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June 27, 2013

Jackie Timothy
ADF&G Division of Habitat
PO Box 110024
Douglas, AK 99811

Re: ADF&G Blasting Standard for the Protection of Fish, Contract #IHP-13-051

Dear Jackie,

Please find the attached report *Management Considerations for Blasting Near Fish and Fish Habitat*. The report contains a description of common methods to minimize and mitigate the impacts of blasting on fish, a detailed summary of resource agency requirements for blasting projects in or near fish habitat, a review of completed marine blasting project specifications and requirements, and a summary of blasting industry best practices relating to the subject.

The report is meant to provide you with a summary of available and tested mitigation methods and examples of what other fish and wildlife agencies responsible for the protection of salmon require for in-water blasting projects. The second portion of the report addresses common requirements and industry best practices pertaining to the mitigation of blasting impacts on fish. The contents of this report are for your consideration during the revision of the ADF&G Blasting Standard for the Protection of Fish.

Please contact me if you have any questions or comments regarding this report.

Sincerely,

Kristen Kolden

Kristen Kolden
Alaska Seismic & Environmental, LLC

Attachment:
Management Considerations Report

ALASKA SEISMIC & ENVIRONMENTAL, LLC
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MANAGEMENT CONSIDERATIONS FOR BLASTING NEAR FISH AND FISH HABITAT

Project: ADF&G Blasting Standard Revision, Contract # IHP-13-051
Submitted to: Jackie Timothy, ADF&G Division of Habitat, Southeast Region
Submitted by: Kristen Kolden, Alaska Seismic & Environmental, LLC
Date: June 26, 2013

INTRODUCTION

Resource managers with the Alaska Department of Fish and Game (ADFG) are in the process of revising and updating guidelines for permitting blasting projects that occur in or near fish habitat. A review of mitigation methods and applications was conducted to provide ADFG resource managers with information to consider during the departmental blasting standard revisions. The review is divided into four sections. The first describes mitigation methods and techniques and summarizes their effectiveness as discussed in the literature. The second section outlines the process and mitigation required by other resource agencies that deal with blasting proposals near fish habitat. The third and fourth sections review marine blasting project specifications and list required mitigation methods and blasting industry best practices.

MITIGATION TECHNIQUES

Many methods have been proposed and applied to minimize or mitigate the effects of blasting on fish and fish habitat. Methods vary in cost, complexity, effectiveness, and in the impact that they are designed to reduce. Keevin and Hempen (1997) provide an overview of mitigation techniques in *The Environmental Effects of Underwater Explosions with Methods to Mitigate Impacts*. The authors summarize the results of a questionnaire sent to natural resource agencies in fifty states regarding the mitigation of blasting effects. Some common mitigation methods are explained and discussed below.

TIMING WINDOWS

The most effective method to avoid blasting impacts to fish is to perform blasting at a time when fish are not present, or when they are the least sensitive to impacts. Resource agencies and biologists have specific knowledge on local species, their life histories, and habitats and this approach may be the most effective to protect fish. Of the natural resource agencies questioned about blasting mitigation measures, twenty-three of fifty considered the use of timing restrictions on blasting (Keevin and Hempen 1997). Resource agencies and biologists have specific knowledge on local species, their life histories, and habitats.

Timing restrictions may be difficult to apply if several species of fish occupy the same area or if a resident population exists. Avoiding fish presence and sensitive life stages may also be difficult when blasting needs to be completed under certain conditions (e.g. seasonal, low-flow, tidal).

Fish Removal

Physically removing fish from an area by trapping, netting, electrofishing, dewatering, etc. can avoid impacts from blasting. Removal may be easily performed in smaller shallow areas and extremely difficult in larger deep-water conditions. Improper handling of fish can cause unnecessary injury or stress and fish removal may require training or permits.

Fish Deterrents

Various methods of deterrents have been used to scare fish away or keep them from entering a particular area. Non-contact fish deterrents include detonating scare charges prior to blasting, hazing fish with boats and personnel, and visual and acoustic technologies. The effectiveness of these techniques has varied during field tests (Knudsen et al. 1992, McAnuff et al. 1994, Keevin et al. 1997, Racca et al. 2004, Johnson et al. 2004).

Repelling or "scare" charges are small explosive charges detonated prior to a larger blast with the goal of driving fish away from the area. Scare charges have been used on several projects and their effectiveness is uncertain (Keevin and Hempen 1997). Fish kills from scare blasts were observed in the Nipigon and Winnipeg Rivers in northwest Ontario (McAnuff et al. 1994). Others have noted that scare charges do not actually cause fish to move from an area (Keevin et al. 1997).

Acoustic deterrents have been tested as fish repellents. Knudsen et al. (1994) successfully deterred migrating Atlantic salmon smolt (*Salmo salar*) in a small river with a 10 Hz tone. Others have had success with pulsed tones at various frequencies and amplitudes (Keevin and Hempen 1997). Strobe lights were examined as a visual deterrent but proved ineffective in high turbidity or other settings where light attenuates quickly (Racca et al. 2004).

Bubble Curtains and Barriers

Bubble curtains are designed to create a barrier of bubbles in the water column around an activity and cause pressures to attenuate as they cross the bubble barrier. Bubble curtain systems can be constructed in several ways including forcing compressed air through a single or multiple pliable hose system, rigid metal pipes, or manifolds (Hempen 1993).

The effectiveness of bubble curtain use varies. Keevin et al. (1997) noted a significant reduction in fish mortality during demolition blasting in deep, swift, turbulent water with the use of a bubble curtain. Nevertheless, they noted the high cost, time, and difficulty of installation as drawbacks. Deployment of a hose based bubble curtain during blasting in a relatively protected area effectively reduced peak water pressures and the mortality radius of pacific herring (*Clupea pallasii*) and surf smelt (*Hypomesus pretiosus*) (Grogan 2005).

Peak pressures were reduced 17 to 73 percent with a bubble curtain during blasting in Vancouver, British Columbia. However, impulse values were increased and the bubble curtain was deemed ineffective (Munday et al. 1986). Others have concluded that bubble curtains are ineffective in conditions with flowing water (Fernet 1982) and extremely expensive to install and operate (McAnuff and Booren 1989).

Additional types of pressure inhibiting barriers include air and steel sheeting. Air-entrained sheeting consists of closed-cell foam or bubble wrap and has been suggested as a highly effective means of reducing pressure in still water environments (Hempen 1993). Steel sheeting barriers, or sheet piles, have been required on several projects to reduce pressures and sedimentation. The effectiveness of these methods has not been reported (Keevin and Hempen 1997).

MONITORING

Damaging effects of blasting can be minimized in many ways with visual observations, species and water sampling, acoustic surveys, and water overpressure and vibration measurements to control the energy source. Monitoring observations and results can be applied to mitigate immediate blasting effects or can be documented to help mitigate effects of future blasting projects.

Visual Monitoring and Surveys

The requirement for marine watch programs has been implemented for blasting projects in areas with sensitive or protected species. In some instances watch programs are designed to delay blasting if species of interest are observed within or approaching the blast area. Marine watch plans are most effective in clear, shallow water environments and for larger fish species or marine mammals. In instances where it is difficult to observe fish, acoustic surveys and sampling techniques (e.g. trawling, set-nets, traps) can help determine if species are in the area. Survey techniques can also be used to assess the number of fish in an area prior to blasting. When mortality models are applied, a total estimate of fish take can be calculated (Carlson et al. 2011).

Pressure and Vibration Monitoring

Monitoring of blast induced pressures and vibrations has been required on several projects to ensure that harmful amplitudes of overpressures and vibrations are not exceeded. During the Columbia River Channel Improvements, the U.S. Army Corps of Engineers specified cautionary and maximum peak pressure values for the protection of fish at a specific distance from perimeter blast holes.

Pressure and vibration amplitudes measured in a linear array from blasts using variable quantities of explosives can be used to develop site-specific attenuation models. Blasting specialists can use this information to optimize blasting plans and reduce excess pressures and vibrations in the surrounding environment. Resource managers can use attenuation information to determine the area of impact to species.

COMPENSATION

When methods cannot successfully avoid or reduce the impacts from blasting, compensation may be required. In a review of mitigation measures used by natural resource agencies, sixteen agencies surveyed have monetary compensation requirements for fish loss. A monetary value can be based on actual counts of dead fish, projected numbers of fish mortality, or caged fish exposures (Keevin and Hempen 1997).

RESOURCE AGENCY REQUIREMENTS

Fish and wildlife agencies from three states were contacted and questioned about how their agencies approach issuing permits for blasting projects in or near fish habitat. Representatives from the Pacific and Northwest Territory (NWT) Canada Department of Fisheries and Oceans (DFO) were also contacted regarding the application of the *Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters* (Wright and Hopky 1998) Their responses are summarized below.

CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE

The California Department of Fish and Wildlife (CDFW) requires notification of any proposed activity that may alter rivers, streams, or lakes. Proposals are reviewed and when CDFW determines an activity may affect fish or wildlife resources, Lake or Streambed Alteration Agreements that may contain conditions or stipulations are issued (Mark Stopher, personal communication, April 12th, 2013). A CDFW Senior Fish Habitat Supervisor provided an example of an approved blasting project in Siskiyou County. Proposed mitigation measures weren't based on any blasting specific technical information, but rather on avoidance techniques (Kevin Gale, personal communication, April 19th, 2013). A summary of the project follows.

> **Project**: *Whites Gulch Dam Removal*
> **Description**: "OSHA certified blasters from the California Department of Fish and Game (DFG) will use explosives to demolish a diversion dam (upper dam) on Whites Gulch in a tributary to the North Fork Salmon River which will allow fish access to approximately 1.5 miles of stream. The dam is a 2 ft. thick, 41 ft. wide, and 7 ft. tall concrete structure. The site will be dewatered by constructing a cofferdam upstream of the site using native streambed material and Visqueen and routing the water around dam via an existing pipe. DFG biologists will remove fish and amphibians and release them to a safe section of stream. The dam would then be drilled, explosive charges set, blasted, and debris removed from channel. All work will take place using hand labor and small gas, electric, or pneumatic powered hand tools. No heavy equipment will be used. Currently there are two downstream barriers (culvert and diversion dam) which are scheduled to be removed after the upper dam is removed. These structures preclude the possibility that coho salmon may exist in the project area. The project is scheduled to be implemented in August, 2009."

Resource protection measures: A blasting plan was submitted including the description of drilling and blasting methods, materials, timeframe, and aquatic life rescue and removal. These details were provided in the plan:

- Fish and other aquatic life will be removed from an area approximately 100 feet upstream and 100 feet downstream of the dam.
- A screen and sandbag barrier will be used to isolate the downstream pool and a 100 foot stream reach above the dam.
- The pools will be partially dewatered. Seining and electrofishing will be used to remove fish from the blast area. Rescued fish will be moved to existing upstream and downstream pools several hundred feet from the dam.

Additional Review: The USDA Forest Service (USFS) Environmental Assessment (EA) concluded that impacts from the sound of the blasting would not affect the salmon because of the distance of 1-½ miles. The EA states that pools will fill in after the dam is removed and stream gradient is not likely to change. The USFS recommends leaving significant large wood or rock structures in the channel for habitat complexity. The EA states that, "the indirect effects of the project in terms of reducing pool habitat will be more than offset by leaving rocks and logs around which the stream will scour. Bedrock along the river-left bank at both dam sites should reduce the risk of bank erosion following demolition." A Decision Notice and Finding of No Significant Impact was issued for the project.

OREGON DEPARTMENT OF FISH AND WILDLIFE

The Oregon Department of Fish and Wildlife (ODFW) works with applicants during the application process to address any issues regarding fish passage and any mitigation measures that may be necessary. ODFW in-water timing guidance to minimize impacts to fish during in-water work and blasting permit applications are posted on the ODFW website at http://www.dfw.state.or.us/lands/inwater/. The Land Use and Water Way Alterations Coordinator provided some examples of terms and conditions for permits to use explosives in Oregon waters (Joy Vaughan, personal communication, April 18th, 2013). All projects included the same 'General Conditions' including:

1. The applicant shall make all necessary notifications 48 hours prior to commencement of blasting activities
2. The permit holder shall obtain necessary permissions before entering lands owned by another
3. ODFW permit is issued in the interest of fish and wildlife protection and does not consider other liabilities or permits that the applicant is responsible for obtaining
4. Potential pollutants should be stored away from the project site to prevent materials from entering the stream in case of spillage
5. Minimize disturbance of stream banks and streamside vegetation. Reseed disturbed soil in fall or spring

6. ODFW reserves the authority to halt or modify the project in case of excessive damage to natural resources
7. The permittee may be required to compensate the state if damaged fish are observed
8. ODFW employees shall be allowed access to the project area at all reasonable times for the purpose of inspecting work performed under this permit
9. ODFW approval for in-water blasting does not authorize the incidental take of ESA listed fish, that issue must be addressed with the National Marine Fisheries Service through the U.S. Army Corps of Engineers permit review process
10. Permit violations are subject to administrative or legal action, permit may be revoked, permittee is responsible for activities of all contractors on site
11. The applicant is responsible for warning recreational users and nearby property owners of potential dangers of blasting, warnings may be in the form of signs, letters, or personal contact
12. All blasting wire, dynamite, boxes, etc. must be cleaned up
13. A copy of the permit must be at the work site during operations

The permit examples provide include 'Notification Requirements' the applicant must make including

1. Notify the district fishery or habitat biologist at least 48 hours before actual blasting so the Department has the opportunity to have an observer present or conduct a pre-blasting site inspection
2. Notify local law enforcement agencies before blasting activities
3. Notify all adjacent landowners, renters, and recreational users within the affected area of the planned in-water blasting schedule. The notice must be by:
    a. Registered letters to adjacent landowners with return receipt;
    b. Publication in the local newspaper;
    c. Postings in the vicinity of the project; and
    d. Auditory warnings before blasting.
4. Applicant must provide evidence to the Department of compliance with subsections 3(a)-(c) at least three days before blasting occurs

Each permit contains a description of 'Compensation for Injury to Fish and Wildlife' that states

> "The applicant must compensate the State of Oregon for any injury to fish, wildlife, or their habitat resulting from failure to comply with the conditions of the in-water blasting permit, or from failure to obtain and in-water blasting permit. Compensation for such injury or damage will be determined as provided for in ORS 4996.705 and 496.992, and OAR 635-001-0025 and 635-410-0030.

A Permit does not relieve the permittee from liability for the injury to persons, property, or fish and wildlife or their habitat resulting from acts conducted pursuant to the conditions of the permit."

'Special Conditions' for each project reviewed are listed below.

Project: *Cougar Dam Fish Trap Construction*
Special Conditions: Since the blasting activities will occur outside the wetted channel and behind a cofferdam, impacts to aquatic species will be minimized. Because of the cofferdam and high velocities in the river, the permit states that a bubble curtain would likely not reduce risk at the site any further. In addition, the following requirements are stated

- Blasting shall be completed between April 15 and May 14, 2009. Work outside this period requires a variance from ODFW
- Detonation delays shall be used to reduce the force of the shock wave
- Remove as much debris as possible from the waterway. Place waste materials and spoils above the high water line and not in wetland areas
- Work area will be isolated from the river and de-watered, this can be done with a cofferdam or similar structure. Fish shall be removed from the area by a contractor with the appropriate permits.

Project: *North Santiam River Explosives Use*
Special Conditions:

- Initial leveling or test blast shall occur between August 22 and September 15, 2011 and may occur prior to cofferdam construction and de-watering. The remainder of blasting shall occur between August 22 and October 31, 2011.
- Blasting shall occur outside wetted channel behind a cofferdam in a de-watered area. A contractor with the appropriate permits shall remove fish from the area.
- Use detonation delays
- Remove debris from waterway, place waste materials above high water and not in wetlands
- Use native material for any backfill
- Use controlled blasting methods to reduce impacts to fish and wildlife. Methods include drilling excess holes that are left empty, delayed blast timing, blasting mats, stemming, etc.
- Restore all areas disturbed by construction and blasting
- All provisions in permit application and blasting plan are incorporated into this permit

Project: *Rogue River Explosives Use near Savage Rapids Dam*
Special Conditions: Since the blasting activities will occur behind a cofferdam, impacts to aquatic species will be minimized. A bubble curtain would likely not reduce risk at the site any further. In addition, the following requirements are stated

- Minimize impacts to migrating spring Chinook by blasting between August 13-17th or August 6-17th if a two week window is required. Contact ODFW for variance.
- Use detonation delays
- Remove debris from waterway, place waste materials above high water and not in wetlands
- De-water work area and remove fish prior to work. Fish salvage must be done by a contractor with appropriate permits

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

The Washington Department of Fish and Wildlife (WDFW) is required to protect fish life from the impacts of hydraulic projects that use, divert, obstruct, or change the natural bed or flow of state waters. Mitigation requirements in Hydraulic Project Approvals (HPA) are designed to reduce project impacts. A WDFW Regulatory Services Coordinator noted their agency rarely receives requests for projects involving blasting. When blasting projects are reviewed biologists can choose from a list of provisions in addition to writing individual project-specific methods for mitigating impacts (Pat Champman, personal communication April 9th, 2013).

- Charges shall be no larger than necessary to accomplish the task and shall be set in a manner (timing, frequency, location) such that in-stream concussion is minimized. Timing shall include micro-second delays to minimize impacts to fish.
- All blast material shall be removed and deposited in an approved upland disposal site so it will not re-enter the stream.
- The permittee shall be financially responsible for any fish kill. Should a kill occur, all blasting activities shall immediately cease and the Area Habitat Biologist listed below immediately notified. A written report detailing the fish kill and subsequent actions shall be submitted to the Area Habitat Biologist as soon as possible following the kill, but no more than 15 days subsequent to the fish kill.
- A diver shall be on site and available for potential damage assessment following blasting activities.
- Blasting operations shall be conducted during periods of low or no stream flow.
- Methods (blasting mats, sandbag berms, etc.) to contain and control possible slide debris resulting from blasting shall be in place prior to any blasting.
- Prior to any blasting, the permittee shall capture and safely move food fish, game fish, and other fish life from an area 75 feet upstream and 75 feet

downstream from the blast site. The permittee shall have fish capture and transportation equipment ready and on the job site. Captured fish shall be immediately and safely transferred to free-flowing water away from the blast area. Once fish are removed, the area shall be blocked to prevent the re-entry of fish into the blast area. This may require the use of block nets or seines. The permittee may request the WDFW assist in capturing and safely moving fish from the job site to free-flowing water, and assistance may be granted if personnel are available.

- A bubble curtain shall be placed around the blast site to minimize impacts to fish.
- Approved fish scare tactics shall be used prior to blasting.
- If at all possible, blasting shall occur in an area that is physically separated from the flowing stream, i.e., inside a cofferdam.

CANADA DEPARTMENT OF FISHERIES AND OCEANS

Canada's Department of Fisheries and Oceans (DFO) is responsible for protecting and conserving marine, intertidal and freshwater fisheries resources. The DFO Pacific Region Fisheries Protection Program reviews activities involving blasting in and near water bodies in British Columbia and the Yukon Territory. Requirements for blasting projects often include best management practices such as the requirement for an environmental monitor to be present at the work site (Eric Chiang, DFO Fisheries Protection Biologist, personal communication, June 12th, 2013). Other methods or practices may be recommended based on the *Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters* (Wright and Hopky 1998) report that was written to provide information to protect fish and fish habitat during blasting projects. The full report can be found on the DFO website at 'http://www.dfo-mpo.gc.ca/habitat/role/141/1415/14155/explosives-explosifs/index-eng.asp' and includes a summary of applicable legislation and policy, effects of blasting on fish and fish habitat, guidelines for the protection of fish and fish habitat, suggestions for the application and review process, and guidelines for review and decision making process. The 'Guidelines' section describes several methods that may be incorporated into a project to mitigate blasting impacts on fish and fish habitat, the methods are summarized below.

1. Applicants should consult DFO early in the planning process
2. Applicant should consult with all relevant authorities
3. The use of explosives (particularly unconfined) is discouraged, use less destructive methods whenever possible
4. Use of ammonium nitrate fuel oil mixtures prohibited in or near water due to production of toxic by-products (ammonia)
5. Use angular gravel approximately 1/12th the diameter of the borehole to stem loaded blast holes
6. Recover all shock tube and detonation wire after each blast
7. Do not detonate explosives within 500 m (1,640 ft) of any marine mammal

8. "No explosive is to be detonated in or near fish habitat that produces, or is likely to produce, an instantaneous pressure change (i.e., overpressure) greater than 100 kPa (14.5 psi) in the swimbladder of a fish." Setback distances, equations, and examples are provided in the report appendices.
9. "No explosive is to be detonated that produces, or is likely to produce, a peak particle velocity greater than 13 mm•s-1 in a spawning bed during the period of egg incubation." Setback distances, equations, and examples are provided in the report appendices.

Setback distances to limit overpressure and vibrations are provided in tables in the report and the equations used to determine setback distances and examples are provided in the appendices of the *Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters* (Wright and Hopky 1998).

The Northwest Territories DFO frequently receives proposals for seismic exploration activities using explosives. Biologists in the region suggest limiting instantaneous pressure change to 50 kPa (7.3 psi) to protect fish from blasting (Pete Cott, personal communication, June 13th, 2013). The lower threshold used in the northern region is based on a study that observed fish injury from instantaneous pressures as low as 69 kPa (10.0 psi) from seismic charges detonated in a frozen lake (Godard et al. 2008). Researchers also determined that the setback distances and equations provided in the *Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters* (Wright and Hopky 1998) report were not accurate and varied greatly between projects (Cott and Hanna 2005). Habitat biologists in the Northwest Territories DFO recommend pressure and vibration monitoring to determine site-specific setbacks (Bruce Hanna, personal communication, June 14th, 2013).

MARINE BLASTING PROJECT SPECIFICATIONS

Project specifications and requirements for three recent projects involving marine blasting were reviewed. Project specifications are a comprehensive description of project objectives and the requirements necessary to satisfactorily complete work. Requirements may come from the original project proposal, federal, state, or local agencies, or other stakeholders. Relevant methods and techniques to mitigate the impact of blasting on fish and fish habitat are summarized for each project below.

Project: *Columbia River Channel Improvements (CRCI)*, Columbia River, Columbia County, Saint Helens, Oregon and Clark County, Washington. (2009).

- Use controlled blasting techniques including a test blasting plan, limit the maximum charge weight per delay, use adequate stemming materials, apply drill hole diameter limitation, detailed methods for positioning shots and drill holes
- All drilling and blasting procedures and equipment shall minimize effects on material beyond the project boundary

- Spill prevention and containment plan
- Recover all exploded shock tube from water
- Safety zone and watch program in place for endangered species and marine mammals
- Incidental take limits specified for endangered species
- Timing restrictions to protect fish
- Maximum peak pressure limit specified, suspend blasting if limit exceeded
- Minimum specifications for pressure monitoring equipment

Project: *Wilmington Harbor Deepening Anchorage Basin*, New Hanover and Brunswick Counties, North Carolina (2012).

- Use controlled blasting techniques including a test blasting plan, maximum charge weight per delay, stemming requirements, detailed methods for positioning shots and drill holes
- Spill prevention and containment plan
- Recover all exploded shock tube from water
- Detonate scare charges prior to each blast
- Safety zone and watch program
- Set gill nets before and after blasting to monitor fish presence and catch injured or killed fish post blasting
- Perform sonar sweeps of blast area, halt blasting if schools of fish are present
- Timing restrictions to protect fish
- Maximum peak pressure limit specified, suspend blasting if limit exceeded
- Minimum specifications for pressure monitoring equipment

Project: *Cushman Dam No. 2 Fish Collection/Sorting Facility and North Fork Skokomish Powerhouse*, City of Tacoma, Washington (2011).

- Use controlled blasting techniques including a test blasting plan, stemming requirements, detailed methods for positioning shots and drill holes
- All drilling and blasting procedures and equipment shall minimize effects on material beyond the project boundary
- Spill prevention and containment plan
- Timing restrictions to protect fish
- Physically separate blasting from water body if possible
- Maximum peak pressure limit specified for areas where fish may be present
- Maximum peak vibration limit where fish embryos may be present
- Suspend blasting if specified pressure or vibration limits are exceeded

- Minimum specifications for pressure and vibration monitoring equipment

All three projects reviewed required in-water pressure monitoring during blasting activities to comply with the limits imposed and monitoring locations as specified in Table 1. Minimum specifications for monitoring equipment differed between projects. CRCI and Wilmington Harbor required similar types of equipment capable of recording peak pressures 0 to 1,000 psi (6895 kPa) and sampling at 500 kHz. The Cushman Dam project required equipment capable of recording up to 47 psi (324 kPa) at a sample rate of 65 kHz.

Table 1. Marine blasting project specifications for overpressure monitoring. Maximum allowable overpressures (psi) and monitoring locations are listed for three projects reviewed.

Project	Monitoring Location	Maximum Allowable Pressure (psi)
Columbia River Blasting, OR	140 ft from blast	cautionary 40 maximum 70
Wilmington Harbor, NC	140 ft from blast	120
Cushman Dam, WA	where fish may be present	2.7

BLASTING INDUSTRY BEST PRACTICES

The explosives industry is highly regulated and follows rules imposed by federal, state, and local agencies. Safety and security are of paramount concern. The International Society of Explosives Engineers (ISEE) promotes the standardization of methods in explosives engineering as well as the professional development, competence, and qualifications of those in the field. The Institute of Makers of Explosives (IME) participates in the development of industry standards and best practices and publishes recommendations and guidelines for all facets of explosives operations as Safety Library Publications (SLPs). Best practices include a wide array of methods and techniques to improve blast efficiency, ensure safety, and minimize unwanted effects. Coincidentally, many of the best practices that improve the efficiency of a blasting project may also minimize unwanted effects on surrounding environments.

Several recent marine project specifications were reviewed for common blasting practices that could minimize blasting impacts on fish and fish habitat. Many of the following practices listed below are considered as standards for marine blasting projects.

- Use qualified blasting specialist and blaster-in-charge
- Use explosives designed for marine environments

- Recover all shock tube and blast waste from the water
- Accurately position all drill holes and shot locations
- Perform a test blasting program prior to operational blasting
- Use controlled blasting techniques
- Maintain contingency plans for misfires and spills
- Submit detailed reports and records for each blast

TEST BLASTING

Test blasting programs are carried out during the beginning phases of a project with the goal of optimizing blast production and establishing safe limits of vibration and pressure by performing attenuation analysis. Results can be used to engineer blasting procedures and site-specific attenuations can be used as a tool to predict vibration and pressure levels at distances from the blast. This can help resource agencies determine safe distances for fish and ensure that blast pressures and vibrations remain within specified limits.

CONTROLLED BLASTING TECHNIQUES

In some cases where rock displacement, vibrations, or pressures are a concern, controlled blasting techniques are utilized to achieve the desired results and minimize impacts. Some controlled blasting techniques include drill hole diameter and depth, loading density, delay patterns, presplitting, line drilling, and cushion blasting. In instances where flyrock cannot be controlled through blasting technique, the use of blasting mats may be required. The blaster-in-charge is directly responsible for the outcome of blasting and is aware of safety, security, and environmental rules that must be complied with. Controlled blasting techniques are applied by the blaster-in-charge who relies on training, knowledge, skills, and experience to select the appropriate techniques.

CONCLUSION

Appropriate and effective mitigation methods depend on a number of factors including the knowledge of the persons proposing them, the type of blasting, species present, site-specific conditions. For instance, a change in blasting technique may be highly effective in reducing in-water overpressures or ground vibrations. However, modifications to the blasting plan are best administered by a blasting specialist or blaster-in-charge who has a cognitive understanding of other effects that may result (e.g. safety, flyrock, proper breakage, total project time, cost). Resource managers and biologists familiar with species, life stages, life histories, and habitats are the most qualified to prescribe meaningful and effective work timing windows and fish removal methods. Identifying appropriate and effective mitigation strategies can be accomplished by coordination between applicants and project reviewers.

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