Blast Monitoring Program for the Kill Van Kull Deepening Project

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EXECUTIVE SUMMARY

This report presents the results of a monitoring program which examined the fish communities of the New York/New Jersey Harbor Complex (Harbor), the potential effects of blasting on the aquatic biota of the Harbor, and recorded water-borne pressures from confined blasts. The study was required by the State of New Jersey Department of Environmental Protection (DEP) for the issuance of a water quality certification pursuant to Section 401(b) of the Federal Clean Water Act to authorize the proposed Kill Van Kull (KVK) Deepening Project. The KVK Deepening Project is part of the New York and New Jersey Harbor Navigation Study, which was authorized by §435 of the Water Resources Development Act (WRDA) of 1996.

The monitoring program for the KVK deepening project was comprised of a detailed literature search, which provided the basis for establishing a list of fish species likely to occur in the KVK and seasonal patterns of use by those species; a literature review of available engineering and scientific papers concerning the impact of underwater blasting on fisheries resources; and, a study recording water-borne blast pressures from confined blasts conducted as part of the ongoing KVK Deepening Project. The Blast Monitoring Program for the KVK Deepening Project was prepared by the U.S. Army Corps of Engineers – New York District (USACE) with contributions from the St. Louis District.

The Kill Van Kull is a tidal strait, located on the north side of Staten Island. This strait connects Newark Bay (Bergen Point) to the Upper New York Bay (Constable Hook). The Kill Van Kull is approximately 5 mi long, approximately 0.5 mi wide, and ranges between 10 and 50 feet deep. Small shoals and shallow areas are located along both shores with one larger shallow area at Port Johnson, located about mid-way on the north side of the Kill. Both shores also have structures such as piers (active and former), wrecks, rocks, piles, and the Bayonne Bridge near the western terminus.

In order to characterize the fish communities of the New York/New Jersey Harbor Complex (Harbor), fisheries catch data were reviewed from sampling projects conducted in the Harbor from 1986 to 1999. During this time period, 11 projects were completed that reviewed species of fish occurring at different locations throughout the Harbor. Results of these studies indicated that a diverse fish community utilizes the Harbor, 96 fish species overall, 1 shark species, and 3 skate species were identified. Methods of collection included otter trawls, gill nets, beach seines, and impingement collections from water intakes at power plants. The studies showed that several fish species inhabit the Harbor year-round albeit in different life stages (i.e., larvae present while adults absent); these species include winter flounder, windowpane flounder, and striped bass. Other species are present only during a portion of the year; these species include blueback herring, American shad, summer flounder and bluefish.

The potential impacts of underwater blasting on aquatic biota were investigated through an extensive literature review. The results indicated that the primary cause of injury and mortality to aquatic organisms from blasting in aquatic environments appears to be damage associated with rupture and hemorrhage of air-filled internal organs, particularly the swim bladder. The weight of the charge and distance from the detonation are the most important factors affecting the extent of injury and mortality. Water depth, substrate type, depth of the fish, and size and species of fish are also contributing factors.

In-situ blast pressure monitoring was conducted to record water-borne blast pressures from confined blasts. Data was collected from actual blasts to compare with open water blasts, which are unconfined and produce high peak pressures in the water. Pressure data was collected from confined blasts of varying intensities to calculate theoretical mortality radii for aquatic organisms.

The blasts were recorded using a trigger-source transducer. This recording method allowed monitoring to take place at a location removed from the immediate blasting area. The blast pressures recorded in the KVK were noted to be quite low. The St. Louis District has performed numerous studies on the waterborne energy from blasting, and stated that the blast pressures recorded during the KVK study were among the lowest levels of maximum pressure recording that they've taken. The validity of the data and collection methods was confirmed through the use of consistency tests and comparison with recordings from previous studies. Based on the results, the St. Louis District judged the KVK blast data to be of high quality. Other measures of impact, both impulse and energy flux density, were to be calculated from the pressure wave data. The complexity of the waveform and the high level of noise relative to the measured pressures did not allow evaluation of either impulse or energy flux density.

Predictions based on the data collected from this study indicate that impacts on the aquatic community may be diminished through the use of arrays configured with maximum charge weights located in the middle of lesser charge weights. The data also infer that the confined charges used in the KVK Blasting Program appear to have less of an impact on aquatic biota than would equivalent open water charges.

1.0 INTRODUCTION

The Kill Van Kull Deepening Project is part of the New York and New Jersey Harbor Navigation Study (Harbor Navigation Study). The Harbor Navigation Study (HNS) was authorized by §435 of the Water Resources Development Act (WRDA) of 1996. The object of the HNS was to determine the best manner in which to provide safe and efficient access to the various marine terminals within the Port of New York and New Jersey for deeper-draft vessels already within the world's commercial fleet, or whose introduction to the fleet was reasonably foreseeable (USACE 2004a).

The channel deepening was originally planned to be an incremental process. However, it was determined that significant project cost savings could be realized from consolidating implementation of the proposed deepening. Savings would result primarily through the avoidance of repeated mobilization and de-mobilization efforts in the same area, reduced repetition of drilling and blasting in the same area, and increased production rates (USACE 2004a). In addition, it was determined that short-term and long-term environmental impacts associated with unconsolidated implementation would apply to consolidated implementation as well; there would be no significant environmental impacts solely attributable to consolidated implementation (USACE 2004b).

As a result, the United States Army Corps of Engineers – New York District (USACE) prepared a Limited Reevaluation Report (LRR) to address the consolidation of separately authorized navigation improvement projects. Vertical consolidation was authorized in §202 of WRDA 2000. Specific to the Kill Van Kull (KVK) deepening, the LRR recommended excavation of KVK Contract Areas 4b and 5 should be undertaken with the implementation of the 50-foot Recommended Plan (USACE 2004a).

1.1 Study Purpose and Need

The LRR recommends the excavation of KVK Contract Areas 4b and 5 to the 50-foot Recommended Plan (with 2-foot overdredge) through vertical consolidation. This would require the use of explosives to facilitate removal of bedrock in portions of the channel. Through issuance of, the State of New Jersey required implementation of a monitoring program to evaluate the impact of underwater blasting activities on aquatic biota that reside in or utilize the area as nursery or as part of migratory routes as part of the special conditions of the State Water Quality Certificate (WQC) (Appendix A). This study examines the fish communities of the New York/New Jersey Harbor Complex (Harbor), the potential effects of blasting on aquatic biota of the Harbor, and records water-borne pressures from confined blasts. Figure 1.1.1 presents the KVK's location in relation to the Harbor and Figure 1.1.2 shows the study area location.

1.2 Study Process

The study was comprised of two major components: a literature search and a water-borne pressure monitoring program including extrapolation of potential impacts to fisheries resources.

The literature search consisted of two sub tasks:

a) A detailed literature search including information from recent (circa. 1975 – 2003) fisheries surveys within the vicinity of the project site. An emphasis was placed on the fisheries of the KVK and Newark Bay. The literature search included examination of NY and NJ State Environmental Agency Archives as well as those of the USACE and the National Marine Fisheries Service (NMFS). This review provided the basis for finalizing a list of species likely to be found in the KVK and the extent of the seasonal periods of concern. This review was compared to those species, which were captured during the monitoring phase of the study. Special consideration was given to migratory species as well as any State or Federally listed species. The report discusses the relative abundance of common species as well as the general likelihood of different species occurring in the project area.

b) A review of the available engineering and scientific papers concerning the impacts of underwater blasting on fisheries resources. This review focused on data collected for marine/estuarine environments with conditions and species relevant to the KVK project. Keevin and Hempen (1997) provided a review of the effects of blasting on aquatic organisms associated with various blasting methods. Equations were provided that were used to calculate the blast impact zone for aquatic organisms. The type and quantity of explosive, how the explosives are set, ignition method, and water depth are important factors in this calculation. These equations were modified to estimate the blast impact zone (mortality distance) for the species of concern in the KVK/NB.

The water-borne pressure monitoring program consisted of the following:

Mid-water pressures, impulse, and energy flux density were determined for four locations from each blast. Eight shots were initiated and monitored. In addition, two small, open-water shots were conducted and used to determine the difference (amplitude reduction, frequency shifts, and temporal variations) between open-water and confined shots. The results of this comparison were used to estimate the kill radius for typical shots based on existing fish mortality models.

The tasks completed before monitoring included: understanding the bathymetry, currents and fauna of the rock removal zone to be monitored; and, fabrication of the pressure monitor positioning system. The tasks completed before each monitored shot included: consideration of shot timing and spatial location relative to monitoring positions, given the shot and marine environment; determination of approximate monitoring calculations for each given monitored shot; deployment of monitoring array and associated buoys; timing the monitors' initiation of the shot. During and following each monitored shot the following occurred; recording the pressure waves; storing the monitoring records; removal or repositioning of the equipment for the next shot or monitoring completion; and, vessel use to reach the drilling/shooting barge and transit to the monitoring locations. Placement of the four pressure monitors required consideration of tide cycle and depth and duration lengths for each production and open-water shot.

2.0 FISH COMMUNITY OF NEW YORK/NEW JERSEY HARBOR COMPLEX

2.1 Introduction

Fisheries catch data were reviewed from sampling projects conducted in the New York/New Jersey Harbor complex from 1986 to 1999. During this time period, 11 projects were completed that reviewed species of fish occurring at different locations in the large and diverse New York/New Jersey Harbor complex. Eight of these studies were reviewed and summarized in the New York and New Jersey Harbor Navigation Study, Final Environmental Impact Study (NY/NJFEIS) in December 1999. Additional fish sampling programs included in this review are the aquatic program 316(b) reports for the Hudson Generating Station on the lower Hackensack River in November 1988, the Linden Generating Station on the northern Arthur Kill in October 1989, and the Hudson River Aquatic Environmental Study in September 1988. The studies are were conducted along the Hudson River on the west side of Manhattan, Upper New York Bay, Lower New York Harbor, Hackensack River, Newark Bay, Kill Van Kull, Arthur Kill, and Raritan Bay. The reports reviewed included the following:

New York/New Jersey Final Environmental Impact Statement:

- Lawler, Matusky & Skelly Engineers. 1993. Arthur Kill Impingement and Entrainment Report, September 1991 – September 1992. Report to Consolidated Edison Company of New York, Inc.

- Lawler, Matusky & Skelly Engineers. 1996. Newark Bay Biological Monitoring Program. April 1995 – March 1996. Report prepared for the Port Authority of New York/New Jersey.

- Louis Berger & Associates, Inc. 1992. Staten Island Bridges Program Environmental Report.

- National Marine Fisheries Service. Undated. Results of a Biological and Hydrological Characterization of Newark Bay, New Jersey, May 1993 - April 1994.

- U.S. Army Corps of Engineers. 1999. New York-New Jersey Harbor Navigation Study-Biological Monitoring Program. USACE–New York District.

- U.S. Coast Guard. 1995. Draft Environmental Impact Statement/Draft Section 4(f) Statement. Staten Island Bridges Program, Modernization and Capacity Enhancement Project.

- Wilk, S.J., R.A. Pikinowski, D.G. McMillan, and E.M. MacHaffie. 1998. Seasonal Distribution and Abundance of 26 Species of Fish and Megainvertebrates Collected in the Hudson-Raritan Estuary, January 1992 – December 1997. Northeast Fish. Science Center Reference Document 98-10. 145 p.

- Woodhead, P.M.J. 1991. Inventory and Assessment of Habitat and Fish Resources and Assessment of Information on Toxic Effects in the New York/New Jersey Harbor Estuary. New York/New Jersey Harbor Estuary Program. Marine Sciences Research Center, State University of New York, Stony Brook, New York.

Other Studies:

- New York City Public Development Corporation. 1988. Hudson River Center Site Aquatic Environmental Study. Prepared by EEA Inc., Garden City, New York.

• Public Service Electric and Gas Company. 1988. Hudson Generating Station Supplemental 316(b) Report. Prepared by EA Science and Technology, Middletown, New York.

• Public Service Electric and Gas Company. 1989. Linden Generating Station Supplemental 316(b) Report. Prepared by EA Science and Technology, Middletown, New York.

The purpose of this literature review was to prepare a report that lists the fish species most likely to utilize or occur in the Kill Van Kull (KVK) and determine seasonal patterns of use by those species. For the purpose of this report, the surveys are referred to by the areas that were sampled, except for the New York and New Jersey Navigation Study, Final Environmental Impact Study which is referred to as NY/NJ-FEIS.

2.2 Fish Community Diversity

Results of the studies reviewed show a diverse fish community occurring within the complex. Overall 96 fish species from 47 families, 1 shark species, and 3 skate species were identified as utilizing or occurring within the Harbor Complex. Table 2.2.1 lists the species caught in the Harbor Complex.

The data that are available include information from collections made with otter trawls in channel, shoal, and interpier areas; and with gill nets, beach seines, and cooling water intake impingement collections at power plants. The more marine areas, including Lower New York Harbor, Raritan Bay, the south part of the Arthur Kill, as well as the power plant impingement data, tend to contain the most diverse fish communities.

Alewife (*Alosa pseudoharengus*) and weakfish (*Cynoscion regalis*) were the only species captured in all 11 surveys reviewed.

Fish species that were captured in a majority of the surveys included American eel (*Anguilla rostrata*), blueback herring (*Alosa aestivalis*), Atlantic herring (*Clupea harengus*), American shad (*Alosa sapidissima*), bay anchovy (*Anchoa mitchilli*), Atlantic tomcod (*Microgadus tomcod*), striped bass (*Morone saxitilis*), red hake (*Urophycis chuss*), spotted hake (*U. regia*), northern pipefish (*Syngnathus fuscus*), striped searobin (*Prionotus evolanis*), grubby (*Myoxocephalus aenaeus*), white perch (*M. americana*), bluefish (*Pomatomus saltatrix*), spot (*Leiostomus xanthurus*), cunner (*Tautogolabrus adspersus*), butterfish (*Peprilus triacanthus*), and winter flounder (*Pleuronectes americanus*).

Additional species that were identified in the surveys included hickory shad (*A. mediocris*), Atlantic menhaden (*Brevoortia tyrannus*), gizzard shad (*Dorosoma cepedianum*), silver hake (*Merluccius bilinearis*), northern kingfish (*Menticirrhus saxatilis*), scup (*Stenotomus chrysops*), striped killifish (*Fundulus majalis*), Atlantic silverside (*Menidia menidia*), lined seahorse (*Hippocampus erectus*), northern searobin (*P. carolinus*), black sea bass (*Centropristis striata*), crevalle jack (*Caranx hippos*), Atlantic moonfish (*Selene setapinnis*), tautog (*Tautoga onitis*), summer flounder (*Paralichthys dentatus*), smallmouth flounder (*Etropus microstomus*), windowpane flounder (*Scopthalmus aquosus*), hogchoker (*Trinectes maculates*), mummichog (*Fundulus heteroclitus*), and northern puffer (*Sphoeroides maculatus*).

Other species of note include conger eel (*Conger oceanicus*), striped anchovy (*Anchoa hepsetus*), rainbow smelt (*Osmerus mordax*), white hake (*U. tenuis*), threespine stickleback (*Gasterosteus aculeatus*), striped mullet (*Mugil cephalus*), naked goby (*Gobiosoma bosc*), Atlantic mackerel.

Table 2.2.1
Fish Species Collected in the New York/New Jersey Harbor Complex During Various Studies from 1986 to 1999

Family/Common Name	Genus Species
Requiem Sharks/ Smooth dogfish [(a)]	*Mustelus canis*
Skates/Clearnose Skate [(a)]	*Raja eglanteria*
Little skate	*Raja erinacea*
Winter skate[(a)]	*Raja ocellata*
Sturgeons/Atlantic sturgeon [(a)]	*Acipenser oxyrzynus*
Freshwater Eels/ American Eel	*Anguilla rostrata*
Conger Eel/ Conger Eel	*Conger oceanicus*
Herrings/ Blueback herring	*Alosa aestivalis*
American Shad	*Alosa sapidissima*
Hickory Shad	*Alosa mediocris*
Alewife	*Alosa pseudoharengus*
Atlantic menhaden	*Brevoortia tyrannus*
Atlantic herring	*Clupea harengus*
Gizzard shad	*Dorosoma cepedianum*
Anchovies/ Bay anchovy	*Anchoa mitchilli*
Striped anchovy	*Anchoa hepsetus*
Smelts/ Rainbow smelt	*Osmerus mordax*
Bullhead catfishes/ White catfish[(a)]	*Ictalurus catus*
Brown bullhead [(a)]	*Ictalurus nebulosus*
Lizardfishes/ Inshore lizardfish	*Synodus foetens*
Carps and Minnows/ Goldfish [(a)]	*Carassius auratus*
Cods/ Silver hake	*Merluccius bilinearis*
Atlantic tomcod	*Microgadus tomcod*
Red hake	*Urophysis chuss*
Spotted hake	*Urophycis regia*
White hake	*Urophycis tenuis*
Atlantic cod [(a)]	*Gadus morhua*
Fourbeard rockling [(a)]	*Enchelyopus cimbrius*
Pollock	*Pollachius virens*
Cusk-eels/ Fawn cusk-eel [(a)]	*Lepophidium cervinum*
Striped cusk-eel [(a)]	*Ophidion marginatum*
Toadfishes/Oyster toadfish	*Opsanus tau*
Goosefishes/ Goosefish	*Lophius americanus*
Needlefishes/ Atlantic needlefish [(a)]	*Strongylura marina*
Killifishes/ Mummichog	*Fundulus heteroclitus*
Striped killifish	*Fundulus majalis*
Banded killifish [(a)]	*Fundulus diaphanous*
Silversides/ Inland silverside	*Menidia beryllina*
Tidewater silverside	*Menidia peninsulae*
Atlantic silverside	*Menidia menidia*

Table 2.2.1 (cont'd)
Fish Species Collected in the New York/New Jersey Harbor Complex During Various Studies from 1986 to 1999

Family/Common Name	Genus Species
Sticklebacks/ Threespine stickleback	*Gasterosteus aculeatus*
Fourspine stickleback [a]	*Apeltes quadracus*
Trumpetfishes/ Bluespotted cornetfish	*Fistularia tabacaria*
Pipefishes/ Lined seahorse	*Hippocampus erectus*
Northern pipefish	*Syngnathus fuscus*
Searobins/ Northern searobin	*Prionotus carolinus*
Striped searobin	*Prionotus evolanis*
Sculpins/ Longhorn sculpins [a]	*Myoxocephalus octodecemspinosus*
Grubby	*Myoxocephalus aenaeus*
Temperate Basses/ White perch	*Morone americana*
Striped bass	*Morone saxatilis*
Sea Basses/ Black sea bass	*Centropristis striata*
Sunfishes/ Black crappie [a]	*Pomoxis nigromaculatus*
Bluegill	*Lepomis macrochirus*
Largemouth bass[a]	*Micropterus salmoides*
White crappie [a]	*Pomoxis annularis*
Pumpkinseed [a]	*Lepomis gibbosus*
Warmouth[a]	*Lepomis gulosus*
Bluefishes/ Bluefish	*Pomatomus saltatrix*
Jacks/ Cravalle jack	*Caranx hippos*
Rough scad [a]	*Trachurus lathami*
Lookdown	*Selene vomer*
Atlantic moonfish	*Selene setapinnis*
Blue runner [a]	*Caranx chryos*
Snappers/ Grey snapper	*Lutjanus griseus*
Porgies/ Scup	*Stenotomus chrysopos*
Drums/ Weakfish	*Cynoscion regalis*
Spot	*Leiostomus xanthurus*
Northern kingfish	*Menticirrhus saxatilis*
Silver perch [a]	*Bairdiella chryosura*
Atlantic croaker [a]	*Micropogon undulatas*
Butterflyfishes/ Spotfin butterflyfish [a]	*Chaetodon ocellatus*
Mullets/ Striped mullet	*Mugil cephalus*
White mullet [a]	*Mugil cerema*
Wrasses/ Tautog	*Tautoga onitis*
Cunner	*Tautogolabrus adspersus*
Gunnels/ Rock gunnel	*Pholis gunnellus*
Stargazers/ Northern stargazer	*Astroscopus gattatus*
Combtooth Blennies/ Feather blenny [a]	*Hypsoblennius hentz*
Sand Lances/ American sand lance	*Ammodytes americanus*
Gobies/ Naked goby	*Gobiosoma bosc*
Seaboard goby	*Gobiosoma ginsburgi*
([a]) Species caught in only 1 or 2 out of 11 sampling programs	

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Table 2.2.1 (cont'd)
Fish Species Collected in the New York/New Jersey Harbor Complex During Various Studies from 1986 to 1999

Family/Common Name	Genus Species
Mackerels/ Spanish mackerels [(a)]	*Scomberomorus maculatus*
Chub mackerel [(a)]	*Scomber japonicus*
Atlantic mackerel	*Scomber scombrus*
Butterfishes/ Butterfish	*Peprilus triacanthus*
Lefteye Flounders/ Smallmouth flounder	*Etropus microstomus*
Summer Flounder	*Paralichthys dentatus*
Windowpane	*Scopthalmus aquosus*
Fourspot flounder	*Paralicthys oblongus*
Righteye Flounders/ American plaice [(a)]	*Hippoglossoides platessoides*
Winter Flounder	*Pleuronectes americanus*
Soles/ Hogchoker	*Trinectes maculates*
Blackcheek tonguefish [(a)]	*Symphurus plagiusa*
Leatherjackets/ Orangespotted fish [(a)]	*Cantherhines pullus*
Planehead filefish [(a)]	*Monacanthus hispidus*
Boxfisbes/ Scrawled cowfish [(a)]	*Lactophrys quadricornis*
Puffers/ Northern puffer	*Sphoeroides maculatus*
Striped burrfish	*Chilomycterus schoepfl*
Goatfishes/ Spotted goatfish [(a)]	*Pseudupeneus maculatus*
([a]) Species caught in only 1 or 2 out of 11 sampling programs	

(*Scomber scombrus*), fourspot flounder (*Paralicthys oblongus*), little skate (*Raja erinacea*), oyster toadfish (*Opsanus tau*), rock gunnel (*Pholis gunnellus*), and American sand lance (*Ammodytes americanus*). Table 2.2.2 lists the species most likely to be found in the KVK based on the year to year occurrence of the species in the complex, on the catch locations in the studies reviewed (e.g., Arthur Kill, Newark Bay, and upper New York Harbor), and the numbers caught each year.

A total of 38 species were caught in only 1 or 2 of the surveys and included freshwater species, incidentals to the area, and species that may not be efficiently captured with the gear used for those studies. These species are marked with a superscript (a) on Table 2.2.1.

Table 2.2.2
Fish Species Likely to be Caught in the Kill Van Kull Based on Collection in Adjacent Portions of the Harbor Complex

Common Name	Genus Species
Skates/ Little skate	*Raja erinacea*
Freshwater Eels/ American Eel	*Anguilla rostrata*
Conger Eels/ Conger Eel	*Conger oceanicus*
Herrings/ Blueback herring	*Alosa aestivalis*
American Shad	*Alosa sapidissima*
Hickory Shad	*Alosa mediocris*
Alewife	*Alosa pseudoharengus*
Atlantic menhaden	*Brevoortia tyrannus*

Table 2.2.2 (cont'd)
Fish Species Likely to be Caught in the Kill Van Kull Based on Collection in Adjacent Portions of the Harbor Complex

Common Name	Genus Species
Atlantic herring	*Clupea harengus*
Gizzard shad	*Dorosoma cepedianum*
Anchovies/ Bay anchovy	*Anchoa mitchilli*
Striped anchovy	*Anchoa hepsetus*
Smelts/ Rainbow smelt	*Osmerus mordax*
Lizardfishes/ Inshore lizardfish	*Synodus foetens*
Carps and Minnows/ Goldfish [a]	*Carassius auratus*
Cods/ Silver hake	*Merluccius bilinearis*
Atlantic tomcod	*Microgadus tomcod*
Red hake	*Urophysis chuss*
Spotted hake	*Urophycis regia*
Fourbeard rockling [a]	*Enchelyopus cimbrius*
Toadfishes/Oyster toadfish	*Opsanus tau*
Killifishes/ Mummichog	*Fundulus heteroclitus*
Striped killifish	*Fundulus majalis*
Silversides/ Atlantic silverside	*Menidia menidia*
Sticklebacks/ Threespine stickleback	*Gasterosteus aculeatus*
Pipefishes/ Northern pipefish	*Syngnathus fuscus*
Searobins/ Northern searobin	*Prionotus carolinus*
Striped searobin	*Prionotus evolanis*
Sculpins/ Grubby	*Myoxocephalus aenaeus*
Temperate Basses/ White perch	*Morone americana*
Striped bass	*Morone saxatilis*
Sea Basses/ Black sea bass	*Centropristis striata*
Bluefishes/ Bluefish	*Pomatomus saltatrix*
Jacks/ Cravalle jack	*Caranx hippos*
Lookdown	*Selene vomer*
Atlantic moonfish	*Selene setapinnis*
Porgies/ Scup	*Stenotomus chrysopos*
Drums/ Weakfish	*Cynoscion regalis*
Spot	*Leiostomus xanthurus*
Northern kingfish	*Menticirrhus saxatilis*
Mullets/ Striped mullet	*Mugil cephalus*
Wrasses/ Tautog	*Tautoga onitis*
Cunner	*Tautogolabrus adspersus*
Gunnels/ Rock gunnel	*Pholis gunnellus*
Sand Lances/ American sand lance	*Ammodytes americanus*
Gobies/ Naked goby	*Gobiosoma bosc*
Mackerels/ Atlantic mackerel	*Scomber scombrus*
Butterfishes/ Butterfish	*Peprilus triacanthus*
Lefteye Flounders/ Smallmouth flounder	*Etropus microstomus*
Summer Flounder	*Paralichthys dentatus*
Windowpane	*Scopthalmus aquosus*

Table 2.2.2 (cont'd)
Fish Species Likely to be Caught in the Kill Van Kull Based on Collection in Adjacent Portions of the Harbor Complex

Fourspot flounder	*Paralicthys oblongus*
Righteye Flounders/ Winter Flounder	*Pleuronectes americanus*
Soles/ Hogchoker	*Trinectes maculates*
Puffers/ Northern puffer	*Sphoeroides maculatus*

Species lists of Essential Fish Habitat (EFH) by management geographic coordinate square have been designated by the Mid-Atlantic Fisheries Management Council and the National Marine Fisheries Service. The two management squares that include the KVK, Newark Bay, and Arthur Kill were reviewed to identify the designated species and life stages for the study area. The two EFH management squares reviewed also include Atlantic Ocean waters within the Hudson River estuary affecting Staten Island from Port Richmond, New York on the north, east around to Great Kills South Harbor of Great Kills, New York, south of Bayonne, New York. The species for which EFH was designated in the KVK, Newark Bay, and Arthur Kill areas included:

- For eggs, larvae, juveniles, and adults—winter flounder, windowpane flounder, scup, king mackerel (*Scomberomorus cavalla*), Spanish mackerel (*S. maculatus*), and cobia (*Rachycentron canadum*)
- For eggs, larvae, juveniles—red hake
- For larvae, juveniles, and adults—Atlantic sea herring, Atlantic butterfish, and summer flounder
- For juveniles and adults—bluefish, Atlantic mackerel, and black sea bass
- For larvae and juveniles—dusky shark
- For larvae and adults—sandbar shark
- For eggs—sand tiger shark.

The king mackerel, cobia, dusky shark, sandbar shark, and sand tiger shark were not caught in any of the projects reviewed for this report.

2.3 Abundance and Seasonal Distribution

The number of species encountered during the year follows a similar pattern among surveys with lowest numbers caught in the winter, increases occurring in the spring, staying at higher numbers in the summer and fall, and then declining into winter. This pattern reflects the overall nature of the complex with the spring migration into and fall migration out of the area by juvenile and adult stages of many anadromous and marine fish species. The adults of anadromous species (e.g., striped bass, Atlantic tomcod, American shad, blueback herring, and alewife) migrate through the harbor area to upstream brackish and freshwater spawning areas in the spring and juveniles migrate downstream into and through the harbor in late summer and fall. Many marine species spawn offshore and juveniles utilize the estuary as nursery habitat (e.g., bluefish, weakfish, and

Atlantic menhaden) from late spring through early fall. Other species may spawn in various portions of the harbor complex (e.g., bay anchovy and winter flounder).

The species that dominated the catches in the Hackensack River during 1988 included killifish, Atlantic silverside, Atlantic tomcod, bay anchovy, and winter flounder. The bay anchovy and Atlantic tomcod were most abundant in the lower Hackensack River. Species of winter flounder, bluefish, weakfish, Atlantic menhaden, and hake were only collected in the lower Hackensack River. In those catches, 90 percent of the Atlantic tomcod, and all of the bluefish and weakfish, were young-of-the-year fish.

The species that dominated the catches in the Arthur Kill during 1988 included winter flounder, weakfish, spotted hake, spot, and Atlantic tomcod, accounting for over 90 percent of the catch in the otter trawls. The catch of bluefish and weakfish were primarily juvenile fish.

The species that dominated the catches in the Hudson River pier study from 1986 to 1988 were striped bass, white perch, winter flounder, and tomcod, accounting for over 90 percent of the trawl catch. Striped bass, bluefish, and Atlantic menhaden dominated the gill net catch.

The NY/NJ-FEIS channel trawl sampling collected bay anchovy, striped bass, and weakfish as the dominant species. For the shoal sampling, the dominant species were bay anchovy, striped bass, winter flounder, and Atlantic silverside.

2.3.1 Winter (January-March)

Impingement catches in the Hackensack River in 1988 had the highest catch for white perch (January), red hake (January), and threespine stickleback (February) during the winter. Atlantic silverside, alewife, Atlantic tomcod, and gizzard shad comprised a large portion of the catch. Otter trawl catches of winter flounder (January) and striped bass (February) were highest during the winter. Trawl catches of white perch, red hake, and grubby were also high.

Impingement catches in the Arthur Kill in the winter of 1988-1989 had the highest catch for Atlantic silverside, striped bass, and gizzard shad in January and threespine stickleback in March. January catches of spot, silver hake, Atlantic menhaden, bay anchovy, windowpane flounder, and grubby were also high. Otter trawls in the Arthur Kill had the highest catch totals for winter flounder (January and February), grubby, white perch, and striped bass (all in January) during the winter. High catches also occurred for windowpane flounder and red hake.

Otter trawl collections in winter along the Hudson pier areas had the highest catch over the year for striped bass in March which, along with white perch, comprised the majority of the catch. Winter flounder and tomcod were also present in the catch in relatively high numbers compared to the remainder of the year.

The NY/NJ-FEIS channel sampling results for Winter 1994 showed the highest catches over the year for striped bass and white perch in March and grubby and rainbow smelt in January. Gizzard shad and winter flounder in January were also collected at that time. Trawl catches in 1996 only had winter flounder, striped bass, and gizzard shad. Trawl catches in 1999 showed the highest catches over the year for white perch, winter flounder, and striped bass in March.

The NY/NJ-FEIS shoal station catches for Winter 1994 had relatively few species and with low abundance. In 1996, the results showed the highest catches over the year for grubby in January. January catches of striped bass and winter flounder comprised the majority of the catch. The shoal catch results for Winter 1999 showed the highest catches over the year for Atlantic silverside in January and February, and for winter flounder and Atlantic herring in March.

2.3.2 Spring (April-June)

Impingement samples in the Hackensack River had the highest catch for blueback herring and summer flounder (May), and Atlantic menhaden, striped bass, and bay anchovy (all in June) during spring. Otter trawl catches were highest for the year for Atlantic tomcod (June) and American shad (May). Trawl catches of red hake and hogchoker were also made.

Impingement sampling in the Arthur Kill during the spring had the highest catch for the year for spotted hake (April). Higher catches of Atlantic silverside, Atlantic menhaden, and blueback herring were also made. Otter trawls in the Arthur Kill had the highest catch totals of the year for spotted hake in May and showed high catch totals for April through June. The winter flounder, grubby, red hake, and Atlantic tomcod all had relatively high catch totals. Spring beach seine collections in the Arthur Kill had the highest catch for the year for bay anchovy in June and Atlantic tomcod and northern pipefish in May. Atlantic silverside, striped bass, and winter flounder comprised the majority of the seine catch.

Otter trawl collections in Spring 1986 along the Hudson River pier areas had the highest catch over the year for Atlantic tomcod, American shad, summer flounder, hogchoker, and American eel in May. Winter flounder and striped bass were also present in the catch in high numbers in April while Atlantic silverside catches in May and June are high. Otter trawl collections in Spring 1987 had the highest catch over the year for Atlantic tomcod and alewife in May; summer flounder, striped bass, white perch, and winter flounder in May; and Atlantic silverside in June. The spring gill net collections had striped bass, Atlantic menhaden, and bluefish comprising the majority of the catch. The highest gill net catches for the year were recorded for striped bass and bluefish during spring.

The NY/NJ-FEIS channel sampling results for Spring of 1993 showed the highest catches over the year for spotted hake in June. Spotted hake was also high in the May catch. Atlantic tomcod, striped bass, grubby summer, and winter flounder were all caught in higher numbers. Trawl catches in 1995 showed the highest catches over the year for spotted hake in May and winter flounder in June. Trawl catches in 1999 showed the highest catches over the year for spotted hake and windowpane flounder in April and Atlantic tomcod in June. Winter flounder and striped bass comprised the majority of the catch in April. Winter flounder and bay anchovy comprised the majority of the catch in June.

The NY/NJ-FEIS shoal station catches for Spring 1993 showed the highest catches over the year for Atlantic herring, Atlantic tomcod, and winter flounder in June. Bay anchovy and striped bass were also present in catches. In 1995, the results showed the highest catches over the year for striped bass in April and May. Winter flounder, bay anchovy, summer flounder, and spotted hake were caught in increased numbers. The shoal sampling for Spring 1999 showed that catches of striped bass, Atlantic tomcod, bay anchovy, alewife, blueback herring, and winter flounder comprised the majority of the catch.

2.3.3 Summer (July-September)

Impingement samples in the Hackensack River had the highest catch for Atlantic tomcod, bluefish, and Atlantic silverside for the year in September. Catches of Atlantic menhaden, weakfish, winter flounder, and blueback herring all occurred at that time. Otter trawl catches were highest for the year for alewife, bluefish, and Atlantic menhaden in August and weakfish in September. Winter flounder and striped bass were also caught in each month.

Impingement samples in the Arthur Kill in the summer had the highest catch for the year for bluefish and Atlantic menhaden in July and for bay anchovy in September. Blueback herring catches were high in July, then declined into September. Otter trawls in the Arthur Kill had the highest catch totals of the year for weakfish, Atlantic tomcod, spot, bay anchovy, striped searobin, and windowpane flounder in September. Catches of spotted hake and grubby decreased into September. Summer beach seine collections in the Arthur Kill had the highest catch for the year for Atlantic silverside and bluefish in August and in September. Bay anchovy catches in July were almost at the highest and then no catch was recorded in August and September. Atlantic silverside, striped bass, and winter flounder comprised the majority of the seine catch.

Otter trawl collections in Summer 1986 along the Hudson River pier areas had the highest catch over the year for Atlantic silverside in July. Catches of the silverside remained high into September. Bluefish, summer flounder, winter flounder, and hogchoker were also present in the catch. Otter trawl collections in Summer 1987 had high catches of striped bass and Atlantic silverside. The summer gill net collections had the highest catch for Atlantic menhaden for the year. Striped bass and bluefish comprised the majority of the summer catch.

The NY/NJ-FEIS channel sampling results for Summer 1993 showed the highest catches over the year for Atlantic tomcod, bay anchovy, summer flounder, and Atlantic menhaden in July and weakfish in September. High catches of striped bass in July and winter flounder were made in August. Trawl catches in Summer 1995 showed the highest catches over the year for Atlantic tomcod in July and bay anchovy in August. Catches of grubby and winter flounder were high in July but decreased in to September. Trawl sampling in 1999 showed the highest catches over the year for weakfish, Atlantic silverside, and alewife in July. High catches of bay anchovy, scup, and butterfish were also noted in summer.

The NY/NJ-FEIS shoal station in 1993 showed the highest catches over the year for summer flounder in July and bay anchovy and bluefish in September. Striped bass catch totals were also high. In 1995, the results showed the highest catches over the year for bay anchovy, Atlantic silverside, bluefish, American shad, winter flounder, white perch, and northern kingfish in September; weakfish in July; and summer flounder in August. In 1999, the results showed the highest catches over the year for weakfish in July and bay anchovy in September. Striped bass had higher catch totals in July and decreased into September.

2.3.4 Fall (October-December)

Impingement samples in the Hackensack River had the highest catch for the year for Atlantic silverside, weakfish, and Atlantic herring in October; alewife, American shad, and gizzard shad in November; and white perch in December. Catches of Atlantic menhaden, bluefish, blueback herring, and Atlantic tomcod were high. Catches of bay anchovy and Atlantic silverside decreased into December. Otter trawl catches were highest for the year for American eel in October and blueback herring and white perch in December. Catches of Atlantic tomcod dominated the totals for all three months.

Impingement samples in the Arthur Kill in Fall 1988 had the highest catch for the year for weakfish in October; blueback herring, American shad, and silver hake in November; and spot and alewife in December. Gizzard shad and Atlantic silverside numbers increased in catch totals from October to December. Otter trawls in the Arthur Kill had the highest catch totals of the year for red hake in November. Winter flounder and Atlantic tomcod have high catch rates, however, tomcod numbers decrease into December. October beach seine collections in the Arthur Kill had Atlantic silverside and bluefish comprising the majority of the catch.

Otter trawl collections in Fall 1986 along the Hudson River pier areas had the highest catch over the year for alewife and white perch in November and winter flounder in December. Catches of striped bass increased to another high point in December for the year. Otter trawl collections in Fall 1987 were low with striped bass, Atlantic tomcod, and winter flounder in the catch. The fall gill net collections had low abundance with Atlantic menhaden, bluefish, and striped bass accounting for the majority of the catch.

The NY/NJ-FEIS channel sampling results for Fall 1993 showed the highest catches over the year for alewife, gizzard shad, and winter flounder in November. High catches of striped bass, white perch, and Atlantic tomcod were evident. Weakfish was abundant in the October catch, then decreased into December. Spotted hake appeared in samples in high numbers from October to December. Trawl sampling in Fall 1995 showed the highest catches over the year for striped bass in December. The grubby and Atlantic tomcod were caught again in December. Weakfish were only caught in October. Trawl catches in Fall 1998 showed the highest catches over the year for bay anchovy in October and American shad in November. Weakfish was abundant in October, and then the catch decreased.

In 1993, the NY/NJ-FEIS shoal station showed the highest catches over the year for striped bass and Atlantic silverside in October. In 1995, the results showed high catches for bay anchovy, Atlantic silverside, and striped bass in October with catches decreasing into December. In 1998, the results showed the highest catches over the year for striped bass in November. Winter flounder, black sea bass, bay anchovy, Atlantic silverside, and smallmouth flounder comprised the majority of the catches.

2.4 Summary

The results show that several fish species are found in the complex for most of the year and most probably would occur in the KVK. These species are present not necessarily at all life stages throughout the year, but may occur during a certain life stage at different times of the year. These species include the anadromous species striped bass and Atlantic tomcod, and also white perch, winter flounder, windowpane flounder, and grubby.

The catch results also show several fish species that spend part of the year in the complex and could be found in the KVK during that time. These species included the anadromous species of blueback herring and American shad, and also weakfish, Atlantic herring, Atlantic menhaden, rainbow smelt, Atlantic silverside, bay anchovy, summer flounder, red hake, spotted hake, and bluefish.

The fish species that dominated the collections included striped bass, white perch, winter flounder, Atlantic tomcod, spotted hake, bay anchovy, Atlantic silverside, Atlantic menhaden, bluefish, spot, and weakfish. Table 2.4.1 lists the dominant species and summarizes probable occurrence during the year based on the sampling data.

Table 2.4.1
Seasonal Occurrence of Dominant Fish Species in the New York/New Jersey Harbor Complex in Sampling Programs from 1986 to 1999

Common Name	Primary Occurrence in Catches During the Year	High Level Months	Peak Months
Striped bass	All year Gill Net – May and June	Nov – March	Jan – March
White perch	Oct – June	Nov – March	Jan – March
Winter flounder	All Year	Nov – June	Nov – March
Atlantic tomcod	All Year	Apr – Dec	Apr – Aug
Spotted hake	Apr – Jul and Oct – Dec	May – June	May – June
Bay anchovy	June – Dec	June – July	July
Weakfish	May – Dec	Aug – Nov	Aug – Oct
Atlantic menhaden	May – Dec	June – Sept	July – Aug
Bluefish	June – Oct	July – Sept	July
Atlantic silverside [(a)]	May – Dec	June – Sept	July – Aug
([a]) Collected primarily in shoal areas			

3.0 Potential Effects of Blasting on Aquatic Biota of the NY/NJ Harbor Complex

3.1 Introduction

This section summarizes scientific information compiled to determine the potential impacts of underwater blasting on aquatic biota of the Kill Van Kull (KVK).

Keevin and Hempen (1997) presented an extensive review of information describing those characteristics of underwater explosions and the associated processes that impact aquatic biota. Much of the information presented here is selectively abstracted from their work, targeting conditions, to the extent possible, representative of the blasting procedures implemented in the Kill Van Kull (KVK) federal navigation channel improvement project.

The KVK navigation channel improvement project requires blasting to fracture and remove bedrock in order to achieve the target project depth of 50-ft below mean low water plus a 2-feet overdredge. The blasting process entails the use of barge-mounted drill towers to bore a series of holes into the bedrock. Typically, the 4.5-in. diameter holes are 10- to 15-feet deep into bedrock, and arranged approximately 12 feet apart in a row configuration referred to as a range. Each range typically consists of 6 holes in a line. Each blast event (shot) may have up to 5 parallel ranges separated by 10 feet with boreholes staggered between adjacent ranges. The arrangement of holes can vary among shots, depending on factors such as location, thickness of rock to be removed, and specific objective of the shot. Each hole is packed with water gel ammonium nitrate derivative high explosive, and stemmed with coarse gravel at the top of the hole to confine and direct the blast energy into the rock. A detonation cord runs from the barge to a booster at each hole. Delays are used for detonation of each shot, i.e., the charges in individual holes are detonated in sequence with a detonation delay of 25 m-seconds between holes.

3.2 Relevant Underwater Blast Shock Wave Characteristics

For detonations in rock such as the KVK channel deepening project, the most important factors in accomplishing the work of fracturing and displacing rock in close proximity (3-10 diameters of the explosives volume) to the explosives material are thermal and high pressure detonation effects (Keevin and Hempen 1997). However, these effects have negligible impacts on aquatic organisms. Beyond this point in the far-field area, the primary source of damage to aquatic organisms is the shock wave.

The nature of the shock created by use of underwater explosives and physical factors that can affect fish survival is the composite result of multiple pressure wave components including the direct wave, air-water surface-reflected wave, bottom-reflected wave, and bottom-transmitted wave (McPherson 1991). The location of the explosive (e.g., mid-water, placement in bedrock) and method of detonation (e.g., single charge, multiple charges with delays) will affect these component waves that are the predominant factors that influence the character of the composite shock wave (Figure 3.2.1). The direct shock wave results in the peak shock pressure or compression and the reflected wave at the air-water surface produces negative pressure or expansion. For confined underwater explosives, these are the primary wave components responsible for injury to aquatic organisms (Wright and Hopky 1998; Keevin and Hempen 1997; Linton et al. 1985; Wiley et al. 1981).

One feature of blasting in aquatic environments is the "cavitation hat," related to the reflected wave in proximity to the air-water surface. The negative reflected wave generated by the deflection of the water surface toward the air results in a shallow disc of negative pressure centered over the explosive. There is high potential for overextension of air filled organs in aquatic biota due to the negative pressure associated with the cavitation hat.

The direct or primary shock wave (P-wave) in the far-field area is an expanding compression wave, marked by a rapid, nearly instantaneous increase to peak pressure (P_m) as it passes a given point at distance from the explosion followed by an exponential decline in pressure (Figure 3.2.1) to ambient hydrostatic pressure. The surface-reflected wave trails the direct wave and is characterized by a rapid decrease in pressure to below ambient followed by an exponential increase to ambient hydrostatic pressure. The resultant effect experienced by an aquatic organism in the path of this wave is a rapid sequence of compression and expansion (oscillation) over a period of microseconds depending on the distance from the detonation.

Three characteristics of the composite pressure wave generated from a detonation have been used to assess the impact of blasting on aquatic biota and predict safe ranges from detonation sites: P_m, impulse (I), and energy flux (E_f). P_m is a function of the weight (W in kg) of the explosive and the distance (r in meters) from the explosive:

$$P_m = 53.1 \text{ x } R_s^{-1.13}$$

where Rs is defined as the scaled range,

$$R_s = r / W^{1/3}$$

The equation to calculate R_s provides a means to scale the effects of blasting for different weights of explosive at a selected distance from the detonation (Linton et al. 1985). That is, P_m is proportional to the cube root of the weight of the explosive (W).

Impulse is a measure of the strength or momentum of the pressure wave as it passes a surface. The impulse is a function of the pressure (psi) and the time over which the pressure is produced (Linton et al. 1985). It is calculated as the integral of the area under the pressure-time curve. Depending on their purpose, various authors have included either or both the positive and negative portions of the pressure-time curve in this calculation (Keevin and Hempen 1997). The severity of injury to fish is generally reported to be proportional to the magnitude of the impulse produced by the explosive (Linton et al. 1985).

Energy flux density is a measure of the intensity of the shock wave or the change in energy across a surface in the path of the shock wave. It is measured in units of energy per unit area (e.g., joules/m^2). The integral of E_f can be approximated in terms of W and R_s (Keevin and Hempen 1997). The shock wave energy is also affected by the detonation velocity of the selected explosive; higher velocity explosives generate greater energy. For example, water gel explosives as used for the KVK project generate less shock energy than dynamite.

The KVK blasting protocol has attempted to optimize production and reduce the environmental effects as defined by Keevin and Hempen (1997). Optimized blasting (Keevin and Hempen 1997) is accomplished by:

- Reducing the weight of explosive by accounting for the characteristics of the media, blasting pattern, and the properties of the blasting material

- Use of water gel explosives

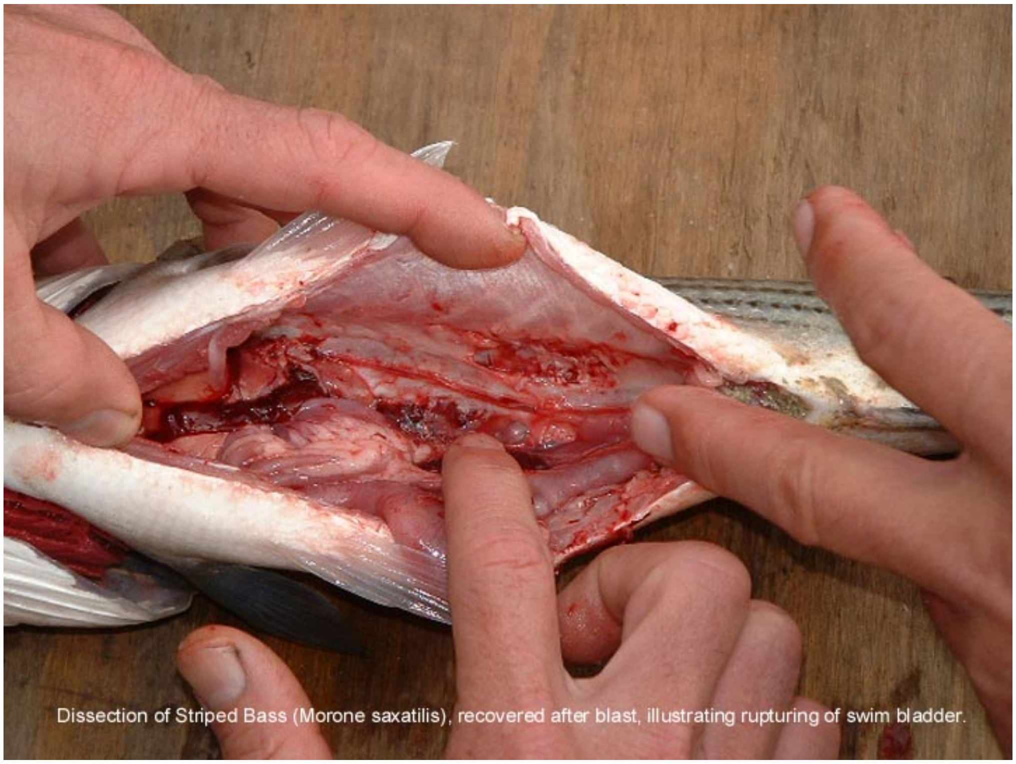
- Increasing the number of delays to progressively displace material
- Stemming boreholes to prevent pre-mature venting of explosive gases and dampen the pressure shock wave.

3.3 Blast Impacts on Aquatic Organisms

The primary cause of injury and mortality to aquatic organisms from blasting in aquatic environments appears to be damage associated with rupture and hemorrhage of air-filled internal organs, in particular the swimbladder (Wright and Hopky 1998; Keevin and Hempem 1997). The gas-filled swimbladder is a structure possessed by many pelagic fish that plays a role in buoyancy. Demersal species, such as flounder, typically do not have swimbladders and are frequently less susceptible to blast impacts. Less information is available, but it is generally reported that there is minimal injury and mortality from blasting to mollusks, shellfish, and crustaceans which do not have gas-filled organs similar to the swimbladder in fish (Wright and Hopky 1998). Although the structure of the swimbladder and the mechanism for adjusting gas volume vary among species, generally the process for release of gas from the swimbladder is too slow to compensate for the rapid fluctuations in hydrostatic pressure associated with the pressure shock wave.

The primary cause of damage in finfish exposed to a pressure shock wave appears to be the outward rupture of the swimbladder as a result of the expansive effect of the negative hydrostatic pressure associated with the reflected air-water surface wave. While the organ may tolerate the compressive portion of the shock wave, the rapid drop to negative hydrostatic gage pressure and expansion of the gas that cannot otherwise be released, causes the rupture of the organ (see photo, below). Vibration, expansion, and rupture of the swimbladder can also cause secondary damage and hemorrhage due to impact with other internal organs in close proximity to the swimbladder. Other organs typically exhibiting damage include the kidney, liver, spleen, and sinus venous. Extensive tearing of tissue has been observed in species where the swimbladder is closely attached to the visceral cavity. Close attachment to the dorsal cavity wall was typically associated with extensive damage to the kidney. Species with thick-walled swimbladders and cylindrical body shape (e.g., oyster toad fish and catfish) appear to be more resistant to pressure waves than species with laterally compressed bodies such as herring and menhaden (Linton et al. 1985). Smaller individuals of a species are generally more sensitive than larger fish. Early larvae do not have swimbladders and are more resistant than older larvae after development of the swimbladder. The extent of injury and mortality decreases with distance from the detonation as the magnitude of the pressure drop declines due to dissipation of the blast impulse (I) and energy flux density (E_f) with distance. In a review of a number of studies of primarily open water blasting, Keevin and Hempen (1997) concluded that I was the best predictor of potential damage for shallow depths (less than 3 m), while E_f was the best predictor for deeper conditions.

The weight of the charge and distance from the detonation are the most important factors affecting the extent of injury and mortality, although water depth, substrate, depth of the fish, and size and species of fish are also important (Keevin and Hempen 1997; Wiley et al. 1981; Teleki and Chamberlain 1978). The shape of the lethal zone is dependent on the depth of the detonation. In shallow water, the horizontal extent is greater than in deep water. However, for buried explosives, the lethal zone is conical with the narrow portion of the lethal zone near the bottom expanding horizontally toward the water surface (Linton et al. 1985).



Dissection of Striped Bass (Morone saxatilis), recovered after blast, illustrating rupturing of swim bladder.

Several authors have developed empirical models to integrate these factors in order to predict impacts to aquatic organisms; however, most of these are based on open water detonations and thus, overestimate the lethal range and impact to fish compared to blasting with explosives buried in the substrate as is the case for the Kill Van Kull project. Keevin and Hempen (1997) reviewed several of these models. A set of computer models was developed by Coastline Environmental Services (1986) that can provide rough approximations of the potential lethal radius for open water and buried borehole blasts based on *I* (IBLAST) for shallow water and *Ef* (EBLAST) for deep water sites.

The Canada Department of Fisheries and Oceans evaluated P_m, I, and E_f as predictive parameters for establishing guidelines for protection of fish and marine mammals during use of explosives in Canadian waters (Wright 1982) and found an impulse-based model to be the best predictor of lethal and safe ranges. Wright found that overpressure greater than 100 kilo Pascals (kPa) (14.5 psi) generally caused internal organ damage in finfish. This 100 kPa threshold has been used a guideline to limit blasting impacts in Canadian waters (Wright and Hopky 1998). However, based on reviews of several studies, Wright (1982) reported that P_m is affected by an array of factors, including size and species of fish, orientation of fish relative to the direction of the pressure wave, target depth, detonation depth, water depth, bottom type, and explosive type and quantity and thus, was a poor predictor of lethal range. Predictive equations (MacLennan 1977) for lethal range based on E_f were inconsistent in their ability to predict lethal ranges under different test conditions (Hill 1978; Roguski and Nagata 1970; Hubbs et al. 1960; Tyler 1960). Field tests (Yelverton et al. 1975) indicated that the lethal impulse values were relatively consistent for various test conditions, but peak lethal pressures varied widely. In a series of tests with bluegill and carp, Wright reported that while peak pressure remained constant with depth at test locations, the impulse and mortality increased with depth. Wright presents a procedure (based on Hill 1978) to calculate the lethal range based on scaled impulse (I_{sc}) (calculated from an impulse value determined to e protective of fish) and R_s that also considers fish size, fish depth, charge size, and detonation depth. Scaled impulse is calculated as;

$$I_{sc} = I / W^{1/3}$$

and compared to R_s using a series of curves that relate W, the depth of the charge (D_c), and depth of the fish (D_f):

$$A = (D_f \times D_c) / W^{2/3}$$

The lethal range (R_m) is calculated from R_s selected based on the ratio, A and the calculated I_{sc}:

$$R_m = R_{sc} \times W^{1/3}$$

Wright concludes that the method will underestimate R_m in shallow water if the water depth is less than 5 times the detonation or fish depth or for rocky bottoms. On the other hand, Wright's procedure is based on field data secured from open water blasts and will overestimate R_m relative to situations where the explosive is placed in stemmed boreholes. In reviewing Wright (1982) and Hill (1978), Keevin and Hempen (1997) indicate that a more precise model would do little to improve the accuracy of the predicted lethal zone, considering the number of conditions that affect mortality, but are difficult to quantify. Examples of information that can generally only be assumed at the time of a blast include: size distribution of fish, depth and horizontal distribution of fish, and fish community structure. Keevin and Hempen indicate that a conservative estimate of potential mortality is provided by the using the model to assess "worst case" potential impact.

Young (1991) presented a model to estimate the range of vulnerability using 90 percent probability of survival as the threshold criteria. This model was generated for shallow water conditions and open water blasts. Because the model is based on a limited range of conditions, Young characterized it as useful for preliminary planning purposes:

$$R_{safe} = 95 \times W_f^{-0.13} W^{0.28} d_w^{0.22}$$

where

R_{safe} = Safe range (ft)
W = Weight of explosive (lb)
W_f = Weight of fish (lb)
D_w = Depth of detonation (ft).

Wiley et al. (1981) developed a dynamic model to simulate the effect of the passage of a pressure shock wave on the oscillatory vibration of a generic swimbladder (Figure 3.3.1); modeled estimates of swimbladder motion (oscillation parameter Z) were correlated with severity of observed injury to fish in caged studies with open water blasts. They present a method for calculation of the probable distribution of mortality as a function of horizontal range and depth. The authors found good agreement between their oscillation damage parameter and the impulse damage parameter developed by Yelverton et al. (1975). It is suggested that this similarity occurs because the oscillatory motion described by their model is a result of the impulse pressure loading on the swimbladder air volume. The model and relationships between characteristics of the pressure wave and severity of injury observed by Wiley et al. were consistent only for detonations in shallow water. Using an average relationship between fish length and swimbladder radius for striped bass, Wiley et al. calculated estimated kill zones (90, 50, and 10 percent) for striped bass, shown on Figure 3.3.2. The authors also presented estimates of variation in mortality as a function of both depth and fish size (Figure 3.3.3). Field tests were performed where water depth was 46 m to minimize the affects of reflected bottom pressure waves; 14 of 15 blasts monitored were detonated at a depth less than approximately 12 m. The testing program looked at a number of species that may be seasonally abundant in the New York/New Jersey Harbor complex including white perch (*Morone Americana*), spot (*Leiostomus xanthurus*), Atlantic menhaden (*Brevoortia tyrannus*), blueback herring (*Alosa aestivalis*), hogchoker (*Trinectes maculates*), toadfish (*Opsanus tau*), and killifish (*Fundulus majalis*). Hogchokers, a species with no swimbladder, were reported to sustain no serious injury. Wiley et al. reported that the damaged swimbladder of some species, such as white perch and spot, healed in as little as 10 days under laboratory conditions, but that the organ was less effective in controlling internal hydrostatic pressure and buoyancy.

The U.S. Army Corps of Engineers – Wilmington District (2000) examined the results of test blasting in Wilmington Harbor/Cape Fear River used to evaluate the model predicted impact zone and the effectiveness of impact reduction using an air bubble screen. This report found that field tests with caged fish demonstrated that the impact modeling conducted for the Environmental Impact Statement on this project significantly overestimated the horizontal extent of fish mortality. The model-predicted impact area (USACE 1996a, 1996b), defined as that area in which 1 percent or more of the fish would die without an air curtain, extended to 656 ft from the blast (34.5 acres). In field test, no significant mortality occurred beyond 140 ft (2.1 acres within 140 ft) with or without the air curtain. The U.S. Army Corps of Engineers – Wilmington District (2000) suggested that the reason for the significant overestimate by the model was that the Environmental Impact Statement model underestimated the reduction in blast effects compared to open water by confining the explosive in rock. The test blasts consisted of 32 to 33 holes with 52 to 62 pounds of explosive per hole with 25 microsecond delays; water depths were 30 to 38 feet. The Waterways Experiment Station found that the effect of a rock blast is 0.014 of a blast in open water; this translates to an equivalence of a 52 to 62 pound blast in rock to a 0.73 to 0.87 pound blast in open water. The reported average P_m and average peak I from the test rock blasting at the 140-ft radius were 75.6 psi and 18.4 psi-msec, respectively; it was reported that these values were similar to impact threshold values estimated by Yelverton et al. (1975). It was suggested that the ineffectiveness of the air curtain was a result of the strong tidal currents in the Cape Fear River that disrupted the air curtain and the establishment of an effective air barrier.

4.0 WATER-BORNE PRESSURES FROM CONFINED BLASTS IN THE KVK

4.1 Introduction

The purpose of the study was to record water-borne blast pressures from confined blasts conducted in the Kill Van Kull and relate them to impacts to resident fishery resources. The blasting was part of the ongoing Kill Van Kull (KVK) Deepening Project. The blasting was confined within the rock floor of the KVK to remove rock for channel deepening. The United States Army Corps of Engineers - New York District funded the study in an effort to record data from actual confined blasts. These data were then compared to data recorded from open-water blasts, which are unconfined and produce higher peak pressures in the water column. The pressure data was recorded to measure the various typical pressures associated with impacts to aquatic and marine organisms. The blast monitoring was conducted during the last two weeks of October 2003.

The formulas and computational methodologies used to develop the information contained in the following chapter are highly technical and have thus been included in an expanded version of this chapter included as Appendix A.

4.2 Materials and Methods

A. Channel Deepening Blasting

Figure 4.2.1 provides the approximate location of the shooting in October 2003 near the Bayonne Bridge at Bergen Point. Acceptance Areas A and B, east of the bridge, were the locations of the removal program. Figure 4.2.2 provides a typical section for channel depth and rock removal.

1. Types of Explosives and Initiation

The main blasting agent used in October 2003 by the Joint Venture was EL957C, a water gel emulsion, manufactured by ETI Canada Ltd. The emulsion is not cap sensitive. The emulsion has a specific gravity of 1.30 and a detonation velocity of 20,000 feet/second (fps). The blasting agent was packaged in 2.75-inch (in) diameter polythene sleeves, each weighing 4.23 pounds (lb). Typically charges ranged between 25 and 29 lb per shot hole, depending on the height of rock relative to the dredge depth of 53.5 feet (ft). Larger emulsion weights were often used in one or more holes for each shot.

The initiation system was comprised of a Detaline dual path, precision delay, **non-electric** initiation cord and components. By using a non-electric initiating system the shot was safely initiated and connected without concern for radio silence. Radios can initiate electric systems. The system utilizes a fine extruded detonating cord with a PETN explosive core of 2.4 grains per ft. The timing and delay sequence to the shot holes were achieved with "Detaslide Delays" detonators. The detonators were used in each booster and were connected via Detaline to "Detaline Surface Delays." The surface delays were connected to a dual trunk of Detaline.

All the shot holes were drilled, loaded and connected to the dual trunk line. The shot was initiated using a "Noiseless Lead-in-Line." An instantaneous detonator was attached to a 500-ft length of hollow shock tube that contained explosive dust. The entire shot was initiated by a simple shot-shell primer, which was fired into the shock tube connected to the trunk line delay system to the individual shot holes.

Upon initiating the blast, each cord carries the detonation to its shot hole. In doing so, the cord itself sets up a "tubular" pressure front that forms around the cord along its entire length. How the pressure from the multitude of Detalines affected the recorded blast pressures or how the lines may impact fish (if separate from the confined blasts) is unknown at this time. It can only be assumed that these "other" pressures were incorporated into recorded values.

2. Shot Patterns

The October 2003 work consisted of a second round of rock removal to assure that the planned channel grade was obtained. This action was conducted to remove high rock points remaining from the first round of shooting to achieve the proposed pay grade. A planned pattern deployment positioned the drilling barges using GPS surveying equipment. Rock above the pay grade was drilled and shot. When rock was not encountered on the pattern above the pay grade, there was no need to place any blasting agent.

To prevent the escape of gas and resultant explosive force each blast hole is "stemmed" with gravel or similar materials after the explosives are placed and the Det-Cord is connected. The type and length of stemming are important measures for confinement. Confinement is an important aspect of reducing the pressure by restricting riffling into the water channel above the shot hole. Previous contact indicated that 5/8-inch to ¾-inch, crushed stone was used as stemming with a minimum stemming length in rock of 30 inches.

3. Timing and Charge Weight per Delay

The delay sequence was resolved by a predetermined evaluation plan and placed by the number of holes drilled in each range and the number of ranges for the particular shot. Thus the actual delay timing deployed was a process of both the plan and the actual holes that were found above the pay grade.

The charge weight per delay is an important element of the blast vibration and water-borne pressure waves. The maximum charge weight per delay is the parameter that will likely be the predictor of the maximum vibration in particle velocity and the maximum water pressure. The maximum charge weight per delay is the largest weight of blasting agents shot at a single delay interval of less than 9 milliseconds (ms), 0.009 second (s). The largest weight may be attributed to a single shot hole or several shot holes with the same delay timing. It so happens that the recorded shots were from single shot holes with maximum charge weights per delay in the 70 to 90 lb per delay range.

4. Shots Used for this study

Table 4.2.1 presents shot locations for shots recorded by the pressure transducer. In addition to locations, table 4.2.1 also presents the shot dates, diagonal corner locations, recording action, and transducer locations. Table 4.2.2 gives shot data important for calculating scaled distance to the leading transducer array or the lagging (further) transducer. Four shots were successfully recorded: 2MB-010, -014, -021 and -022.

Table 4.2.1
KVK Joint Venture Shot & Transducer Locations

Blast 2MB-#	Oct 2004 Date	Borehole Corner Position		Shot Corners		Record Action	Transducer Azimuth From shot	Transducer Locations	
		L-Rng	X-Rng	N	E			N	E
008	Tu, 21	N	W	593,952	659,713	Pretriggered-no info	east	594,569	659,626
		S	E	593,967	659,680			594,715	659,681
009	Tu, 21	N	W	593,712	659,559	Not permitted			
		S	n/a	593,717	659,538				
010	W, 22	N	W	593,706	659,721	**record**	east	594,403	659,767
		S	n/a	593,759	659,622			594,564	659,778
011	W, 22	N	E	593,662	659,648	Below threshold	west	592,948	659,600
		S	W	593,523	659,619			592,794	659,584
014	Th, 23	n/a	E	593,548	659,814	**record**	west	593,082	659,720
		n/a	W	593,540	659,812			592,929	659,662
020	Tu, 28	N	n/a	594,363	659,779	Below threshold	east	594,642	659,817
		S	E	594,412	659,730			594,699	659,673
021	W, 29	N	W	594,431	659,747	**record**	east	594,932	659,751
		S	n/a	594,519	659,663			595,070	659,667
022	Th, 30	N	E	592,417	659,518	**record**	east	592,840	659,629
		S	W	592,343	659,430			592,990	659,613

Table 4.2.2
KVK Shot Operations & Data

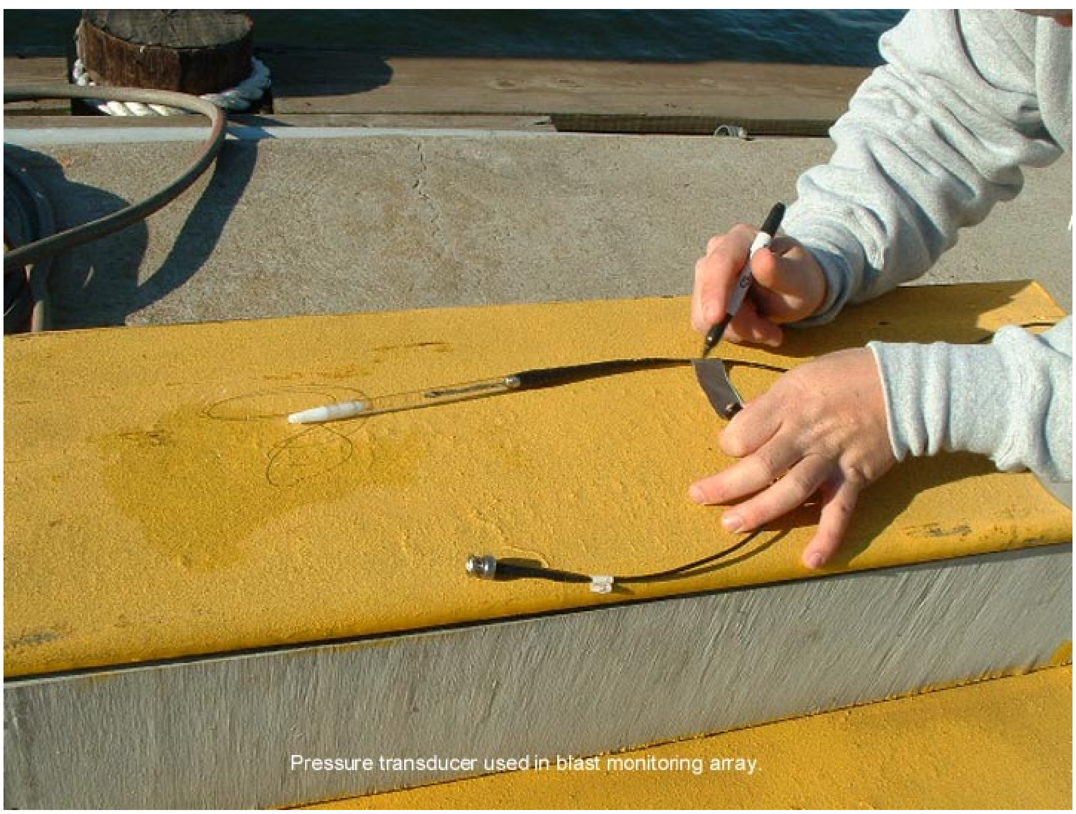
Shot-test	MxCharge Wt/Delay (lb)	Charge Distribut'n	Hole/ Range Ref	Lead T Dist (ft)	Lag T Dist (ft)	Lead Scal Dist (ft-lb1/2)	Lead Scal Dist (ft-lb1/3)	Lag Scal Dist (ft-lb1/2)	Lag Scal Dist (ft-1b1/3)	Data Result
008										Pre-triggered - no info
010	**73**	single	8/ R 31	660	820	77	158	96	196	**record**
011	133	2 – 24'	2/ R 19	580	740	56	122	72	156	Below threshold
Open wtr 1										Signaling problem*
Verift'n 1	cap	single		5.6						~ 5.58' from cap at 5' depth
Verift'n 2	cap	single		5.6						~ 5.58' from cap at 5' depth
014	**72**	single	15/ R 47	480	640	57	115	75	154	**record**
020	54	2 – 8'	2/ R 44	250	300	48	83	58	100	Below threshold
021	**87**	single	16/ R 46	500	640	54	113	69	144	**record**
022	**73**	single	16/ R 40	570	700	67	136	82	167	**record**
Open wtr 1										JV could not shoot; small charge below threshold or outside of time range.

* not ready to record when shot

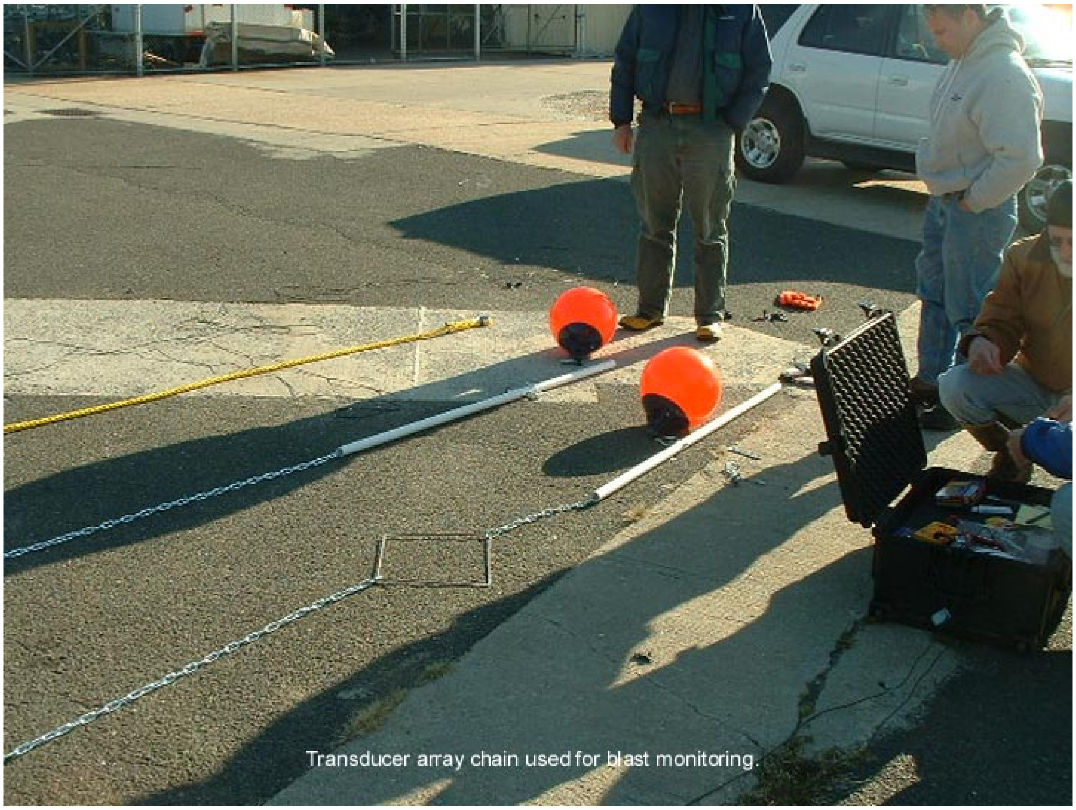
B. Recording the Shots

The recording system for acquiring water-borne pressures is a sophisticated electronic set of systems. The recording of pressures must respond to pressure changes in the 1 to 5 microsecond (μs, 0.000001 s) range. The analog signal must be digitized and stored a long distance from the submerged transducer. Furthermore, the system must be initiated either by a signal from the actual shot initiation or by a pressure rise at one of the recording transducers. The latter is termed the trigger-source transducer. Since a non-electric shot initiation system was employed for safety reason the recording vessel was well removed from the shot hole pattern, therefore, a trigger-source transducer was required. Images of the hardware are included below and in Appendix C. The pressure transducer system consists of the transducers themselves, cabling, and array configuration. The transducers are typically calibrated before and after use. Verification shots show that the calibration is approximated and the system is properly recording. The beginning, two verification shots were conducted on 23 OCT 03. An ending verification was not available from the Joint Venture. The ending verification would have been performed on the remaining three transducers still active at the end of the program. The transducers used and recorded file names for each shot are provided in Table 4.2.3.

The transducers and file names for the two, beginning verification shots are provided at the bottom of Table 4.2.3. The calibration data and verification approximation are provided in Table 4.2.4.



A suitable transducer array support line was constructed for this study. Three transducer cable



Transducer array chain used for blast monitoring.

positions were created for the leading, or closer, suspension to the shot. One mid-depth position was suspended for the lagging, or further, suspension from the shot. The photograph record (Appendix C) provides images of the transducers, array cable, and array placement.

The transducers were taped with plastic electrical tape to 3/8-in link, steel chain and square reinforcement rods holders. The reinforcement holders allow the transducers to be suspended in approximately the center of the square. This prevents a pressure "shadow" from affecting the suspended transducer relative to a transducer taped directly the side of a rope or chain. The depths to each transducer on the two suspensions were relative to the top of a 3-ft long, 2-in diameter, white PVC pipe. Eyes for pumpkin buoys on part of the PVC pipe containing the start of the cable allowed attachment to both buoys and the array line. During deployment the top of the PVC cable to the water line provided the depth of each transducer.

An array line was created for quick deployment of buoys, anchors and transducers. The 200-ft long line was braided, ¾-in, yellow rope. Each end of the array line had quick opening hasps. There were two positions along the array line, 150-ft apart loose, for hasp connection of the transducer suspension chains. Hasps about 25-ft apart were zip tied into the braided array line to hold the transducer cable lines leading to the recording vessel.

The transducer skiff would take the GPS position and PVC top to water line length following a shot. Then the skiff would reverse the process of removing the transducer cables from the support vessel and disconnect and store the transducer chains in the trays. The Hudson would then remove anchors for the array line. Deployment and recovery would each take 60 to 90 minutes depending on wind and tidal flow conditions.

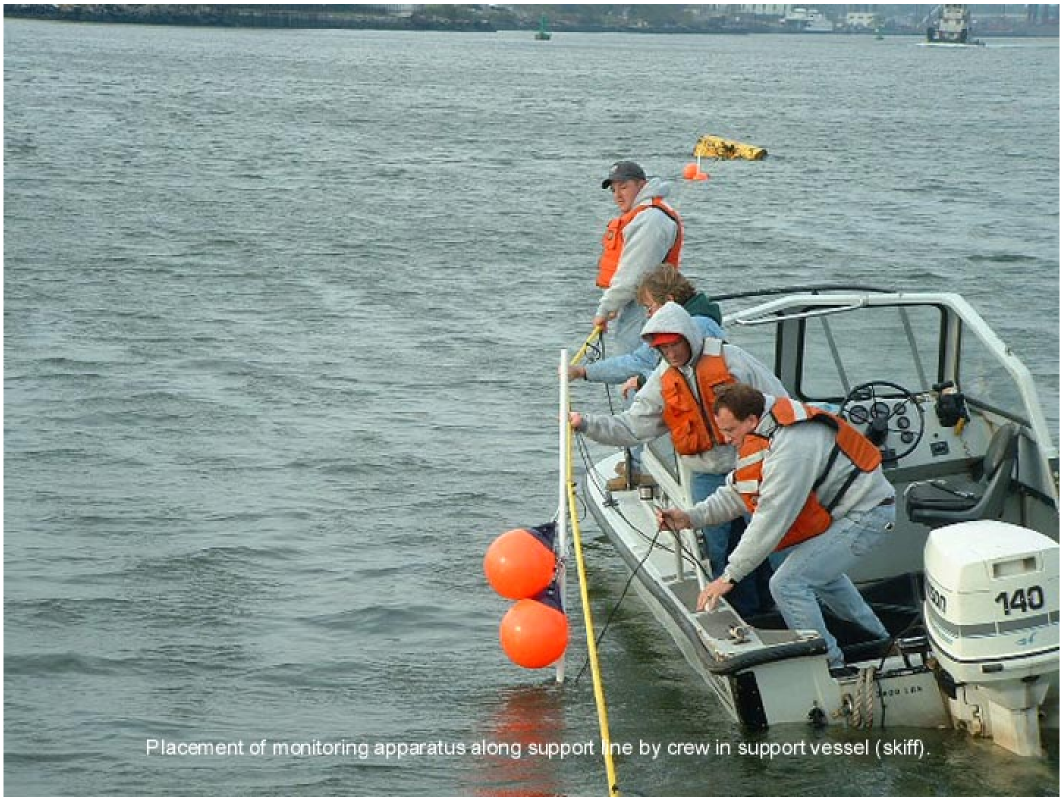

Placement of monitoring apparatus along support line by crew in support vessel (skiff).
140

Table 4.2.3
KVK Pressure Transducer Data

Shot	Transducer Depth (ft)				Transducer #/ File Names				
File ext	Lead top	Lead mid	Lead btm	Lag mid	Lead top	Lead mid	Lead btm	Lag mid	Data Result
Ref depth	7.1	28.0	51.2	27.1					
010	5.6	26.4	49.7	24.8	2708	2329	2632	2714	**Record** Level 37.8 mV
.wft					22O04	22O01	22O02	22O03	
.pcx					0102708	0102329	0102632	0102714	
011	5.6	26.4	49.7	24.8	2708	2329	2632	2714	Below threshold
014	5.6	26.4	49.7	24.8	2708	2333	2632	2714	**Record** Level 50.6 mV
.wft					23O12	23O09	23O10	23O11	
.pcx					0212332	0212333	0212693	0212714	
020	5.5	26.3	49.6	25.5	2332	2333	2693	2714	Below threshold
021	5.1	26.0	49.2	25.2	2332	2333	2693	2714	**Record** Level 50.6 mV
.wft					29O01	29O02	29O03	29O04	
.pcx					0212332	0212333	0212693	0212714	
022	5.7	26.6	49.8	25.7	2332	2693		2714	**Record** Level 50.6 mV
.wft					30O01	30O02		30O03	
.pcx					0222332	0222693		0222714	
					1	**2**	**3**	**4**	
Verift'n 1	5.0	5.0	5.0	5.0	2708	2333	2632	2714	~5.58' from cap at 5' depth Level 142 mV
.wft					23O01	23O02	23O03	23O04	
.pcx					CAP 1				
Verift'n 2	5.0	5.0	5.0	5.0	2708	2333	2632	2714	~5.58' from cap at 5' depth Level 142 mV
.wft					23O05	23O06	23O07	23O08	
.pcx					CAP 2				

Table 4.2.4
KVK Pressure Transducer Calibration

Transducer	Type	Channel	Calibration (psi/V)	Verftn 1 (V)	Verftn 2 (V)	Verftn 1 (psi)	Verftn 2 (psi)
2708	138A05	1	927	0.5144	> 1.0291	Limiting Test	
2329	138A05	2	960				
2632	138A05	3	1,031	0.1827	0.1728	188	178
2714	138A01	4	216	0.6808	0.7373	147	159
2333	138A01	2	206	0.8504	0.8976	175	185
2332	138A01	1	208				
2693	138A01	3, 2	200				

Figure 4.2.3 depicts the transducer array, while Figure 4.2.4 depicts the transducer array as deployed from the recording vessel. Figure 4.2.5 presents the blast and blast monitoring locations for this study. Table 4.2.2 presents the lateral distance from each shot's maximum charge weight per delay shot hole to the leading and lagging chain suspension positions. Table 4.2.3 provides the depth below the water line for each transducer.

1. **Pressure Recording**

A four-channel Nicolet Model 440 Digital Recording Oscilloscope transformed the analog voltage data to digital points. The voltage data from respective transducers was recorded on 3.5-in diskettes.

The oscilloscope was set to record the time interval between data points and the total length of record. The range of voltage to be recorded was established. A high range would not have sensitive intervals. A low range could be over-scaled and data lost beyond the range.

The oscilloscope allows a trigger for the initiation of data collection or may trigger data collection when the source channel exceeds a threshold voltage. The latter was required so the source channel and threshold voltage needed to be selected to acquire the voltage data. When the trigger source voltage is exceeded, all the transducers' inputs are recorded

2. **Pressure Data Calculation**

The transducer voltage file names (.wft extensions) for each shot and the verifications are provided in Table 4.2.3. Every record is provided in Electronic Appendices on compact disk.

Vu-Point II software, Version 2.0 (Maxwell Laboratories, Inc.) was used to scale voltage ".wft" digital files to create pressure data. This software was also used to create graphic ".pcx" files. These graphic files may be printed. The graphic file names are provided in Table 4.2.3. The calibration factor for a given transducer is provided in Table 4.2.4. The maximum pressure for each transducer and shot are given in Table 4.2.5 with other data. The pressures are recorded to two significant digits. One to three shot-transducer pressure wave records (.pcx extensions) are provided in Electronic Appendices on compact disk. Figure 4.2.6 depicts the full recorded record, as an example, for the leading mid-depth transducer and the lagging mid-depth transducer of Shot 2MB-014. Figure 4.2.7 depicts the location of the monitoring stations relative to Shot 2MB-014. Figures 4.2.8a and 4.2.8b provide the Drill Log and Blast Reports for the shot.

Table 4.2.5
KVK Shot & Water-borne Pressure Data

Shot	# Holes Shot	Delay Interval (s)	Timing of Max Wt. (s)	Record Length (s)	Lead Scale Dist. (ft-lbs 1/3)	Maximum Pressure (psi) during Record Length				Calculated Open-Water Pressure (psi)
						lead top	lead mid	lead btm	lag mid	
010	25	.100 - .742	0.330, 0.492	0.700	158	**29**	**14**	Stray	**7.1**	71
014	2	.517 - .617	0.517	0.360	115	**27**	**21**	**26**	**18**	101
021	28	.100 - .480	0.400	0.900	113	3.4	Stray	**16**	**20**	104
022	39	.075 – 1.042	0.492	0.900	136	5.1	**19**	None	**14**	84

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New York District

Appendix B presents a complete set of transducer records and Drill Log and Blast Reports for the study.

High-quality, maximum pressure values are noted in bold in Table 4.2.5. The recorded pressures are quite low and are the lowest levels of maximum pressure recordings that USACE has monitored. The data were judged to be of high quality when they met consistency tests and corroborated with other recordings. Some transducer records did not record the high-pressure waveform. The maximum pressure for these poor records is provided in Table 4.2.5, but the values are not shown in bold. The leading top transducer for both Shots 021 and 022 seem too low relative to the other recordings for the same shot and the other top transducer on different shots. A stray current or noise issue for the circuit caused a mis-recording of pressure for the leading bottom transducer of Shot 010 and for the leading midlevel transducer of Shot 021. These two shot-transducer records are listed as "stray" in Table 4.2.5. The graphs of both transducers show that neither transducer has a typical waveform relative to the other transducers.

The data of Table 4.2.5 indicates that the record length for three shots (010, 014, 021) exceeded the interval of the shot hole delays. Therefore, if the first shot hole in time caused the threshold voltage to be exceeded the entire record could still be recorded. In shot 022, the timing of the maximum charge weight per delay would be recorded whether or not the first shot hole started the voltage recording. So the maximum pressure should be recorded regardless for Shot 022.

Other measures of impact, both impulse and energy flux density, were to be calculated from the pressure wave data. The complexity of the waveform and the high level of noise relative to the measured pressures did not allow evaluation of either impulse or energy flux density. Both measures would require integration of the pressure-time history over a defined length. The time length for integration is so short that it is not meaningful or that produced pressure only modestly exceeds the background noise with the lesser reverberation for impulse and energy. As noted in Hempen (1993), "complete digital recording of shock-wave pressure is the only means certain of proper correlation development with faunal impact." Yet at these low amplitude pressures, the other two measures have neither meaning nor impact if the full waveform cannot be resolved.

The Leading Transducer suspension distance from the shot's location of the maximum charge weight per delay hole was used to determine the scaled distance. The scaled distance allows computation of the theoretical single, open-water shot's pressure for an equivalent charge weight and distance. The equation from Cole (1948) was used to resolve the open-water shot's pressure provided in the last column of Table 4.2.5. The hard rock surface and shallow water depth may act as a wave-guide to increase the pressure above the calculated pressure for the open-water equivalent.

Unfortunately, the single open-water test provided by the Joint Venture had insufficient operational communication to record the small charge. The charge would have needed to have been closer to the transducers to have recorded pressures. A second opportunity was not available to have a test of an open-water shot.

4.3 Study Results

Actual maximum pressures were successfully recorded in the adverse (radio-wave) environmental conditions of this channel reach. The maximum, high-quality pressures shown in bold in Table 4.2.5 are relatively small compared to the theoretical value of an equivalent charge weight, open-water shot. Unfortunately, actual recording of an open-water shot for confirmation of comparison procedures was unsuccessful on the only attempt.

The complex pressure waveform does not allow integration of the pressure record to determine impulse and energy flux density.

4.4 Discussion

A. Study Limitations

There were some obstacles to overcome in coordination and capture of the blast pressure-wave monitoring. The primary difficulties were: weather conditions, coordination of a shot's exact timing, interference in the noisy radio-frequency environment, cable saturation/lowering of the dielectric capacity, and low blast pressure released into the water column. The team was operationally able to record shots from about 21 through 30 October 2003. Pre-triggering and interference problems prevented the first shot (2MB-008) from being captured, but relative to later shots the Shot 008 pressure values were likely below the triggering level to be recorded. Pressure waves have been recorded that are attributed to the blasting. The system was available to record blasting but did not trigger recording for several shots: 2MB-008 (22 Oct 03), 2MB-011 (22 Oct 03), and 2MB-020 (28 Oct 03). It has been judged that the system was functioning, but that the pressures were below the trigger levels to record pressure data. Low-threshold triggers are required because there is not a physical link to the blast initiation. Pressure waves were recorded for shots: 2MB-010 (22 Oct 03), 2MB-014 (23 Oct 03), 2MB-021 (29 Oct 03), and 2MB-022 (30 Oct 03). One attempt to record a small charge, open-water blast was unsuccessful due to unsuccessful communication of the timing and perhaps too great of a distance between the shot location and transducers. Another open-water shot could not be coordinated. For detailed description of limitations see Appendix A.

B. Discussion of Results

The maximum pressures of four shots were successfully recorded. Quality, maximum pressures are shown in bold in Table 4.2.5. The maximum pressures and their waveforms show very short duration peaks that may be related to destructive interference from a complex shot pattern. There is reasoning that having a uniform maximum charge weight per delay could reduce some of the maximum peaks, but this is a hypothesis. For several of the shots the maximum charge in one shot hole was several multiples of most other holes.

1. Blast Pressures

The maximum pressures from the confined shooting are significantly lower than theoretical open-water shot pressures. Radiation of the wave energy into rock reduces the available energy reaching the water column. The pressures entering the water column are well below those pressures that typically propagate away from open-water (unconfined by solid media that may radiate the energy away with less harm) charges relative to charge weight per delay.

The maximum pressures recorded are related to the maximum charge weight per delay. This cannot be directly correlated due to the complexity of shot pattern and potentially to the confinement of the charge within the rock. The number of drill holes and the average charge weight per delay varied among shot patterns. Uniform charge weight per delay would likely have had less variable impact on stunning and killing fish. [When there is a need for a drill hole with a large charge weight per delay relative to other array borings of average charge weight per delay, the position of the boring with the maximum charge weight per delay is important. At the outer perimeter the boring the maximum charge weight per delay will extend the kill radius significantly in the direction away from the shot pattern's borings. The boring with the maximum charge weight per delay will have a lower impact when it is positioned near the center of the shot pattern. The lowered impact is due to the kill radius of the worst impact drill hole needing to surpass the kill radii of the surrounding borings with smaller kill zones due to their average charge weights per delay.

The maximum pressure clearly is unrelated to the total weight of blasting agents shot. Shot 014 had only 98 lb total explosive weight but had comparable maximum pressures to other shots with many multiples for the total charge weight. The shot pressures were relatively uniform, while the shots varied significantly in total charge weight.

2. Blasting Impact: Fish Mortality

Hubbs and Rechnitzer (1952) determined that the lethal threshold peak pressure for a variety of marine fish species exposed to dynamite blasts varied from 40 psi (280 kilopaschals, kPa) to 70 psi (480 kPa). Keevin (1995) found no mortality or internal organ damage to bluegill exposed to a high explosive at pressures at or below 400 kPa (60 psi). Canadian guidelines for the use of explosives have established the conservative value of 100 kPa (15 psi) as the "theoretical lethal range" (i.e., the range, or distance, over which the overpressure exceeds 100 kPa or 15 psi).

Fish kill was likely very close to the placed charges. The actual limits of the kill radii cannot be determined without caged fish. Stunned and killed fish were recovered by handnet from the surface. Many fish noted at the water surface after a shot may have been only stunned and may have recovered except for immediate predation by gulls (see photos below and Appendix C). The NY District had initially planned to trawl for dead and stunned fish after each recorded blast. Several issues arose which prevented those plans from being executed. First, safety guidelines prevent any craft from approaching the blast area for about 10 minutes *after* the blast due to a loss of buoyant force in the water caused by release of gas from the explosion. By the time the "all clear" is sounded, the currents in the KVK had most likely widely dispersed fish located below the surface. Second, the complexity and logistics of setting up each shot pattern and need for the

View of bird predation on killed/stunned fish immediately following blast.

US Army Corps of Engineers New York District contractor to make frequent changes in the blasting schedule made keeping a contracted boat and crew on standby infeasible.

There are a number of physical attributes of the pressure waveform from the confined shots measured in this study that may suggest that mortality would be lower than indicated by the peak-pressure measurements. The impulse of a pressure wave gives the best indication of potential organ damage and mortality (Keevin and Hempen 1997). The impulses from the KVK confined shots were unable to be assessed for the lowered amplitude pressures within the rapidly alternating noise field.

The rapid oscillation from a high, brief overpressure and a moderate, but longer, underpressure associated with detonation of high explosives in the water column is most probably responsible for fish mortality. This oscillation in waveform is responsible for the rapid contraction and overextension of the swimbladder resulting in internal damage and mortality.

It has been suggested that the negative phase (relative to ambient) of the pressure wave is responsible for organ damage (particularly the swimbladder) and mortality (Keevin and Hempen 1997). This conclusion was reached by the observation of swimbladders that were burst outward. For example, postmortem observations of striped bass (*Morone saxatilis*) and trout (*Cynoscion regalis*) found "the edges of holes in the swim bladder were turned outward and that blood from broken vessels in the wall of the bladder had been blown into the abdominal cavity" (Anonymous 1948). During the current study, the abrupt compressing pressures, usually associated with the detonation of high explosives, were reduced in amplitude and negative pressures were not observable relative to the background noise.

The more conservative pressure of 40 psi from Hubbs and Rechnitzer (1952) was used as a basis of mortality, even though their range extends to 70 psi and Keevin (1995) found pressures below 60 psi did not impact small, fresh-water fish. This is also a conservative standpoint because the waveform of the tested citations were from open-water tests and not from similar confined shots that did not have clear extension phases for measurable impulse and energy measures. Mortality is presumed when fish are exposed to 40 psi, but not killed below 40 psi. There is some evidence, as stated in preceding paragraphs, that confined shots would not have mortality pressures as low as those open-water shots.

The recorded data of Table 4.2.5 clearly demonstrates that no fish would have been killed at the recorded distances; 480 to 660 feet (Table 4.2.2), from the KVK confined shots. Theoretically, equivalent open-water shots would have killed fish beyond these distances. As the pressures required to trigger recording for Shot 020 did not exceed 34 psi, this recording distance, 250 feet, would not have been lethal.

Cole's equation for the open-water pressures may be manipulated using the lethal pressure of 40 psi. The mortality radius for single, open-water shots, MR_{OW}, is:

$$MR_{OW}\ \text{(feet)} = 260\ w_{OW}^{\ 1/3},$$

where

w_{OW} = the maximum charge weight (in pounds) per delay of a single, open-water blast.

The data set of Table 4.2.5 for KVK confined, channel rock-removal blasting may be resolved to an equivalent form of Cole's equation. The assumption, which is conservative for mortality, is that the attenuation factor is similar for both explosive positions; the attenuation should be greater for rock. Insufficient information has been collected to resolve the rock attenuation exponent for this location, although the Joint Venture's records may have sufficient material to resolve the attenuation. The maximum pressure, p_C, from a single confined charge for the KVK data is:

$$p_C \text{ (psi)} = 5{,}600 \; SD_C^{-1.13},$$

where

SD_C = the confined scaled distance and $SD_C = d / (w_C^{1/3})$,
d = is the distance from the single confined blast to the point of pressure value, p_C,
w_C = the maximum charge weight (in pounds) per delay of a single, confined blast.

The mortality radius for confined shots from the KVK data may be resolved from the confined pressure equation and using the lethal pressure of 40 psi. The mortality radius for single, confined shots, MR_C, is:

$$MR_C \text{ (feet)} = 80 \; w_C^{1/3},$$

where

w_C = the maximum charge weight (in pounds) per delay of a single, confined blast.

Theoretical mortality radii are computed and listed in Table 4.2.6. The table lists (for the six shots where the transducer array was in place) the number of drill holes shot and the maximum charge weight per delay of each shot. The table provides the leading and lagging distances for each shot from the boring with the maximum charge weight per delay to the transducers. For three shots the boring with the maximum charge weight per delay was the closest boring to the transducer array. For Shots 014, 021 and 022 the typical 25-lb charged boring was the closest boring to the transducer array. Both MR_C and MR_{OW}, which are theoretically determined, are given in Table 4.4.1. MR_C and MR_{OW} for the typical 25-pound charge in a boring are 230 and 760 feet, respectively. For most shots there was a field of borings all with 25-lb charges, except for one to three drill holes with a larger maximum charge weight per delay. The noted MR_C may be more conservative, or larger, than the actual mortality radius, as noted above. MR_C is less than one third the corresponding radius of equivalent single, open-water blasts. The complexity of the shot pattern and heterogeneity of the rock cause the actual pressures to have greater amplitudes than pressures from a single shot.

Table 4.4.1
Mortality Distances

Shot	# Holes Shot	Max Charge Wt/Delay (lb)	Lead T Dist (ft)	Lag T Dist (ft)	M Radius Confined (ft)	M Radius Open-wtr (ft)
010	25	73	660	820	330	1,100
011	17	133	580	740	410	1,300
014	2	72	470	630	330	1,100
020	19	54	250	300	300	980
021	28	87	500	640	350	1,200
022	39	73	570	700	330	1,100

4.5 Conclusions from Blast Monitoring

Pressure waves from the actual confined shots of the KVK rock removal program were recorded. The pressure waves and their maximum amplitudes were determined for four shots. The pressures from the confined shots were significantly lower than equivalent shots theorized as detonated in the water column.

An equation was approximated to predict maximum pressures from the confined shooting of the KVK rock removal. Theoretical mortality relations were resolved for both confined and open-water shooting. The confined mortality radii may overestimate the kill zones for fish, as there is insufficient data on fish kill at this location and other measures of impulse and energy, which could be used to corroborate the maximum pressure impacts, could not be attained. The mortality radii for the performed confined blasting are much smaller than equivalent open-water mortality radii.

5.0 PROGRAM CONCLUSIONS

5.1 Dominant Fish Species

The fish species that dominated Harbor Complex collections included striped bass, white perch, winter flounder, Atlantic tomcod, spotted hake, bay anchovy, Atlantic silverside, Atlantic menhaden, bluefish, spot, and weakfish. It can be expected that these species will also be present in the KVK.

The species diversity and abundance varied seasonally. The data reviewed indicate that species diversity was low in winter collections, and increased in the spring. Species diversity was highest in the summer and fall. This pattern reflects the spring migration into and fall migration out of the area by juvenile and adult stages of many anadromous and marine species. For example, winter flounder, an important recreational and commercial species, was most abundant from November through March; though it was present in collections all year. Striped bass were present year round, but striped bass abundance peaked from January to March. Atlantic menhaden were also present year round, but this species was most abundant in samples from July through August. Table 2.4.1 presents the seasonal occurrence the fish species dominant in the sampling studies reviewed for this report.

5.2 Fish Observations During Blast Pressure Measurements

The primary cause of injury and mortality to aquatic organisms from blasting in aquatic environments appears to be damage associated with rupture and hemorrhage of air-filled internal organs, particularly the swimbladder (Wright and Hopky 1998; Keevin and Hempem 1997). Many pelagic fish possess swimbladders; this organ plays a role in buoyancy. In contrast, demersal species, such as flounder, typically do not have swimbladders and are frequently less susceptible to blast impacts.

During the Blast Monitoring study, study participants observed the types of fish that appeared at the surface following blasting events. Attempts were made to capture fish that were stunned or killed by the blast. However, heavy gull predation in the vicinity of the blast interfered with collections; gulls are opportunistic and quickly preyed upon the fish that floated to the surface. Even so, several fish species were captured by netting using a small support boat or were observed floating in the vicinity of the anchored R/V *Hudson*. Observations were as follows:

- ***21 October 2002*** – Morning shot – *Menidia* sp. (silverside) floating, striped bass (approximately 18-in. total length)
- ***22 October 2003*** – Morning shot - eel and sea robin (approximately 3- to 4-inch total length) floating; afternoon shot – striped bass (approximately 18-in. total length) and butterfish (approximately 3- to 4-in. total length)
- ***23 October 2003*** – Afternoon shot – 22 menhaden (approximately 12- to 15-in. total length) floating on surface plus one striped bass (approximately 18-in. total length)
- ***29 October 2003*** – Late morning blast – observed many *Menidia* sp. (silverside) and herring (approximately 3- to 4-in. total length) floating; support boat collected one 20-lb striped bass (stunned), three blueback herring (two at 3-in. total length and one at 8-in. total length), and one menhaden (4-in. total length).

It is likely that the species observed is reflective of seasonal patterns. It is expected that winter, spring or summer monitoring would show a difference in the species affected.

5.3 Blast pressure and Fish Mortality

The primary cause of damage in finfish exposed to a pressure shock wave appears to be the outward rupture of the swimbladder as a result of the expansive effect of the negative hydrostatic pressure associated with the reflected air-water surface wave. The weight of the charge and distance from the detonation are the most important factors affecting the extent of injury and mortality, although water depth, substrate, depth of the fish, and size and species of fish are also important (Keevin and Hempen 1997; Wiley et al. 1981; Teleki and Chamberlain 1978). The shape of the lethal zone is dependent on the depth of the detonation. In shallow water, the horizontal extent is greater than in deep water. However, for buried explosives, the lethal zone is conical with the narrow portion of the lethal zone near the bottom expanding horizontally toward the water surface (Linton et al. 1985). This study looked to estimate the radius of this lethal zone, the mortality radius, based on a derived relationship between confined blasts and open-water blasts.

Using a conservative pressure value of 40 psi as the basis for mortality (Hubbs and Rechnitzer 1952), an equation was approximated to predict maximum pressures from the confined shooting of the KVK rock removal. Based on the resulting data, it appears that the mortality radii for the performed confined blasts are much smaller than equivalent open-water mortality radii. This is demonstrated by the data recorded for the shots listed in Table 4.2.5. No fish would have been killed at the recording distances for these shots (480 to 660 feet) as the maximum pressures fell below the lethal pressure of 40 psi. A theoretical estimate of the pressure and impact of the "average" blast event monitored during this study would result in a pressure of about 90 psi with a kill radius of about 375 feet. The calculated open water charges would have ranged in pressure from 71 to 104 psi, therefore theoretical open water shots would have killed fish within and beyond these distances. Although these data are conservative, it should be noted that the calculated confined mortality radii may overestimate the kill zones for fish, as there was insufficient data on fish kill at the study location, and other measures of impulse and energy, which could be used to corroborate the maximum pressure impacts, could not be attained. While it is stated elsewhere in this report that fish "close" to the blast point would be killed, it is not possible to quantify the kill zone radius based on data collected during this study or other studies consulted as part of the literature review.

Review of blasting literature revealed that the position of drill holes with maximum charge weights within arrays of multiple charge weights affects the kill radius. When drill holes with maximum charge weights are located at the outer perimeter of an array, the kill radius is significantly larger. However, when maximum charge weight borings are positioned near the center of the shot pattern, the impact is diminished. It appears that the pressure waveform of the maximum charge is dampened by those of the surrounding lesser charges.

In conclusion, the blast pressure monitoring data implies that impacts on the fish may be diminished through the use of arrays configured with maximum charge weights located in the middle of lesser charge weights. The data also implies that the confined charges used in the KVK Blasting Program appear to have less of an impact on fish than would equivalent open water charges. However, without completion of a caged fish study, quantitative estimates and/or calculations of mortality radii may not be made.

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Section 2

Contained within Text.

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