13.0 Assessment of Impacts Associated with Rock Blasting

13.1 Description of the Blasting Project

Approximately 229,000 cubic yards of bedrock from the Delaware River near Marcus Hook would be removed to deepen the navigation channel to a depth of 47 ft mean low water. Approximately 70,000 cubic yards, covering 18 acres, will be removed by blasting, with the remainder being removed by mechanical methods. In order to remove the rock by blasting, holes drilled into the rock are packed with explosive to direct the force of the blast into the rock. The depth and placement of the holes and the size of the charges control the amount of rock that is broken. The project would be conducted by repeatedly drilling, blasting, and excavating relatively small areas until the required amount and area of bedrock is removed.

13.2 Fish Communities Near Marcus Hook

The Marcus Hook area is well-studied, although most recent studies have avoided sampling in the winter, the period of greatest relevance for this project. Most of the winter studies were conducted during the 1970s and thus do not represent present conditions. Water quality in the Delaware River improved in the 1980s (Albert 1988), and the species composition and abundance of fish near Marcus Hook has changed dramatically (Weisberg et al. in press).

The most relevant study was conducted by the Atlantic City Electric Company (ACEC) as part of an entrainment and impingement study from December, 1989 until March, 1990 using both pelagic and bottom trawls (ACEC, 1991). Fish were most abundant in deepwater habitats. White perch (Morone americana) and hogchoker (Trinectes maculatus) comprised 57 and 21 percent of the catch, respectively (Table 13-1). Other dominant species captured included channel catfish (Ictalurus punctatus) and silvery minnow (Hybognathus reglus) which, together, comprised an additional 14 percent of the total catch during the study period. Total monthly finfish density in the deepwater habitat for the 4-month study period ranged from 0.021 to 0.047 fish/m^3.

Other winter studies conducted in the Delaware River provide little insight as to whether sampling conducted during the winter of 1990 was representative of most years. Public Service Electric and Gas (PSE&G) conducted winter fish surveys in the Delaware River from 1970 through 1976 (PSE&G 1980), but these studies collected samples near Artificial Island, where salinities are much higher than those at Marcus Hook. Harmon et al. (1975) conducted fish surveys associated with an earlier blasting project at Marcus Hook from March 4 until April 10, 1975 using gillnets. However, because gillnets are typically size selective, they are not the most appropriate gear type for characterizing entire fish communities.

Table 13-1. Species composition and relative abundance near Marcus Hook during winter (data from ACEC [1991] bottom trawl sampling)

Species	# Collected	% of Catch
White perch _Morone americana_	2,066	57.1
Hogchoker _Trinectes maculatus_	772	21.3
Channel catfish _Ictalurus punctatus_	261	7.2
Silvery minnow _Hybognathus reglus_	230	6.3
Blueback herring _Alosa aestivalis_	150	4.1
Striped bass _Morone saxatilis_	65	1.8
Bay anchovy _Anchoa mitchilli_	28	< 1.0
Sea lamprey _Petromyzon marinus_	11	< 1.0
American shad _Alosa sapidissima_	10	< 1.0
Alewife _Alosa pseudoharengus_	9	< 1.0
American eel _Anguilla rostrata_	5	< 1.0
Gizzard shad _Dorosoma cepedianum_	2	< 1.0
Brown bullhead _Ameiurus nebulosus_	2	< 1.0
Tesselated darter _Etheostoma olmstedi_	2	< 1.0
Naked goby _Gobiosoma bosc_	2	< 1.0
Atlantic sturgeon _Acipenser oxyrhynchus_	1	< 1.0
Atlantic menhaden _Brevoortia tyrannus_	1	< 1.0
White crappie _Pomoxis annularis_	1	< 1.0
Total	**3,618**	**100.0**

Other studies of the area serve to confirm which species use this portion of the Delaware River during their life cycles, but do not provide data for the winter period. The most comprehensive fish survey in the Marcus Hook area was conducted by O'Herron et al. (1994). They summarized field data from the spring, summer, and fall of 1992 and 1993. Sampling occurred in shallow ($\leq$ 3.05 meters (m) mean low water (MLW)), intermediate (3.05 to 7.62 m MLW), and deep ($\geq$ 7.62 m MLW) habitat at four stations near Marcus Hook using a variety of gear including beach seines, gillnets, trawls, trotlines, and electrofishing. O'Herron and colleagues collected 31 species in the Marcus Hook vicinity. Nine species made up 92% of the catch (i.e., Atlantic croaker (Micropogonias undulatus), white perch, bay anchovy, hogchoker, channel catfish, mummichog (Fundulus heteroclitus), silvery minnow, banded killifish (Fundulus diaphanus), and striped bass. Fish were most abundant during the fall, when Atlantic croaker represented 45% of the catch. The most abundant species during spring and summer were white perch and hogchoker, respectively. Striped bass were most abundant during the fall, and the largest number of American shad were collected during the summer.

Weisberg et al. (in press) examined beach seine data collected by the New Jersey Department of Environmental Protection (NJDEP) annually during summer and fall from 1980 through 1993. The NJDEP captured 40 species during the surveys, many of which were found in the O'Herron et al. (1994) survey. However, these data are not as useful for characterizing fish communities in deep water habitats near Marcus Hook because they used only beach seines.

Several other recent studies provide comprehensive surveys of ichthyoplankton abundance and density (Burton and Weisberg 1992; Weisberg and Burton 1993; Burton et al. 1994). All three of these studies documented that the Marcus Hook area has high densities of anadromous fish larvae from April through June. The ACEC study, discussed above, documented that larval fish abundance during the anticipated blasting period is likely to be extremely low. No larvae were collected using plankton nets during December, January, or February. Some Atlantic menhaden larvae were captured in March (density 0.36 larvae/m^3); however, the majority of the menhaden stocks along the east coast spawn in off-shore waters (Jones et al. 1978).

13.3 Potential Effects of Blasting Shock Waves

Several studies have demonstrated that underwater blasting can cause fish mortality (Teleki and Chamberlain 1978, Wiley et al. 1981, and Burton 1994). These studies have shown that size of charge and distance from detonation are the two most important factors in determining fish mortality from blasting. Depth of water, type of substrate, and the size and species of fish present also affect the number of fish killed by underwater explosions.

Teleki and Chamberlain (1978) conducted blasting mortality experiments in Long Point Bay, Lake Erie, at depths of 4 to 8 m. Fish were killed in radii ranging from 20 to 50 m for 22.7-kg charges and from 45 to 110 m for 272-kg charges during 28 monitored blasts. Explosives were packed into holes bored into the lake bottom. The kind of substrate determined the decay rate of the pressure wave, and mortality differed by species at identical pressure. Teleki and Chamberlain (1978) presented their results for several species in terms of 10% and 95% mortality radii (i.e., radii at which 10% and 95% of the caged fish were killed).

Wiley et al. (1981) measured the movement of fish swim bladders to estimate blast mortality for fish held in cages at varying depths during midwater detonations of 32-kg explosives in the Chesapeake Bay. Pressure gages were placed in cages that contained spot and white perch. The study was conducted at the mouth of the Patuxent River in depths of about 46 m. Using data collected during 16 blasts, Wiley and colleagues predicted the distances at which 10%, 50%, and 90% mortality of white perch occurred. For 32-kg charges, the pressure wave was propagated horizontally most strongly at the depth at which the explosion occurred.

Burton (1994) conducted experiments on the Delaware River to estimate the effects of blasting to remove approximately 1,600 cubic yards of bedrock during construction of a gas pipeline. Charges of 112 and 957 kg of explosives were detonated in the river bed near Easton, Pennsylvania, during July 1993 in depths ranging between 0.5 and 2.0 m. Smallmouth bass were caged at a range of distances from the blasts. In the larger of the two blasts all fish in cages positioned farther than 24 meters from the blast survived (Table 13-2).

13.4 Methods to Reduce Impacts to Fish From Blasting.

There are three strategies for minimizing impacts to fish from blasting: 1) perform blasting during the winter when the least number of species and individual fish are present, 2) employ fish avoidance devices to reduce fish abundance in the area affected, and 3) conduct blasting in ways that minimize the magnitude of the shock waves produced.

13.4.1 Winter Blasting

Since the density and diversity of fish species are lowest during the winter months (1 December to 15 March), limiting blasting to this time period should minimize impacts to fish. Blasting is prohibited in this reach of the Delaware River from 15 March to 1 December by the Delaware River Basin Fish and Wildlife Management Cooperative to minimize impacts to fish.

Table 13-2. Results of Blasting Mortality Experiments Conducted near Easton, Pennsylvania, July 1993. (Source: Burton 1994)

Test Date	Survival (%)	Distance from Blast (m)
23 July (112.5 kg of explosives)	100.0	48
	100.0	24
	100.0	12
	0.0	6
	0.0	3
30 July (957 kg of explosives)	100.0	48
	100.0	24
	80.0	12
	20.0	6
	0.0	3

13.4.2 Fish Avoidance Techniques

13.4.2.1 Strobe Lights

Many species of fish exhibit strong avoidance responses to underwater strobe lights; however, avoidance is species-specific and varies with other factors, such as current velocity and turbidity (McIninch and Hocutt 1987). Strobe lights were effective at repelling juvenile American shad from intakes at night at the York Haven Hydroelectric Plant on the Susquehanna River (SWES 1990), but were ineffective for American shad during the day at the Roseton Station on the Hudson River (Matousek et al. no date). Combining strobe lights with an air bubble curtain increased effectiveness for white perch, spot, and Atlantic menhaden in a laboratory setting (McIninch and Hocutt 1987) but attracted fish during the day at the Roseton Station (Matousek et al. no date). Sager and Hocutt (1987) found that the effectiveness of strobe lights was less at a current velocity of 0.5 m per second than it was at lower velocities.

13.4.2.2 Low Frequency Sound

Pneumatic poppers project a loud, broadband signal of relatively low frequency (20-1000 Hz) into the water. Most of the sound energy from pneumatic poppers is at approximately 60 Hz. Haymes and Patrick (1986) found that a 12-popper array was up to 99% effective in excluding adult alewife from an experimental area; however, the poppers attracted large numbers of small unidentified fish on at least one occasion. The area of influence of a popper was limited to approximately 10 m, which may make it effective for power plant intakes, but would limit its value for excluding fish from a blast mortality zone. Furthermore, Richard (1968) found that some predatory fish species could be attracted by pulsed low-frequency sound (25-50 Hz), and at the Roseton Station on the Hudson River, the pneumatic popper was ineffective at repelling alewives and blueback herring and attracted American shad (LMS 1988a).

Loeffelman et al. (1991) projected low-frequency sounds at various fish species and repelled 66% to 94% of the fish; however, the authors believe that signals need to be customized to fish species, life stages of fish, and site conditions. This methodology, therefore, would require on-site testing and development, making it less appropriate for the Marcus Hook project.

13.4.2.3 Fishpulser

The fishpulser is a spring-mass impact device that produces a repetitive sharp sound of low fundamental frequency (38 Hz) and high amplitude. A fishpulser was effective in excluding adult alewife at the Pickering Station on Lake Ontario, reducing the number of alewives moving inshore by 85% (Patrick et al. no date). Adult alewives did not habituate to the hammers after six hours of continuous exposure. American shad, however, did not consistently avoid the sound of the fishpulsers at the Annapolis Generating Station on the Bay of Fundy (LMS 1988b).

13.4.2.4 High Frequency Sound

Dunning et al. (1992) examined the response of adult alewife to high frequency sound by exposing fish to continuous-tone, pulsed-tone, and pulsed-broadband sound in a cage suspended in a flooded quarry. The fish habituated to continuous tones; pulsed broadband sound between 117 and 133 kHz at 163 dB//1μPa elicited the most consistent response. Fish were completely excluded from the half of the cage exposed to higher sound levels.

Nestler et al. (1992) produced significant behavioral responses in blueback herring using high frequency sound. In daytime tests, blueback herring responded strongly and consistently to high frequency sound between 110 and 149 kHz at sound pressure levels greater than 190 dB//1μPa. The optimum frequency, in terms of intensity of the immediate avoidance response, appeared to be between 120 and 130 kHz. Hydroacoustic surveys showed a maximum effective distance of 50 to 70 m at a source level of 200 dB//1μPa at 1 m. The fish did not habituate to the sounds during 1-hour test periods. Nestler et al. were also able to overcome an attracting light stimulus using high frequency sound.

Based on unpublished tests of this technology, high frequency sound is likely to be ineffective on non-Alosid species. Some researchers believe that the effectiveness of high frequency sound is limited to the genus Alosa because of cranial structures unique to this taxonomic group (John Nestler, personal communication).

13.4.2.5 Scare Charges

Scare charges are a frequently used, inexpensive, but poorly studied method of moving fish away from an area. Small, nonlethal charges (usually blasting caps) are detonated underwater to produce a pressure wave similar to that produced by larger construction blasts but of smaller magnitude. Because this methodology is not documented, its effectiveness is not known; nevertheless, setting off scare charges before major blasts is inexpensive, easy, and could be effective for at least some species.

13.4.3 Reducing Shock Wave Magnitude

Reducing the magnitude of the pressure wave which fish experience can be accomplished by using bubble curtains and/or specific energy-dispersing blasting techniques. Both of these strategies are reviewed below:

13.4.3.1 Bubble Curtains

Bubble curtains are vertical walls of air bubbles within the water column which are intentionally produced using various types of air diffusers placed on the bottom. They are placed between the blast site and resources requiring protection (e.g., fish, bridges supports, etc.). Bubble curtains are effective at reducing the pressure wave experienced by such resources by essentially creating an energy-absorbing volume of air within the water column. Keevin et al. (in press) have demonstrated the effectiveness of this technology at reducing fish mortality. As discussed in Section 13.3, mortality of fish exposed to blasting is directly and positively correlated with the magnitude of the pressure wave which they experience. In experiments using bluegill (Lepomis macrochirus), peak pressure reductions ranged from 87.5 to 99.4 percent when bubble curtains were employed. Mortality of bluegill, at all distances tested (6.5-14.0 meters from the blast) fell from 100 percent, without the bubble curtain, to zero percent with the bubble curtain in operation.

Bubble curtains appear to be extremely effective at reducing fish mortality. However, deploying and operating a bubble curtain could be costly because the large area of the river where blasting will occur would require that the system be moved several times.

13.4.3.2 Construction Blasting Methods

The following blasting methods were suggested by Keevin and Hempen (1995), to reduce the impacts of blasting on fish. Although the appropriateness of these techniques could vary with site-specific factors, the Wilmington District of the Corps of Engineers (1995) estimated that these techniques could significantly reduce the impact of blasting (Table 13-3).

1) Plan the blasting program to minimize the size of explosive charges per delay (time lag during detonation) and the number of days of explosive exposure;
2) Subdivide the explosives deployment, using electric detonating caps with delays (preferable) or delay connectors for detonating cord (less useful), to reduce total pressure;
3) Use decking (explosives separated by delays) in drill holes to reduce total pressure; and
4) Use angular stemming material (rock piled at an angle on top of drill holes) to reduce energy dispersal.

13.5 Recommended Methods to Minimize Blasting Impacts

Adverse impacts to fish will be minimized by conducting blasting between 1 December and 15 March as recommended by the Delaware River Basin Fish and Wildlife Management Cooperative, and using construction blasting methods described in Section 13.4.3.2 to reduce the amount of energy that would impact fish. In addition, scare charges will also be used. Monitoring of impacts to fish from blasting will also be conducted to verify that impacts are minimal.

TABLE 13-3. Estimated Reduction of Fish Mortality from Blasting Using Construction Techniques

Blasting Impacts Estimated For A General Underwater Blasting Plan (Stemming the Top 1 Foot of Holes and Inserting Delays After Rows)

Fish Weight in Lbs.	LD50* Feet	Acres for LD50	LD1* Feet	Acres for LD1
0.125	1,610	196	2,780	573
1.000	899	63	1,550	181
12.000	446	17	768	47

Blasting Impacts Estimated For A General Underwater Blasting Plan (Stemming The Top 1 Foot of Holes and Inserting a Delay at Each Hole)

Fish Weight In Lbs.	LD50* Feet	Acres for LD50	LD1* Feet	Acres for LD1
0.125	381	12.5	656	34.5
1.000	213	4.5	364	11.5
12.000	105	1.4	180	3.4

The blasting plan consisted of 80 holes in 10 rows of 8 holes, each spaced 8 feet apart. Each hole is 4.5 inches in diameter and contains 98.5 pounds of explosive.

* LD50 (Lethal Distance) Feet is the distance from the blast where 50% of the fish died. LD1 Feet is the distance from the blast where 1% of the fish died.

It is evident from the stemming and inserting delays (a minimum of 25 milliseconds) on each hole reduces the size of the blast impact zone for the worst-case scenario, (i.e., LD1 for a 2-ounce swimbladder fish) by approximately 94 percent (from 573 acres to 34.5 acres).

SOURCE: Wilmington District, U.S. Army Corps of Engineers, 1995.