | --- | 15 |
| 1978 | | | | |
| 1/ 9 | Indian Point/2 | 42 | 178 | 27* |
| 1/27 | Indian Point/3 | 42 | --- | 65** |
| 3/ 2 | Indian Point/3 | 42 | 227 | 54* |
| 3/27 | Indian Point/3 | 42 | 194 | 64* |
| 11/14 | Indian Point/2 | 42 | 530 | 940** |
| 1979 | | | | |
| 2/28 | Indian Point/2 | 42 | 420 | 567** |
| 4/ 3 | Indian Point/3 | 42 | 448 | 450* |
| 4/29 | Indian Point/2 | 42 | 460 | 625** |
| 5/ 4 | Indian Point/3 | 42 | 405 | 595* |

* Dead   ** released alive

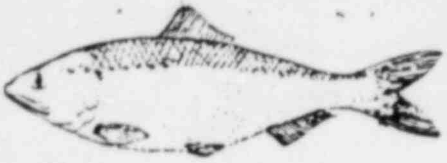
34 [illegible]

most from IP

[illegible]

2 Dead

2 Dead

SHAD  PAD

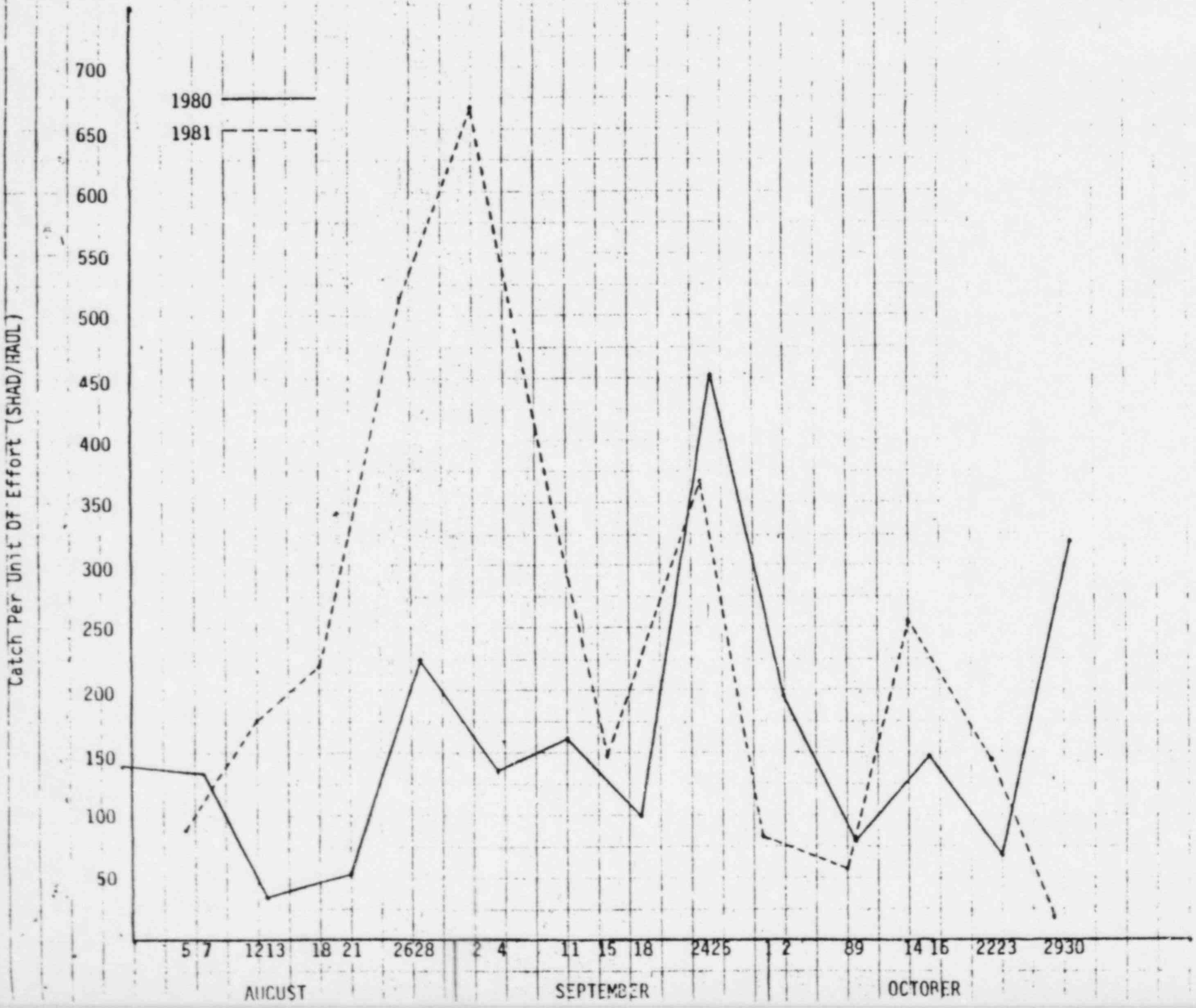
Elaine,

Attached is rough graph of juvenile shad CPUE at Byram for 1980-81. In addition data for 1981.

A. Lupine

Lupine, A.J. 1982. Juvenile American shad catch per unit of effort in the Delaware River at Byram, N.J. (RM 156.7) 1980-81. Provided by author 18 Sep 1982, 1p.

Juvenile American Shad Catch Per Unit of Effort in the Delaware River at Byram, NJ



Masnik Exhibit 1

# ASSESSMENT OF THE IMPACTS OF THE PROPOSED POINT PLEASANT PUMPING STATION AND INTAKE ON THE SHORTNOSE STURGEON, *ACIPENSER BREVIROSTRUM*

For

Neshaminy Water Resources Authority
County of Bucks

By

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January 1982

by shortnose sturgeon, an assessment of potential impacts of construction and operation of the proposed water intake was requested. This assessment provides a detailed description of the proposed project, describes the distribution, habitat requirements, and relevant life history of the shortnose sturgeon, evaluates potential effects of the proposed project, and discusses measures to mitigate any potentially adverse effects.

## 2.0 SITE DESCRIPTION

### 2.1 Location

The Point Pleasant Pumping Station will be located on the Delaware River, near Point Pleasant, Pennsylvania, at river kilometer (rkm) 252.9. The water intake will be a submerged, in-channel structure comprised of cylindrical profile-wire screen arrays set ca. 75 m (245 ft) off the Pennsylvania shore at about mid-depth in 3.1 m of water (see Section 3.3 for details). Water will be delivered some 213 m west to a pumping station located between the Pennsylvania Canal and Route 32. The system will withdraw water immediately upstream of an approximately 2.0-km long pool formed by the Lumberville wing dam (Fig. 2-1).

The area in the vicinity of Point Pleasant is sparsely populated; primary land use is farming although there are a few small river-bank communities upstream. The nearest major population centers are Allentown-Bethlehem and Easton, Pennsylvania, on the Lehigh River, which joins the Delaware River some 43 km upstream of Point Pleasant.

## 2.2 Hydrology

The Delaware River at Point Pleasant is running, non-tidal, freshwater. The site is located approximately 37 km upstream of the fall line at Trenton, New Jersey. Tohickon Creek, located approximately 244 m upstream of the site, is the only major tributary near Point Pleasant.

The Delaware River in the vicinity of Point Pleasant averages 166 m in width and has a gradient of ca. 0.85 m per kilometer.

River discharge, as measured at the Trenton gage (approximately 41 km downstream), during October 1912 through September 1979 averaged 11,772 cfs with a maximum of 329,000 cfs in 1975 and a minimum of 1,180 cfs in 1963. Mean monthly river flow at Trenton during January 1970 through December 1979 is given in Table 2-1 (USGS, 1981a). Maximum flows occur during March and April and minimum flows during July through September.

Current velocities in the vicinity of the site vary seasonally with river flow and, to a lesser degree, with depth and position in the river. Results of velocity measurements along the Point Pleasant Pumping Station intake centerline on 7 November 1980 (flow at Trenton ca. 3,000 cfs) and 23 July 1981 (flow at Trenton ca. 4,500 cfs) are given in Tables 2-2 and 2-3 and shown in Figures 2-2 and 2-3, respectively. On 7 November 1980 velocity was greatest (0.52 m/sec) on the surface at intake centerline station 9+3 (ca. 100 m from the Pennsylvania shore) and on 23 July 1981 velocity was greatest (1.07 m/sec) on the surface at intake centerline station 9+24 (ca. 91 m from shore). An upstream back eddy which extended from intake centerline station 6+99 to 7+74 was detected on 23 July.

## 2.3 Temperature

The water temperature in the Delaware River near Point Pleasant ranges from about 0 C in winter to a maximum of about 31.5 C in summer (USGS, 1981b).

## 2.4 Water Quality

The Delaware River at Point Pleasant can be characterized as a well-oxygenated warm water stream with a carbonate base and relatively good water quality (Kahnle et al., 1978). The water is moderately hard (Hem, 1971) and contains adequate but not excessive concentrations of nutrients.

Water quality data collected by the Bucks County Planning Commission, Department of Natural Resources, during 1971-1975 and by Kahnle et al. (1978) on August 20, 1978 are presented in Table 2-4. The coliform bacteria count during 1971-1975 was undesirably high although within the permissible range; the count on the 1978 sampling date was significantly less. The levels of iron, manganese, and phenols during 1971-1975 were also elevated relative to 1978. Kahnle et al. (1978), after examining individual values for the 1971-1975 analyses rather than mean values, determined that iron and manganese were found in excessive concentrations on relatively few occasions, all associated with high turbidity. The mean (1971-1975) phenol value was found to be artificially elevated by the practice of using the analytical detection limit as the actual value on occasions when the actual value was less than the detection limit.

## 2.5 Bathymetry and Substrate Composition

Water depth in the immediate vicinity of the proposed intake site is about 3.1 m during periods of minimum flow. Maximum depth in the region is about 4.3 m during periods of minimum flow and located about 1 km downstream of the site.

The river bottom in the vicinity of Point Pleasant is comprised principally of coarse gravel, cobbles, and boulders (Table 2-5) (William G. Majors Associates, 1981). Sand and black silt predominate in the shallows near the Pennsylvania shore. Silt was found to cover cobbles and boulders in pools and back eddies. The bottom in the immediate vicinity of the proposed intake is scoured relatively clean of silt by water currents (diver observation, 25 October 1981).

## 2.6 Macrobenthic Community

Representative species of all major orders of aquatic insects, except Plecoptera, were found in the benthos of the Delaware River near Point Pleasant (Smith and Harmon, 1974). Oligochaets, molluscs, and crustaceans were also well represented (Table 2-6). Chironomidae was the most abundant taxon and accounted for 67.3% of the total number of invertebrates taken in September 1972. Gammarus, Cheumatopsyche, Baetis, Oligochaeta (primarily Tubificidae and Lumbriculidae), and Hydropsyche were also common. The benthic community near Point Pleasant is typical of a clean or mildly polluted warm water stream in this part of the United States (Kahnle et al., 1978).

## 2.7 Fish Community

The Delaware River near Point Pleasant supports a diverse fish community which includes warm water resident game and forage fishes, anadromous species, and the catadromous American eel.

Table 2-1. Monthly mean discharge (cfs) of the Delaware River at Trenton, NJ, during 1970-1979 (from USFS, 1981a).

| | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1970 | 6,779 | 18,140 | 11,340 | 34,980 | 11,430 | 5,689 | 5,288 | 4,708 | 4,146 | 8,480 | 15,890 | 8,260 |
| 1971 | 7,661 | 16,600 | 23,850 | 19,150 | 12,620 | 7,238 | 4,232 | 8,746 | 9,299 | 7,639 | 9,936 | 19,720 |
| 1972 | 13,030 | 10,600 | 25,450 | 23,560 | 18,700 | 33,460 | 15,400 | 4,866 | 4,055 | 4,152 | 24,990 | 25,010 |
| 1973 | 20,010 | 19,380 | 15,880 | 26,680 | 23,630 | 17,850 | 18,500 | 9,157 | 5,544 | 5,111 | 6,306 | 31,070 |
| 1974 | 19,440 | 16,360 | 19,250 | 26,380 | 14,620 | 7,594 | 4,825 | 5,729 | 11,690 | 8,570 | 9,254 | 19,700 |
| 1975 | 18,640 | 21,510 | 23,460 | 18,120 | 16,840 | 14,760 | 13,750 | 6,694 | 12,170 | 17,680 | 16,610 | 10,470 |
| 1976 | 19,770 | 26,830 | 16,450 | 13,420 | 12,670 | 7,490 | 8,610 | 8,007 | 4,800 | 18,020 | 10,800 | 7,475 |
| 1977 | 3,755 | 7,511 | 38,410 | 26,530 | 11,280 | 4,454 | 3,723 | 3,515 | 8,275 | 19,930 | 17,240 | 25,550 |
| 1978 | 29,120 | 12,350 | 25,050 | 23,200 | 20,600 | 9,669 | 4,818 | 6,141 | 4,289 | 4,045 | 4,127 | 8,821 |
| 1979 | 34,950 | 15,170 | 30,240 | 18,340 | 19,920 | 10,540 | 5,330 | 4,366 | 9,062 | 15,490 | 14,050 | 11,310 |
| Mean | 17,316 | 16,445 | 22,938 | 23,036 | 16,231 | 11,874 | 8,448 | 6,193 | 7,333 | 10,912 | 12,920 | 16,739 |

Road gaging station, pumpage for the Limerick Station would not have been required during December, January, February, or March and only during one of the 19 April weeks and three of the 16 November weeks.

## 3.2 Construction Methods

Construction methods have been described in detail in a document entitled "Point Pleasant Pumping Station Intake Facilities General Construction Procedures" by E. H. Bourquard Associates, Inc., Consulting Hydraulic Engineers (1981). This document is attached as Appendix A.

## 3.3 Intake Description

The intake system proposed for the Point Pleasant Pumping Station represents essentially state-of-the-art technology for mitigating the effects of entrainment and impingement of aquatic organisms.

The intake will be a submerged, in-channel, structure comprised of cylindrical profile-wire screen assemblies set ca. 75 m off the Pennsylvania shore at mid-depth in 3.1 m of water (Fig. 3-1). Each intake screen will consist of a 1.02 x 1.02-m cylinder of V-shaped (enlarging inward) profile- or wedge-wire wound and helically welded to internal support rods set 2.36 cm apart (Fig. 3-2). Slot size will be 2 mm and the slots will be oriented perpendicular to ambient river flow. The 1:1 length to diameter ratio will minimize intake velocity gradients across the screen face.

A pair of screen cylinders will be mounted on a tee and two such screen cylinder-tee assemblies will be set at approximately a 45 degree angle to a 1.07-m diameter vertical conduit coming up from the bottom to form a "screen array" (Fig. 3-3). There will be six screen arrays, set in line, with the axis of each parallel to ambient river flow. Streamlined cones will be attached to the upstream and downstream screen cylinders. Each screen cylinder will be a minimum of 0.6 m off of the river bottom.

The screens are designed to provide a maximum through-slot velocity of 0.15 m/sec (0.5 fps) at the maximum design capacity of 95 mgd.

15 cm/sec

A compressed air backwash system will be available to facilitate clearing of screens clogged with detritus or frazzle ice. Screen clogging is not, however, expected to be a major problem. Cook (1978) reported that debris tends to bypass profile-wire screens at through-screen velocity below 0.15 m/sec. Moreover, ambient river currents in the vicinity of the intake are generally 0.30 m/sec or greater, even at very low flow, which will greatly facilitate the bypass of both detritus and aquatic organisms.

## Factors Influencing Entrainment of Shortnose Sturgeon Eggs

Shortnose sturgeon eggs are demersal and are usually laid on rubble, cobble, or gravel substrates (Dadswell, ms). Moreover, the eggs strongly adhere to rough-surfaced substrates within one minute of fertilization (see Section 4.6.2). The negative buoyancy and strong adhesiveness of the eggs, combined with the irregular topography of the spawning substrate preclude substantial downstream transport or dispersion of eggs through the water column. Since shortnose sturgeon eggs do not occur in the water column they will not be vulnerable to entrainment at the Point Pleasant intake which will withdraw water from mid-depth strata.

spawn on
Bottom

In addition, shortnose sturgeon eggs are 3.0-3.2 mm in diameter, substantially greater than the 2-mm slots of the profile wire to be employed at the Point Pleasant intake.

## Factors Influencing Entrainment of Shortnose Sturgeon Larvae

Size - To be entrained a shortnose sturgeon must be smaller in two dimensions than the 2.0- by 23.6-mm slots of the Point Pleasant intake screens. Total length of larvae relative to slot dimensions is frequently employed to predict size of larval exclusion. Tomljanovich et al. (1977), however, found that cross-sectional dimensions are generally superior to, and definitely more conservative than, total length for predicting potential entrainment.

An analysis of the head dimensions of shortnose sturgeon larvae, which represent maximum body width and depth, was conducted using measurements by Bath et al. (1981) and Washburn and Gillis Associates, Ltd. (1981). Head width was found to increase with total length according to the equation:

$$Y = 0.060\ X^{1.327} \qquad (r^2 = 0.948)$$

where Y = head width and X = total length in millimeters (Fig. 6-1).

No measurements of the head depth of shortnose sturgeon larvae are presented in the literature. An estimate of the ratio of head depth to head width was obtained by measuring these dimensions, with a dial micrometer, on a drawing of a 16.3 mm TL shortnose sturgeon collected in the Hudson River (Pekovitch, 1979; p. 42). Head depth was found to be 76% of head width.

On the basis of the relationship between head dimensions and total length, the minimum size of a shortnose sturgeon larvae that could be excluded by the 2-mm mesh of the intake screening is 14.25 mm TL (Fig. 6-1), assuming that the larva was oriented head first with head width parallel to the minimum dimension of the slot. The maximum entrainable size is a function of both head width and head depth and the degree of diagonal orientation to the slot. An orientation of head width at an angle of about 38 degrees to the long dimension of the slot was determined graphically (Fig. 6-2) to be the smallest angle (i.e., the greatest head width) which allowed a head depth within the internal dimensions of the slot. Head width at this critical angle was 3.25 mm and head depth 2.47 mm. Figure 6-1 shows that a larva with a head width of 3.25 mm would be 20.5 mm TL. Extension of pectoral fins and approach to the screens in other than head first position would significantly decrease the minimum excludable and the maximum entrainable sizes. Harmon (1980) reported that several species of river herring (Alosa spp.) were resistant to entrainment through profile-wire screens at a size less than necessary to achieve physical exclusion.

Tomljanovich et al. (1977) reported that fish with body depths up to 84% greater than mesh size could be retained, compressed, and extruded through the mesh. Retention on, and subsequent extrusion through, the Point Pleasant intake screens in unlikely. Ambient river currents in the vicinity of the proposed intake generally exceed the maximum through-slot velocity (0.15 m/sec) by a factor of two, even at very low flows (see Section 2.2). Current velocity during April and May, when small shortnose larvae are potentially present, will be much greater. Ambient currents will tend to sweep material off of the screen face thereby limiting exposure time and the opportunity for extrusion.

Life Stage Duration - Shortnose sturgeon are potentially vulnerable to entrainment only during the period between hatching and growth beyond the maximum entrainable size (i.e., 20.5 mm TL). Growth of shortnose sturgeon larvae is very rapid and can be calculated according to the equation:

$$\text{Log}_e L_t = \text{Log}_e L_o + 0.036t$$

where $L_t$ = total length at time t, $L_o$ = 10.7 mm, and t is days from hatching date (Dadswell, ms) (Fig. 6-3).

Figure 6-3 shows that the minimum excludable length (14.25 mm TL) occurs 8.5 days after hatching and the maximum entrainable length (20.5 mm TL) 18.5 days after hatching.

Vertical Distribution and Microhabitat Preference - Shortnose sturgeon larvae are highly demersal and remain closely associated with the cobbles and rubble which comprise the spawning area. Observations of shortnose sturgeon larvae by Washburn and Gillis Associates, Ltd. (1981) demonstrated that larvae up to 16 days of age remain almost exclusively on the bottom, frequently occupying interstitial spaces in the substrate with their heads under rocks. Although the frequency of movement off of the bottom was found to increase with age, larvae to an age of 43 days spent most of their time on the substrate (see Section 4.6.3).

This highly benthic and often interstitial existence is further evidenced by the very low numbers of shortnose sturgeon larvae taken in field samples despite intensive efforts by a number of investigators (Washburn and Gillis Associates, Ltd., 1981). Most of the methods employed would have been effective only if the larvae had entered the river drift.

Since the Point Pleasant intake screens will be situated a minimum of 0.6 m off of the bottom it is highly unlikely that shortnose sturgeon larvae of entrainable size would occur within the intake's zone of influence.

Avoidance Capability and Zone of Influence - A shortnose sturgeon larva's ability to avoid the intake's zone of influence is a function of its sensitivity and response to velocity gradients and turbulence and its swimming speed and endurance. As a result of the microhydrodynamics of profile-wire and the low maximum through-slot velocity of the proposed intake (0.15 m/sec) the zone of influence will be very small. Flume studies by Hanson et al. (1979) showed who is this? that striped bass eggs were influenced by a .4 ft/sec 0.12 m/sec flow through a 2-mm slot profile-wire cylinder only if they were within ca. 5.1 cm of the cylinder at a .5 ft/sec 0.15 m/sec bypass current velocity, 2.5 cm at a 1 ft/sec 0.3 m/sec bypass velocity, and 1.2 cm at a 2 ft/sec 0.61 m/sec bypass velocity. Specimens beyond these distances were bypassed by the ambient current.

Masnik Exhibit 2

**UNITED STATES DEPARTMENT OF COMMERCE**
**National Oceanic and Atmospheric Administration**
NATIONAL MARINE FISHERIES SERVICE
Washington, D.C. 20235

JUL 19 1982

F/MM2:PC

RECEIVED BY
HERSHEL J. RICHMAN
JUL 27 1982

Lt. Colonel Roger L. Baldwin
District Engineer
Corps of Engineers
U. S. Army
Philadelphia, Pennsylvania 19106

Dear Lt. Colonel Baldwin:

Enclosed is the Biological Opinion prepared by the National Marine Fisheries Service (NMFS) pursuant to Section 7(b) of the Endangered Species Act (ESA), as amended, concerning impacts of the Neshaminy Water Resource Authority's proposed Point Pleasant Pumping Station (PPPS) on endangered and threatened species.

The enclosed opinion is based on the best available scientific and commercial data. These data contain little information concerning the biology and distribution of the shortnose sturgeon, the only endangered species under the jurisdiction of the NMFS that may occur in the project area. Based upon the available data the NMFS believes that project construction during the period November-March should cause no significant adverse effects on shortnose sturgeon present in the area. It is also our opinion that the proposed state-of-the-art design of the water intake structure and projected schedule of withdrawals are adequate to ensure that juvenile and adult shortnose sturgeon as well as sturgeon eggs and larvae present in the project area will not be significantly affected. We conclude therefore, that construction and operation of the Point Pleasant Pumping Station is not likely to jeopardize the continued existence of the endangered shortnose sturgeon in the Delaware River. However, we recommend that further research and monitoring be conducted to obtain site specific data on shortnose sturgeon occurrence in and utilization of the project area. Such information would enable NMFS to render a more reliable opinion concerning the potential effects of the identified activities on the shortnose sturgeon and allow COE to reach a more reliable conclusion on the likelihood of jeopardy to the endangered shortnose sturgeon from the proposed project.

Consultation must be reinitiated if new information reveals potential impacts of the proposed activity that may affect any listed species or critical habitat; the identified activities are modified in a manner not considered herein; or a new species is listed or new critical habitat is designated that may be affected by the proposed activity.

This Biological Opinion does not constitute authority to "take" endangered or threatened species. "Take" is defined in Section 3 of the ESA as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, collect, or to attempt to engage in any such conduct. Any "taking" of endangered or threatened species is prohibited under Section 9(a) of the ESA, 50 CFR, Part 222.21, 50 CFR Part 227.71, such "takings" are subject to prosecution unless covered by a Section 10(a) of the ESA permit or ESA regulations (for threatened species). Nothing in the Biological Opinion should be construed as authorizing a Section 10(a) permit.

I look forward to continued cooperation in future consultations.

Sincerely yours,

William G. Gordon

William G. Gordon
Assistant Administrator
for Fisheries

Enclosure

# ENDANGERED SPECIES ACT
## Section 7 Consultation -- Biological Opinion

Requesting Agency: U.S. Army Corps of Engineers

Activity Considered: Section 10/404 Permit to construct and operate a water intake structure in the Delaware River at Point Pleasant, Buck's County, Pennsylvania.

Consultation Conducted By: National Marine Fisheries Service

Date Issued:

Backround Information:

In a letter dated February 12, 1982, the Philadelphia District of the U.S. Army Corps of Engineers (COE) provided the National Marine Fisheries Service (NMFS), Northeast Region, with a biological assessment (Brundage, 1982) for the Neshaminy Water Resource Authority's proposed Point Pleasant Pumping Station (PPPS), and requested that the NMFS conduct a formal consultation and provide the COE with a Biological Opinion under Section 7 of the Endangered Species Act of 1973, as amended (ESA). The shortnose sturgeon is the only endangered species under the jurisdiction of the NMFS that may occur in the project area or that may be affected by project construction or operation. No other listed or proposed species for which NMFS is responsible occurs in the project area. No critical habitat has been designated in the area.

The Public Notice of an application for a COE permit under Section 10 of the River and Harbor Act of 1899, and Section 404 of the Clean Water Act of 1977, as amended, was issued on April 6, 1981. The Delaware River Basin Commission (DRBC), the lead agency for the entire project, of which the PPPS is only a portion, prepared a Final Environmental Impact Statement (FEIS) in 1973, and an updated Environmental Assessment in 1980, for the overall Point Pleasant water diversion project. In addition, the Nuclear Regulatory Commission issued an FEIS in 1973 for construction of the Limerick Generating Station, Units 1 and 2, and is preparing an EIS for its operation.

In response to the COE's request of April 14, 1981, for comments on the Public Notice, NMFS by letter of June 6, 1981, to the COE raised several concerns about potential impacts to shortnose sturgeon associated with the diversion and consumptive use of Delaware River water and discussed initiation of ESA Section 7 consultation procedures. In response to a COE letter dated August 24, 1981, requesting information on the shortnose sturgeon and NMFS's advice on how to proceed, NMFS by letter of September 28, 1981, to the COE raised concerns about possible impacts of the construction and operation of the PPPS water intake structure on shortnose sturgeon, and stated that insufficient information existed at that time to determine what shortnose sturgeon life stages utilize that part of the Delaware River. The NMFS indicated that unless new data on shortnose sturgeon life history in the Delaware River showed that certain life stages would be unaffected by the proposed project, the assessment should address the potential effects of the project on all sturgeon life stages in order to fulfill both the NMFS' and the COE's obligations pursuant to Section 7 of the Endangered Species Act.

This Biological Opinion responds to the COE's request of February 12, 1982, and is based on consideration of information contained in the biological assessment (Brundage, 1982), as well as other pertinent reports, including: Pottle and Dadswell (1979), Dovel (1981), Washburn & Gillis Associates (1981), and Dadswell (ms). In addition, information concerning the hydrologic and hydraulic operational characteristics of the proposed project was submitted by DEL-AWARE UNLIMITED, INC., in letters dated May 14, and June 14, 1982. These data were evaluated by the NMFS and the COE and included in the consultation process.

## Description of Proposed Action

The PPPS and intake structure are components of the planned Neshaminy Water Supply System (NWSS), which is designed to provide a supplemental water supply for central Bucks and Montgomery Counties in Pennsylvania and deliver supplemental make-up water to the Philadelphia Electric Company to compensate for evaporative loss from the cooling towers of the Limerick Nuclear Generating Station. Water to supply the NWSS will be withdrawn from the Delaware River by the PPPS through an in-channel intake.

The PPPS will be located on the Delaware River near Point Pleasant, Pennsylvania, at river kilometer (rkm) 252.9, slightly more than 1 km above the Lumberville wing dam and 37 km upstream of the fall line at Trenton, New Jersey. The PPPS will withdraw water immediately upstream of a pool about 2 km long formed by the Lumberville wing dam.

The water intake structure will be a submerged, in-channel structure made of cylindrical profile-wire screen arrays set about 75 m off the Pennsylvania shore at mid-depth in about 3.1 m 10.25 ft of water at minimum river flow. The intake system for the PPPS represents state-of-the-art technology for mitigating the effect of entrainment and impingement of aquatic organisms. Slot size in the intake screen will be 2 mm, and the axis of the slots will be perpendicular to ambient river flow. Each screen cylinder will be at least 0.6 m 2 ft above the river bottom. Maximum through-slot velocity will be 0.15 m/sec .5 ft/sec at the maximum design capacity of 95 million gallons per day (mgd).

Water withdrawals will vary seasonally and probably will be heaviest from April or May through October. Maximum river flows occur during March and April. Therefore, water withdrawals should not significantly affect flows in the early spring. Minimum river flows (about 3,000 cfs, or 1,938 mgd) generally occur during July-September. Maximum water withdrawals during low flow periods will only be 2-5% of the total available flow. Ambient river currents in the vicinity of the intake structure are generally 0.30 m/sec or greater, even at very low flow (Brundage, 1982).

Pursuant to an agreement with the DRBC, in-water construction operations will be conducted only from November through March. A barge-mounted clam-shell dredge or dragline will be used to excavate a trench for the intake pipes and intake screen foundations. Excavated material will be temporarily stockpiled on barges, and the trench will be backfilled after installation of the intake pipes and foundations. Water removed from the Pennsylvania Canal to allow installation of the intake conduit will be pumped to a sedimentation basin, and any fish present in the area will be transported downstream. Little, if any, submarine blasting will be required during the construction phase of the project. Geologic studies (William G. Majors Associates, 1981) at the intake site show that only the lower 0.6 m of rock to be excavated in the immediate vicinity of the intake screen may require blasting. In the event that some blasting is required, a submarine blasting procedure designed to minimize potential impact to aquatic life, has been developed. This procedure incorporates the use of small charges and slow-burning powder. In addition, small "fish scaring" charges will be detonated on the surface near the blast area before detonating each main charge.

## Biology and Distribution of the Shortnose Sturgeon

According to Dadswell (ms), the shortnose sturgeon ranges from the St. John River, New Brunswick, Canada, to Indian River, Florida. Throughout its range, the shortnose sturgeon occurs in rivers, estuaries, and the sea. Populations tend to be most abundant in the estuary of their respective river. Any captures at sea have occurred within a few miles of land.

The species is anadromous. The young are hatched in fresh water, usually above tidal influence. Ripe adults have been captured as far upstream as rkm 246 in the Hudson River, New York (Dovel 1981).

In the Delaware River drainage, shortnose sturgeon have been taken in upper Delaware Bay, in the upper tidal portion of the river from Philadelphia to Trenton, and above the fall line at Scudder's Falls to Lambertville, New Jersey (rkm 240), about 13 km below the Point Pleasant project site (Brundage, 1982). The Delaware River is free-flowing above Lambertville and contains no physical obstructions that would block shortnose sturgeon migrations upriver.

In spring, in the northern part of their range, adult shortnose sturgeon move upriver from overwintering areas to the upper tidal and lower non-tidal freshwater reaches of rivers to spawn. After spawning, adults generally move downstream to summer foraging areas. In fall, most adults and some juveniles migrate from foraging areas to overwintering areas in relatively deep water. The seasonal spatial distribution of shortnose sturgeon in the Delaware River appears to correspond to this generalized pattern (Brundage, 1982).

According to Dadswell (ms), shortnose sturgeon appear to be strictly benthic feeders. Adults eat molluscs, insects, crustaceans, and small fish; juveniles eat crustaceans and insects. Feeding in freshwater largely is confined to periods when water temperatures exceed 10°C; feeding is heavy immediately after spawning in spring and during the summer and fall, and light in winter.

According to Brundage (1982) and Dadswell (ms), shortnose sturgeon grow more slowly, mature later, spawn less frequently, have larger eggs, and live longer in northern latitudes than in the southern part of their range. The oldest (a 67-year-old female) and largest (a 122-cm, 23.6-kg female) shortnose sturgeons were taken from the St. John River in New Brunswick, Canada. Females mature at age 6 in Georgia and age 12 in New Brunswick, Canada. First spawning after maturity may be delayed up to five years in females. Average age of first spawning females in the St. John River is 15 years. First spawning in the Hudson and

Delaware Rivers may occur at about one-half the age reported for the St. John River, or about 7-10 years. In the St. John River, females spawn approximately once every three years, and resting periods may be as long as 5-11 years. Spawning periodicity in more southern populations is unknown.

In any consideration of shortnose sturgeon, each population must be considered independently. There are gaps between the northern, central, and southern populations of shortnose sturgeon. Moreover, shortnose sturgeon in the various river systems may be independent since no apparent migration between river systems has been observed.

Brundage (1982) and Dadswell (ms) found that fecundity of shortnose sturgeon ranges from about 12,000 to 14,000 eggs/kg body weight for fish from Canada to Georgia. Ripe eggs have a diameter of about 3 mm. Eggs probably are released close to the bottom, where they are fertilized. After fertilization, the eggs rapidly sink to the bottom and become very adhesive, strongly adhering to rough-surfaced substrates within about one minute. Hatching occurs in 12-16 days at 8-12°C.

According to Dadswell (ms), spawning occurs at or above the limit of tidal intrusion between February and May, depending on latitude. Spawning occurs at temperatures varying from 9-12°C during or soon after peak river flows in the spring in river sections of fast flows (40-60 cm/sec) with gravel or rubble bottoms, generally well upriver of summer foraging and nursery grounds (rkm 100-200).

Brundage (1982) reported that ripe and running-ripe adults occur during the middle two weeks of April in the Delaware River. Spawning in the Delaware River is believed to occur either in the upper tidal river, from Trenton to Scudder's Falls (rkm 222), or possibly in the lower non-tidal river above Scudder's Falls to or above the Point Pleasant area. Although the precise spawning areas in the Delaware River have yet to be defined, the above seem to be the most likely areas. This assumption is based on habitat and substrate considerations, the capture of two ripe females at Scudder's Falls (Hoff, 1965), the capture of 12 adults above Lambertville in April 1981 (Brundage 1982), and the similarity of this region to known shortnose sturgeon spawning areas in other drainages.

According to Washburn & Gillis (1981), shortnose sturgeon larvae hatch at lengths of about 7-10 mm, but those less than 8 mm may not survive. Larvae tend to remain on the bottom for the first 7-10 days after which they move off the substrate occasionally, but remain on or near the bottom most of the time. The yolk sac disappears in approximately 10 days (when larvae are about 14 mm), and feeding activity begins. Older larvae become more active as they begin feeding. However, limited success in collecting larvae with standard field sampling methods suggests that larvae may occupy interstitial spaces in gravel during their first weeks of life.

Larvae lying on the bottom or inhabiting the interstices between gravel or rocks would be subjected to very low current velocities, perhaps approaching zero on the downstream sides of rocks or between rocks (Brundage, 1982). According to Brundage (1982), Washburn & Gillis (1981), and Pottle and Dadswell (1979), 11-day-old shortnose sturgeon larvae (15.5-16.5 mm) can maintain swimming speeds of about .69 - .16 ft/sec 3-5 cm/sec (2-3 body lengths per second). Similarly, juvenile shortnose sturgeon (17-26 cm) can maintain an ~~1.5 ft/sec~~ average speed of about 48 cm/sec (2-3 body lengths per second). Larvae (15.5-16.5 mm) can attain burst speeds of about 6-8 cm/sec (4-5 body lengths per second). The maximum burst speed of one 16.5 mm larva was .48 ft/sec 14.7 cm/sec (9 body lengths per second).

## Potential Impacts on Shortnose Sturgeon

All developmental stages of shortnose sturgeon could be affected by either construction or operation of the proposed project. Dredging activities could cause lethal or sublethal effects by increasing turbidity, smothering eggs and larvae, or burying food organisms. Blasting operations could injure or kill larval, juvenile, or adult shortnose sturgeon or reduce their food supply. Operation of the pumping station could injure or kill shortnose sturgeon eggs and larvae through impingement on intake screens or entrainment through the pumping station. Additional diversion and consumptive use of water could adversely affect shortnose sturgeon by reducing flows in the Delaware River or by further decreasing dissolved oxygen levels near Philadelphia.

Brundage (1982) provided a reasonably thorough assessment of potential impacts of the proposed project on shortnose sturgeon. The assessment takes a worst-case approach and assumes that all life stages of shortnose sturgeon could be present in the Point Pleasant area. This approach was used because no empirical information is available regarding utilization of the project area by shortnose sturgeon. Although shortnose sturgeon have been taken above the fall line at Lambertville, New Jersey (rkm 240), none ever have been taken near Point Pleasant (rkm 252.9), despite the fact that there are no physical obstructions to upstream migration above Lambertville. Thus, the importance of the area to the various developmental stages of the species is unknown and only can be inferred until adequate studies are completed.

Brundage's (1982) assessment was based on: (a) the known distribution and habitat requirements of the shortnose sturgeon in various river systems; (b) a comparison of environmental conditions in the Delaware River near Point Pleasant with those in river systems where shortnose sturgeon are known to spawn, forage, and overwinter; and (c) features of the project's design construction, and operation that would mitigate or preclude impacts on any shortnose sturgeon developmental stage that may occur in the area. Major conclusions of Brundage's (1982) assessment were as follows:

1. Most adult and some juvenile shortnose sturgeon migrate to overwintering areas in fall. Two overwintering locations within the estuary have been suggested, utilization of which is thought to be dependent on reproductive condition. The deeper portions of the lower estuary appear to be utilized by non-ripening adults, ripe (but not running) males and older juveniles. Some ripening adults may migrate upriver and overwinter with younger juveniles in fresh water. Overwintering of juvenile or adult shortnose sturgeon near Point Pleasant is unlikely. Since construction would be limited to the period November through March, it is unlikely that shortnose sturgeon will occur in the area during the construction period. Therefore, the potential impacts of dredging, blasting and other construction activities on shortnose sturgeon in or migrating through the area should be slight to non-existent.

2. The lower non-tidal Delaware River from the Point Pleasant area to Scudder's Falls may be utilized in the spring as a shortnose sturgeon spawning, nursery, and feeding area, and during the summer and fall as a feeding

area. Spawning is likely to take place in the Delaware River in April; thus, eggs and larvae could be present in April and May. Major project water withdrawals probably would occur primarily from April or May through October. Since water flows peak in March and April, the withdrawals during April and May should not affect flows significantly in the early spring when the greatest number of shortnose sturgeon developmental stages may be present in the area. Since shortnose sturgeon eggs are demersal, very adhesive, and relatively large compared with the intake screen openings, they should not be significantly vulnerable to entrainment or impingement. Small shortnose sturgeon larvae (less than 10 days old and 15.5 mm) also are demersal and, therefore, should not be significantly vulnerable to entrainment or impingement. Occasionally larger larvae may occur above the bottom; however, they should be strong enough swimmers to avoid significant impingement or entrainment. Operation of the water intake structure should not adversely affect juvenile or adult shortnose sturgeon or their food supply.

3. The small volume of water projected to be withdrawn by the Point Pleasant project relative to total river flow will preclude significant impact of downstream water quality. The Point Pleasant project is designed to withdraw a maximum of 95 mgd (147 cfs) representing less than 5% of available freshwater flow during periods of minimum flow at Trenton (3,000 cfs) (DRBC, 1980). In addition, a simulation

model developed by the Delaware River Basin Commission showed that under extreme low river flow condition (2,780 cfs at Trenton) and maximum diversion by the proposed project, the level of dissolved oxygen in the Philadelphia to Trenton reach would be reduced by about 0.08 PPM (DRBC, 1980). Reduction of dissolved oxygen levels by this small amount is not believed to be detrimental to the species. In view of the above, project operation should not significantly affect shortnose sturgeon by decreasing freshwater flows or further lowering downstream dissolved oxygen concentrations in the Delaware River near Philadelphia.

## Conclusions

The NMFS concludes that the biological assessment (Brundage, 1982) is based on the best scientific and commercial data presently available, and that it provides a generally realistic assessment of the potential impacts of construction and operation of the Point Pleasant Pumping Station on shortnose sturgeon in the Delaware River. However, we are concerned that many conclusions presented in the assessment are based solely on engineering data, laboratory experiments, and extrapolations from shortnose sturgeon life history data collected from other river systems, and that the actual extent to which various life stages of shortnose sturgeon utilize the Point Pleasant region of the Delaware River still is unknown. Despite recent intensive sampling efforts (October-December 1981), no spring surveys have been conducted in, or upstream of, the Point Pleasant area and the limits of the spawning grounds in the Delaware River are unknown. Although shortnose sturgeon have been taken 13 km downstream at Lambertville, no adults have been taken in the Point Pleasant area, no eggs have been collected from the river, and the extent of the habitat utilized by shortnose sturgeon larvae and post-larvae is undetermined. We are concerned that the assessment is weakened because site-specific information has not yet been collected and believe that sufficient information should be collected on the occurrence of shortnose sturgeon in the project area in the spring (April-May), when passage of shortnose sturgeon through or utilization of the area by shortnose sturgeon for spawning, can be best determined.

Based upon these scant available data concerning the shortnose sturgeon in the project area the NMFS believes that project construction during the period November-March should cause no significant adverse effects on any shortnose sturgeon that may be overwintering in or migrating through the project area. The NMFS also believes that project operation should not significantly affect shortnose sturgeon by decreasing river flows or further lowering downstream dissolved oxygen concentrations. It is our opinion that the proposed state-of-the-art design of the water intake structure and the projected schedule of withdrawals are adequate to ensure that juvenile and adult shortnose sturgeon in the project area will not be significantly affected. Additionally, shortnose sturgeon eggs and/or larvae that may be present in the area in the spring probably would not suffer significant entrainment or impingement.

From the above factors, the NMFS concludes that construction and operation of the Point Pleasant Pumping Station is not likely to jeopardize the continued existence of the endangered shortnose sturgeon in the Delaware River. However, a reassessment of potential impacts may be necessary if future research and monitoring studies conducted in the Delaware River significantly modify the bases for this opinion.

## Recommendations

Although the best available evidence leads us to believe that the proposed construction schedule and methods design of the water intake structure, and projected operating schedule are such that the expected impacts to shortnose sturgeon will be insignificant, we also believe a far more reliable opinion could be given if site specific data on shortnose sturgeon occurrence in and utilization of the project area were obtained. Therefore, we recommend that adequate field surveys be completed to determine:
(1) whether, and to what extent, adult shortnose sturgeon

occur in or above the project area in the spring (March-May); (2) whether they spawn in or above the project area; and (3) whether the area is important to foraging shortnose sturgeon. It would also be desirable, although difficult, to determine whether shortnose sturgeon eggs and larvae occur in the area. If shortnose sturgeon eggs and larvae do occur in the project area, we recommend that a monitoring program be designed and implemented to determine the impact of project operation on those early life stages. Adopting these recommendations would provide the information needed for a more precise evaluation of the impacts of this project on shortnose sturgeon and enable the COE to determine more reliably if the activities identified herein are likely to violate the provisions of Section7(a)(2) of the Endangered Species Act.

## Reinitiation of Consultation

Consultation must be reinitiated: (1) if new information reveals impacts of the identified project that may affect listed species or critical habitat; (2) if the proposed activities are modified; or (3) if a new species is listed that may be affected by the project.

Nothing in this Biological Opinion should be construed as authorizing any takings (as defined in Section 3 of the ESA) of endangered or threatened species pursuant to Section 10(a) of the ESA or immunizing any actions from the prohibitions regarding unauthorized takings contained in Section 9(a) of the ESA.

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