United States Department of the Interior

FISH AND WILDLIFE SERVICE

Snake River Fish and Wildlife Office
1387 S. Vinnell Way, Room 368
Boise, Idaho 83709
Telephone (208) 378-5243
http://IdahoES.fws.gov

APR 20 2007

Philis J. Posey
Acting Secretary
Federal Energy Regulatory Commission
888 First Street, NE
Washington, D.C. 20426

Subject: Arrowrock Dam Hydropower Project—Boise River, Elmore and Ada Counties, Idaho—Request for Early Consultation
File #FERC 4656 2007-R-0417

Dear Ms. Posey:

The Fish and Wildlife Service (Service) is writing in response to your March 22, 2007, letter requesting initiation of early consultation for the Arrowrock Dam Project (Project), Federal Energy Regulatory Commission (Commission) project No. 4656. The Commission determined that implementation of the proposed Project is likely to adversely affect bull trout (*Salvelinus confluentus*), and may affect, but is not likely to adversely affect, bald eagles (*Haliaeetus leucocephalus*). Both species are listed as threatened under the Endangered Species Act of 1973, as amended. The Service has determined that there is sufficient information available in the Project record and in Service files to initiate early consultation.

The procedures for early consultation can be found in section 402.11 of the regulations for interagency cooperation (50 CFR 402). Pursuant to these regulations, the Service will prepare a preliminary Biological Opinion (Opinion) within 135 calendar days of the date we received your letter—March 26, 2007—no later than August 4, 2007. Should the action change substantially between our delivery of the preliminary Opinion and the Commission's approval of proposed license amendments, the Service reserves the right to modify the final Opinion as necessary to reflect those changes and ensure that all potential effects are fully considered. We will notify you in writing if we anticipate changes to the timeframes identified in this letter for issuance of the preliminary Opinion. Likewise, if the Commission identifies project changes associated with the amendment that would necessitate modification of the Opinion, we expect you to inform us. If substantial modifications are necessary prior to issuance of a final Opinion, the regulatory 135 day timeframe for standard formal consultation may apply.

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The Licensees for the Project are represented by Mr. Albert Barker of Barker Rosholt & Simpson LLP, in Boise, Idaho. The Service will continue to work with Mr. Barker for any additional information needs or project clarifications.

Thank you for your continued interest in and consideration of threatened and endangered species. Please contact Kendra Womack at (208)866-5247 or Mark Robertson at (208) 378-5287 if you have any questions or concerns.

Sincerely,

for Jeffery L. Foss, Field Supervisor
Snake River Fish and Wildlife Office

cc: Barker Rosholt & Simpson LLC, Boise (Albert Barker)
Bureau of Reclamation – Snake River Area Office, Boise (Lesa Stark)
Boise National Forest, Boise (Michael Kellett)
USDA Forest Service, Salt Lake City (Gerrish Willis)

Snake River Fish and Wildlife Office

TAILS 14420-2007- R - 0417
Associated Project 2006-P-0076
Staff Kendra
Retention Schedule

SURNAME SLIP

Title	Initials	Date	Required TAILS Data
DRAFT, Author	KLW	4-5-07	
DRAFT, Other			
DRAFT, Reviewer	[illegible]	4-6-07	
FINAL, Admin Support	BB	4-9-07	
FINAL, Author	KLW	4-9-07	
FINAL, Reviewer	[illegible]	4-10-07	
Supervisor (Signer)			

DATES
First Contact Date
Date of Correspondence
Start Date
Date Formal Consultation Started
Draft BO Due Date
Draft BO Date
Final BO Date
Due Date
Conclusion Date 4-20-07
ABC Code

Core Information (Optional)

Title
Description

Consultation Type Complexity Species
Action/Type Work
Lead Agency Other Agencies
Hardcopy Location

Scan In I:\Electronic File Room\2007\ incoming\07-032707 – Grow Rock Dam ETB
Scan Out I:\Electronic File Room\2007\
Close Out
QA/QC

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FEDERAL ENERGY REGULATORY COMMISSION
Washington, D.C. 20426

OFFICE OF ENERGY PROJECTS

Project No. 4656 - - Idaho
Arrowrock Dam Hydroelectric Project
Boise-Kuna Irrigation District, et. al

Jeffrey Foss, Supervisor
Snake River Field Office
U.S. Fish and Wildlife Service
1387 South Vinnell, Suite 368
Boise, ID 83709

March 22, 2007

Subject: Request for Early Consultation on the Arrowrock Dam Project, No. 4656

Dear Mr. Foss:

We are submitting the attached information to your office in partial fulfillment of our responsibilities under the Endangered Species Act of 1973, regarding potential effects of proposed construction and operation at the Arrowrock Dam Project, FERC No. 4656, on threatened and endangered species, species proposed for listing, and candidate species. The project is located at the Bureau of Reclamation's (BOR) Arrowrock Dam, on the South Fork of the Boise River, Idaho. The proposed construction involves a license amendment to decrease the project's generating capacity, that would eliminate 10 miles of transmission lines and two large tunnels through Arrowrock Dam. Additionally, the proposed construction would eliminate any need for work in Arrowrock Reservoir, thereby reducing impacts that would have occurred at the project as licensed.

In a February 27, 2007 letter to the licensees,[1] you identified two species listed as threatened that may occur in the project area, bald eagle and bull trout. Your letter also indicated that formal consultation must be initiated for any project that is likely to adversely affect threatened or endangered species. In an earlier letter from your office, dated September 1, 2005, it was noted that, with the amount and quality of existing information, including the completion of recent BOR consultation[2] and information already provided by the licensees' representative during informal consultation, it should

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[1] Boise-Kune Irrigation District, Nampa and Meridian Irrigation District, New York Irrigation District, Wilder Irrigation District, and Big Bend Irrigation District.

[2] Biological Opinion for Bureau of Reclamation Operations and Maintenance in the Snake River Basin above Brownlee Reservoir, U.S. Fish and Wildlife Service, March 2005.

be possible to prepare a biological opinion (BO) in considerably less time than that specified in the regulations. In a January 25, 2007 telephone conference,[3] Commission staff, the licensees' representative, and staff from your office discussed that, given the information available, it appeared appropriate to move forward using Early Consultation. We are therefore providing this request for Early Consultation with your office. The additional information required for initiation of consultation, as identified under 50 CFR 402.14(c), is contained in the attachment to this letter, which includes a CD, provided by the licensees.

After reviewing the available material, we conclude that work under the proposed license amendment, followed by project operation, would be likely to adversely affect bull trout, possibly through sedimentation and other construction disruption, and then by possible entrainment during project operation. We conclude that bald eagles would not likely be adversely affected by the proposed work or project operation. We understand that the closest eagle nest to the project location is approximately 5 miles from Arrowrock Dam, and that construction work would be far enough away that it would not affect nesting eagles. Furthermore, we understand that there may be no good perching areas near the dam or transmission lines that would be harmed by construction, and that there is sufficient habitat through the Boise River Basin that any temporary disturbances would not affect the eagle population. It is noted, however, that some wintering eagles may avoid the construction areas at the dam and transmission line work sites.

Please provide us with a draft of your BO when it is available, and we will return it with any comments as quickly as possible as discussed with your staff in the January 25 telephone conference and pursuant to 50 CFR 402.14(g)(5). If we don't hear from you within 30 days of the date this letter, we will assume that you have sufficient information on which to base your draft BO.

Please file an original and 8 copies of your draft BO with: Philis J. Posey, Acting Secretary, Federal Energy Regulatory Commission, 888 First Street, NE, Washington, D.C. 20426. Please put the docket number P-4656 on the first page of your response. Alternatively, your draft BO may be filed electronically via the internet in lieu of paper.

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[3] Telephone conference between Alison Beck-Haas and Kendra Womack, FWS; Albert Barker, licensees' representative; and T.J. LoVullo and B. Peter Yarrington, Commission staff.

We look forward to continuing to work with you to protect listed species at the Arrowrock Dam Project. If you have any questions, please contact B. Peter Yarrington at (202) 502-6129 or Thomas J. LoVullo at (202) 502-8900.

Sincerely,

George H. Taylor
Chief, Biological Resources Branch
Division of Hydropower Administration
and Compliance

cc: Kendra Womack
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
1387 South Vinnell, Suite 368
Boise, ID 83709

Albert P. Barker (w/o attachment)
Barker Rosholt & Simpson LLP
1010 W. Jefferson, Suite 102
P. O. Box 2139
Boise, ID 83710-2139

REQUEST FOR INITIATION OF EARLY FORMAL CONSULTATION

Arrowrock Hydroelectric Facility FERC License No. 4656

I.
INTRODUCTION

Applicants are Licensees under License No. 4656 issued by the Commission. Applicants have a definitive proposal to amend the License. The details of the proposal and its effects are outlined herein. Applicants are in the process of assembling the Amendment, including updating the Exhibits and consulting with other affected agencies. Applicants intend to implement the proposal outlined herein, if authorized by the Commission.

Accordingly, Applicants have discussed with the Commission and the Service the possibility of the Commission and the Service engaging in early consultation under 50 CFR section 402.11, to reduce the likelihood of conflicts with listed species and it appears to all entities that early consultation would be appropriate in this instance.

Applicants have reason to believe that the proposed action may affect listed species, but have no reason to believe that the proposed action may affect critical habitat. The basis for this belief is that Applicants and the Commission originally described the action to amend the License and concluded that the project would not be likely to affect any listed species. (G. Taylor Letter, Sept. 29, 2004.) After discussing this proposed action with the Fish and Wildlife Service, the Service advised that it did not concur with this conclusion. (J. Foss Letter to Secretary Salas, Dec. 21, 2004.) Subsequently, the Applicant, acting as the designated non-Federal representative, engaged in informal consultation with the Service and provided the Service with sufficient information to proceed with formal consultation. (J. Foss Letter to Secretary Salas, Sept. 1, 2005.) Based on this informal consultation and discussions with the

Service, the Commission and Applicants request early formal consultation with the Service. The species of particular concern are bald eagles and bull trout.

This request for consultation encompasses all of the activities authorized by the proposed License Amendment, including all associated construction and operation activities. The Applicant recognizes that additional coordination with the Service may be necessary to complete early consultation. We are committed to this ongoing coordination and a flexible timeline for completion of early consultation.

The proposed Amendment eliminates 10 miles of transmission lines, two large tunnels through the dam, and does not require work in the Arrowrock Reservoir, consequently reducing some of the impacts when compared to the Licensed Project.

II.
DESCRIPTION OF THE ACTION TO BE CONSIDERED

The Licensees of the Arrowrock Hydroelectric Facility (FERC No. 4656) are proposing an Amendment to the License. The License allows construction of a 60 MW project located on the South Fork of the Boise River in Elmore and Ada Counties, Idaho. The project is located at the U.S. Bureau of Reclamation's existing Arrowrock Dam and Reservoir and the project's tailrace discharges to the United States Army Corps of Engineers' Lucky Peak Reservoir. The Licensees propose an amendment to the license to decrease the project capacity by changing the project from the current licensed project of two 30-MW generating units with two 13-foot diameter 180 foot long penstock through the Arrowrock Dam. In its stead, the Licensees are proposing to develop a 15-MW project consisting of two 7.5 MW generating units. Rather than installing tunnels through the dam and a new outlet works, the project, as contemplated, would receive water from two of the existing outlet works which lead to Clamshell gates downstream of

the dam, which are at a lower elevation. The Licensees also propose eliminating about 10 miles of transmission line from the project as licensed. The Commission determined that an amendment to the License was necessary for these proposed changes. Boise-Kuna Irrigation District, et al. 112 FERC ¶ 61, 240 (September 1, 2005). As an amendment seeking a decrease in the project capacity, the Licensees proposed amendment is a non-capacity related amendment. 18 CFR § 4.201(b).

The proposed amendment involves tapping into the existing Outlet Conduits No. 1 and No. 2 near their downstream end, just upstream of the newly installed Clamshell Gates, for conveyance of flow through two penstocks to the powerhouse containing two 7.5 MW units for a total of 15 MW capacity. The arrangement of installation of the required bifurcations is such that the two outlet conduits can be operated for releases when the powerhouse units are inoperable. This plan of utilizing the outlet conduits for conveyance of flow to the units requires modification to the recently completed gate structure of the outlet conduits. These required modifications are shown on the drawings included. SK-01 to SK-05.

Operation of the conduits for flow releases produces considerable turbulence downstream of the outlets. In particular, releases through Outlet Conduits 1 through 3 produce considerable erosive forces against the rock bench in the area (the same rock bench considered as the powerhouse site for the recommended plan). Construction of the powerhouse, as proposed, would harness the energy for beneficial uses, would release relatively tranquil flow some distance downstream, and would eliminate this problem.

The powerhouse would be located on the left bank (looking downstream) on the basalt rock bench that is seasonally flooded and then re-emerges when the Lucky Peak Lake (immediately downstream reservoir) recedes in the fall. The powerhouse will be located in the

same location and footprint as originally licensed. The powerhouse would be approximately 80 ft. high above its foundation. This results from the deep submergence requirement for the turbines and from the required flood protection when the Lucky Peak Lake reaches its maximum level in the summer recreational season.

The project will require turbine selection for the very wide hydraulic head variation at the project. The head variation for the full output conditions can vary from about 180 feet to less than 50 feet. Kaplan turbines proved most attractive, considering the equipment costs, the cost of civil works construction, and the energy output. The turbines would be double regulated with moveable runners and adjustable wicket gates for maximum efficiency of operations. The Kaplan turbines require a deep setting. The tailrace channel slopes up and leads to a weir that controls the tailwater elevation for periods when the Lucky Peak lake is drawn down.

Operationally, the Licensees will utilize a smaller proportion of flows through the Arrowrock Dam than the licensed project. The flows which are not diverted to the powerhouse would be passed through the other eight existing Reclamation outlet works and the spillway, according to existing Reclamation operation guidelines. The operation of the proposed facility would utilize the authority of Articles 402 and 403 of the FERC license that permits daily "shaping of the releases" which follow the need for power.

The average annual energy generation for the project is 81,120 megawatt-hours per year, considering the entire period of record from October 1927 through September 2000. The average annual generation for the best 30 consecutive year period is 86,940 MW-hours. The average annual generation for the worst 30 consecutive year period is 78,830 MW-hours.

The power output of the project would be stepped up to 34.5 kV for transmission and interconnection to the Idaho Power Company (IPC) system. Licensees propose to replace the

existing Bureau of Reclamation's 23 kV line between Arrowrock Dam and IPC's 34.5-kV Boise Bench feeder with a new 34.5 kV line, utilizing the existing right of way, terminating where the existing 23 kV line is presently tapped from IPC's single circuit distribution line north of the Lucky Peak Nursery. The remainder of the licensed transmission line would not be necessary for the project. The amendment will propose elimination of approximately ten miles of transmission line from this point of interconnection near the Lucky Peak Nursery to IPC's Boise Bench substation, as authorized by the License.

Unlike the licensed project, no work will take place upstream of Arrowrock Dam, and no drawdown of Arrowrock Reservoir will be necessary for construction.

Work on the construction site cannot be undertaken when Lucky Peak Lake level is above elevation 3016. The left bank bench is at elevations varying from about 3030 to 3040. The existing (upper) access road reaches the site at elevation 3070. The construction will take place as part of the ordinary drawdown of Lucky Peak Reservoir by the Corps of Engineers. Site work is therefore limited to the time between mid-October and the following late-April to early May, unless the work is being done inside a partially completed powerhouse or protected by cofferdams. Then work can continue inside the powerhouse during the high water period. Also, installation and testing of the equipment and systems can then continue during the high water period. Two seasons of the work will be necessary for construction when Lucky Peak Reservoir is drawn down.

There is work that is not dependent directly upon the water levels, such as construction of the transmission lines and the inter-connection to Idaho Power system; ordering, fabrication and delivery of the major equipment and auxiliaries; and, ordering and delivery of the bifurcations and the penstocks. That work can be done at any time during construction. Additional

information on construction activities associated with the proposed action is available in Attachment A.

The License requires that the Project shall not interfere with water delivery. No change is proposed to that License provision. Ongoing operation of the project will involve using water as it is released by the Bureau of Reclamation through Arrowrock Dam as part of its normal operational releases. The project will involve daily shaping of flows between 500 and 1000 cfs flow September to March to increase generation capacity during those times. Specific information on the reservoir and water operations associated with this proposed action is available in Attachment B-Reservoir Operations. More specific information on the Bureau of Reclamation's operational regime at Arrowrock Dam can be found in the Biological Opinion of the United States Fish and Wildlife Service for Bureau of Reclamation Operation and Maintenance in the Snake River above Hells Canyon (March 31, 2005).

III.
DESCRIPTION OF AREA TO BE AFFECTED

The areas to be affected by the construction and operation of the project as proposed in the amendment will include the Arrowrock Dam, the Arrowrock Reservoir, and the Lucky Peak Reservoir, all on the Boise River.

IV.
DESCRIPTION OF LISTED SPECIES

The species which the project has a potential to impact are listed in the letter dated February 27, 2007 from Jeffrey Foss, United States Department of Interior Fish and Wildlife Service to Albert Barker.

V.
DESCRIPTION OF POTENTIAL FOR THE PROPOSED ACTION TO AFFECT ANY LISTED SPECIES OR CRITICAL HABITAT

Attachment A (Construction Approach) describes the likely impacts to bull trout and bald eagles associated with the construction of project apparatus such as the powerhouse, turbines, and transmission lines. We anticipate that bull trout entrained in Lucky Peak reservoir may be affected by sediment from construction activities. Please see Attachment A for more specific information. We also anticipate that proposed operations of the project over the period of license implementation is likely to adversely affect bull trout by increasing the potential for entrainment, during September and October, when few bull trout are present near the dam, and infrequently in November and December. These potential effects are more fully described in Attachment B (Reservoir Operations).

The Biological Opinion for operations and maintenance of Reclamation's facilities in the upper Snake River basin fully describes the impacts of reservoir operations on bull trout and other listed species over the next 30 years. The proposed action contemplates only minor changes to Reclamation's reservoir operations, particularly installation of two turbines on two of the 10 outlet works, and the opportunity for daily shaping. Otherwise, operations remain the same as have been evaluated in the 2005 Biological Opinion. Hence, we are describing those impacts that will occur in addition to Reclamation's operations. All other likely impacts to bull trout and other listed species in the area were evaluated in the 2005 Biological Opinion for Reclamation Operations on the Upper Snake. See Attachments (A) Construction Approach – Arrowrock Project, and (B) Reservoir Operation – Arrowrock Project.

VI.
RELEVANT REPORTS

1. Biological Opinion of the United States Fish and Wildlife Service for Bureau of Reclamation Operation and Maintenance in the Snake River Basin above Brownlee Reservoir (March 31, 2005). www.fws.gov/idahoes/BORBO.htm

2. Biological Assessment of the Bureau of Reclamation Operation and Maintenance in the Snake River Basin above Brownlee Reservoir, United States Department of Interior, Bureau of Reclamation (November, 2004). www.usbr.gov/pn/programs/UpperSnake/pdf/complete.pdf

3. Final Rule: Designation of critical habitat for the bull trout. 70 Fed Reg 56212 (Sept. 26, 2005).

VII.
OTHER RELEVANT INFORMATION ON ACTIONS, SPECIES OR CRITICAL HABITAT

The following documents and information are relevant to this consultation and describe either anticipated effects to listed species, specific elements of the proposed action, or baseline conditions in the action area. These documents are attached to this request for early consultation.

1. Drawings - SK01-SK06.
2. Hydromet discharge data, Arrowrock Reservoir. (Bureau of Reclamation) (Excel).
3. Hydromet elevation data, Arrowrock Reservoir. (Bureau of Reclamation) (Excel).
4. Arrowrock daily mean discharge, 1994-2005 (Bureau of Reclamation).
5. Table 5, Arrowrock Operations shaping information. Table and description.
6. Appendix 3.1 – Arrowrock Turbined Flows (cfs).
7. Appendix 3.2 – Arrowrock Spilled Flows (cfs).
8. Project Summary, April 2005.
9. Reclamation blasting standards and July 19, 2005, email from John Tiedeman, Bureau of Reclamation.

10. Update on blasting plan for Arrowrock Project, email from Len Garrity, Shaw Stone & Webster, concerning agreement with Reclamation from August 25, 2005 meeting between Shaw Stone & Webster and Reclamation.

11. "Fisheries Impact Assessment – Pile Installation Demonstration Project" (August 2001).

12. Electric Power Research Institute "Fish Entrainment and Turbine Mortality Review and Guidelines" (September 1992).

13. Hydro Quebec, "Evaluation of Fish Mortality after Passage through the Chute-Bell Hydroelectric Generating Station" (2002).

Fish and Wildlife Letter

United States Department of the Interior

FISH AND WILDLIFE SERVICE

Snake River Fish and Wildlife Office
1387 S. Vinnell Way, Room 368
Boise, Idaho 83709
Telephone (208) 378-5243
http://IdahoES.fws.gov

FEB 27 2007

Albert Barker
Barker, Rosholt & Simpson LLP
205 N. 10 Street, Suite 520
Boise, Idaho 83709

Subject: Arrowrock Hydropower Project—Ada and Elmore Counties, Idaho—Species List
File #970.0100, 970.2100 2007-SL-0329

Dear Mr. Barker:

The Fish and Wildlife Service (Service) is providing you with a list of endangered, threatened, proposed, and/or candidate species, and proposed critical habitat which may occur in the area of the proposed Arrowrock Hydropower project. You requested this list via e-mail on February 23, 2007. This list fulfills the requirements for a species list under section 7(c) of the Endangered Species Act of 1973 (Act), as amended. If the project decision has not been made within 180 days of this letter, regulations require that you request an updated list. Please refer to the species list (SL) number shown above in all correspondence and reports.

Section 7 of the Act requires Federal agencies to assure that their actions are not likely to jeopardize the continued existence of endangered or threatened species. Federal funding, permitting, or land use management decisions are considered to be Federal actions subject to section 7. If the proposed action may affect a listed species, consultation with the Service is required. Formal consultation must be initiated for any project that is likely to adversely affect a threatened or endangered species. If a project involves a major construction activity and may affect listed species, Federal agencies are required to prepare a Biological Assessment. If a proposed species is likely to be jeopardized or if proposed critical habitat will be adversely modified by a Federal action, regulations require a conference between the Federal agency and the Service. A Federal agency may designate, in writing, you or another non-Federal entity to represent them in an informal consultation.

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If you have any questions about your responsibilities under section 7 of the Act, or require further information, please contact the Snake River Fish and Wildlife Office at (208)378-5243. Thank you for your continued interest in endangered species conservation.

Sincerely,

for Jeffery L. Foss, Field Supervisor
Snake River Fish and Wildlife Office

Enclosure

February 2007

ARROWROCK HYDROPOWER PROJECT – BARKER, ROSHOLT AND SIMPSON LLP
ADA AND ELMORE COUNTIES, IDAHO
SPECIES LIST 2007-SL-0329

LISTED SPECIES	COMMENTS
Bald eagle *(Haliaeetus leucocephalus)*	LT - Wintering area
Bull trout *(Salvelinus confluentus)*	LT

PROPOSED SPECIES/CRITICAL HABITAT

None

CANDIDATE SPECIES

None

February 2007

Exhibit A

CONSTRUCTION APPROACH
ARROWROCK PROJECT

Arrowrock Dam is constructed on granite bedrock that underlies the project area. The proposed powerhouse would be built on a basalt bench that extends along the south side of the Boise River Canyon. The basalt rises from 50 to 80 feet above the underlying granite. Most of the basalt formation is hard to very hard and varies from dense to vesicular (containing cavities) to locally very vesicular. The basalt has columnar jointing, and typically erodes in large block fragments. The proposed powerplant access road and proposed road improvements would be a slope wash characterized as silty or silty sand. See Arrowrock Project License.

The construction of the powerhouse addition to the Arrowrock Dam is anticipated to commence in the fall of 2008. At this time of the year after Labor Day and the close of recreation season in Lucky Peak, the Lucky Peak Reservoir is drawn down according to existing operational protocol. This existing protocol is continued in the proposed action of the Bureau of Reclamation for Operation of Upper Snake River Projects. November 2004 Biological Assessment, Appendix D, Table D-2. See also Boise River Water Control Manual, 1985, US Army Corps of Engineers. This draw down of Lucky Peak Reservoir allows access to the basalt bench areas that will need to be excavated. The construction effort commencing in the fall of 2008 will focus on the excavation for the foundations for the powerhouse, tailrace channel and the penstocks, locations of which are shown on Arrowrock Dam, General Plan, sketches SK-01 and 02. The location of the powerhouse, tailrace channel and penstocks is in the same location described in the original license drawings.

The excavation will extend approximately 45 feet below the natural basalt bench that exists along the left abutment just downstream of the Arrowrock Dam. The excavation will be addressed in a manner fully meeting the Bureau of Reclamation's requirements. Controlled blasting techniques will be used for the rock excavation and the peak particle velocities generated by the blasting will be carefully controlled and will be monitored. The blasting charges and arrangements will be modified as necessary to meet the Bureau of Reclamation's requirements. The blasting plan will be structured so as to limit the energy transfer to the adjacent rock and will be kept below the level that would have negative impact to the adjacent fisheries or the dam structure.

The Bureau of Reclamation's requirements for protection of Arrowrock Dam will be stringent enough to ensure no impacts in the water at either Arrowrock or Lucky Peak Reservoirs. It is expected that this blasting operation and civil work will take place during the period from the fall of 2008 though early spring of 2009. No blasting will take place during the eagle nesting season (March through July). Blasting will occur when Lucky Peak Reservoir is drawn down such that the excavation area, as shown on SK-01, is dry. It is expected that the blasting would be done from December 2008 through February 2009, concrete work in March and April of 2009 and then the construction operation would demobilize until the fall of 2009 when construction would resume. Blasting is not anticipated during the second year of construction, the fall of 2009 to spring 2010 construction period.

The excavation will be initiated at a distance away from the dam near the downstream end of the

tailrace channel. The excavation is shallow in this area. The excavation procedure will be monitored and tested in this area, as it progresses upstream toward the powerhouse. It is currently planned to excavate a ramp in the tailrace area to be used for hauling out the excavated material from the powerhouse area. Sediment control will be provided in the area being excavated. The excavated material will either be stored on site for future use as backfill during construction (ref. SK-02, Section 1-1) or hauled off site to a disposal area near the project that is agreed to by the Bureau of Reclamation and/or other regulatory agencies. It is not anticipated that there will be any more than the normal drawdown of the Arrowrock Reservoir required for this construction effort in 2008 and 2009 or for the follow-on efforts in 2009 and 2010.

With the construction schedule currently envisioned, the initial period of construction between the Lucky Peak draw down in the fall of 2008, extending to the high water period in the spring of 2009 will be important. During that time it will be necessary to substantially complete much of the civil works necessary to excavate and start to place powerhouse foundations. Not all excavation may be completed, but priority will be given to items necessary to start placing the powerhouse concrete floor mat and then bringing up the powerhouse walls as much as practical at that time. If possible, the penstocks entering the powerhouse will be installed and encased in concrete.

It is anticipated that the remainder of civil work will be completed during the dry period from the fall of 2009 to the spring of 2010. During this period the walls of the powerhouse will be completed up to elevation 3060; then work will continue inside the powerhouse, even as water level rises in Lucky Peak Reservoir. This will include the installation of the embedded parts of the turbine and placement of the second stage concrete, and construction of the intermediate floors, work on the gate structure, the bifurcations, penstocks, turbine shutoff valves, electrical equipment, electrical substation, etc. The discharge gate structure, bifurcations, penstock and valving will have to be worked on during low water period, when Lucky Peak Reservoir is drawn down below these elevations during its normal draw-down cycle.

As discussed above, a major consideration is locating suitable spoil areas within proximity of and downstream of Arrowrock Dam for disposal of excess material from the required excavation that will not be used as backfill material. Some of the material may be used to reshape the area downstream of the tailrace channel, subject to approval by the Bureau of Reclamation. Also, it is planned to extend the lower level road to the tailrace excavation area, which will utilize some of the excess excavation material. The spoil material is expected to be all rock with no dirt or soil that could flow into the Lucky Peak Reservoir. As required by the FERC license, Article 401, a detailed spoil disposal plan will be submitted to the Service prior to construction showing exact locations of spoil and the monitoring plan to protect sedimentation of Lucky Peak Reservoir.

It is anticipated that concrete removal on the downstream face of the dam for installation of the bifurcations will be done by hand tools and small construction equipment, subject to approval by the Bureau of Reclamation. The Clamshell gate structure modifications requiring removal of existing concrete are likely to be done by saw cutting and jack hammers, subject to approval of the Bureau of Reclamation. No blasting is planned. It is anticipated that this work will commence in the fall of 2009. No work will be done on the

upstream face of Arrowrock Dam. It is not anticipated that drawdown of the Arrowrock Reservoir will be required. Work on the bifurcations, penstocks and valves which connect to the Bureau of Reclamation outlet works will be done in the winter. As shown on SK-5 and SK-6, connections will be made only to the two outlet works nearest to the left bank. This work will be done from the bank by crane and temporary platforms. No work will be done in the water or bed of the channel. As work will only be done on two outlet works, the other eight valves remain available for use by Reclamation while work is done on the two outlets connecting to the powerhouse. There is more than sufficient capacity in the other eight valves to handle all the wintertime flows from Arrowrock to Lucky Peak Reservoir. Therefore, the connections to the Bureau of Reclamation outlets will not affect the flows from Arrowrock to Lucky Peak. See Biological Opinion on Arrowrock Valve Rehabilitation Project.

The seasonal submergence of the powerhouse site presents many construction challenges that must be addressed. The work on excavation and concrete placement, once the site is available, must be planned and executed effectively to achieve the established goals and milestones before the Lucky Peak water level rises again. This requires a concentration of effort when the site is available for work. No work will take place in the water. Once the rising waters of Lucky Peak are approaching, precautions must be made to protect the completed work and to remove equipment from the areas subject to flooding. Because of the construction schedule requirements, powerhouse structural components placed in the first season will be exposed to uplift loads before the balance of the structure is constructed. Depending upon the extent of this early construction effort, rock anchors may be required to resist uplift forces. Bringing the exterior walls up to elevation 3060, without the intermediate floors, if this is possible in the first season, may also require internal temporary bracing to provide structural support. These rock anchors and internal bracing, if required, will have no affect on any aquatic species that might enter the area in rising water conditions.

One other item that enters the construction planning is shipment of material, construction equipment, and permanent equipment to the site. It is our understanding from discussions with the Bureau of Reclamation that the existing gantry crane, with the rails along the deck of the dam, cannot be pulled away to clear the roadway on top of the dam. The construction approach (subject to approval of the Bureau of Reclamation) is to partially disassemble the gantry crane, allowing for the passage of the temporary construction crane that will be used during construction of the powerhouse. Once the temporary construction crane has passed, the permanent gantry crane will be immediately reassembled so that it is available for dam operation and maintenance as required. Material delivered to the powerhouse construction site during construction will be of such a size that it can pass through the reassembled gantry crane.

At the completion of construction of the powerhouse, the gantry crane will again be disassembled, allowing the temporary construction crane to be removed from the site. The gantry will then be reassembled so that it is available for operation. This approach imposes restrictions on the type of construction crane that can be mobilized and may possibly require double handling of large shipments of the permanent powerhouse equipment.

The disassembly and assembly of the gantry crane will have no affect on bull trout or any aquatic species and will have no affect on eagles. The construction activities will have no affect on bull trout in Arrowrock Reservoir. The construction activities have the potential to cause sedimentation to Lucky Peak Reservoir and the potential to affect entrained bull trout in Lucky Peak. However, with sedimentation control methods required by the FERC License, the construction will have no effect on any bull trout in Lucky Peak Reservoir.

Once the necessary permit approvals have been obtained and arrangements made, construction of the transmission lines and the interconnection to the Idaho Power Company (IPC) grid can proceed at a prudently flexible pace, as it is not dependent on other activities, except that it will need to be coordinated with the Bureau and IPC and completed prior to the start-up and testing of the units. At this time it is anticipated that repair and upgrade of the transmission line will take approximately twelve months. Work is planned to commence in May 2009 ending in May 2010. The line runs from the powerhouse at the Arrowrock Dam to the interconnect point with IPC on Highway 21 near Mores Creek Bridge, approximately five (5) miles away. (See Figure 8.1.) The line will be constructed using the existing BOR's right-of-way and installing new wood poles. The new poles will be located within the existing right-of-way using the same pole locations where possible. The design of the new line will incorporate raptor protection. The design will meet or exceed the requirements of Article 413 of the FERC license. The installation of the transmission line will not involve any work in the reservoir. Sediment traps will be provided as necessary to prevent runoff from the transmission line construction. The transmission line construction will therefore have no effect on eagles and no effect on bull trout.

There are two known eagle nests near Arrowrock Reservoir and none near Lucky Peak. U.S. Fish & Wildlife Service, March 2005 Biological Opinion on Bureau of Reclamation Projects, Table 16, page 75. The former Grouse Creek nest near the Arrowrock Dam is no longer occupied, as the tree blew over in 2001. The nearest nest to Arrowrock Dam or to the transmission line work is the Arrowrock nest, located some five miles upriver from the Arrowrock Dam. The powerhouse and transmission line construction work is far enough away that it will not affect the nesting eagles. It is possible that some wintering eagles might avoid the construction areas at the dam and the transmission line work areas. There are no good eagle perching location near the dam or the transmission line that would be harmed by the construction work. There is sufficient habitat throughout the Boise River Basin that these temporary disturbances will have no long-term effect on the eagle population.

Exhibit B

RESERVOIR OPERATION
ARROWROCK PROJECT

The Boise River Basin is operated as a system for irrigation and flood control as primary purposes, and in accordance with the Water Control Manual Boise River Reservoirs revised in 1985. Since hydropower is a secondary purpose of Boise Reservoir System, the addition of a power plant at Arrowrock must not interfere with the primary purposes listed above. Thus, the Arrowrock power plant will generate power using flows released from Arrowrock for primary purposes, without interfering with those primary purposes. In addition, the FERC license requires that the power generation shall not interfere with water delivery. As a consequence, operations of the power plant depend upon the operations of the Arrowrock and Lucky Peak reservoirs by the Bureau of Reclamation.

Arrowrock reservoir operation has been evaluated on a monthly average discharge basis. Arrowrock reservoir operation monthly data were presented for average conditions in Figure 3.3 of the Feasibility Report. In comparison to Arrowrock inflow, lower discharges occur during the months of April, May, and June, reflecting flood control regulation. Arrowrock's discharge is greater than inflow in the months of July and August, to maintain Lucky Peak as near full supply level as possible for recreation purposes. Arrowrock reservoir elevation decreases faster than Lucky Peak elevation as a result of this purpose.

The Bureau of Reclamation's Proposed Action for Operation of the Upper Snake Projects modifies the historic operations to increase water storage in Arrowrock. Under the proposed operations approved by the Service in its 2005 Biological Opinion, the minimum elevation is 3044, but elevations would only rarely drop below elevation 3078. Reclamation has established an administrative conservation pool of 28,700 acre-feet in Arrowrock. That pool corresponded to an elevation of 3078.32 ft, but Reclamation's sedimentation survey has since determined that the administrative conservation pool corresponds to an elevation of 3090. Under Reclamation's Proposed Action approved by the Service, Arrowrock is near maximum storage (elevation 3215) from April through July in mean and maximum water years. Arrowrock hydro operations are evaluated based upon this same Proposed Action.

Lucky Peak monthly reservoir elevation variations are encountered with a minimum monthly value of 2907.45 ft to a maximum of 3055 ft. On a daily time step, it can be expected to sometimes reach the minimum pool elevation of 2905 ft in November and/or December. Higher reservoir elevations in Lucky Peak of 3040 to 3055 are met during the May to August period, for recreational purposes.

At maximum pool elevation (3055), Lucky Peak operation causes the water to rise about 90 ft on the downstream face of the Arrowrock Dam. The backwater from Lucky Peak Dam reduces the effective net head for the projected Arrowrock power plant, thus reducing generator output. Recreational constraints on Lucky Peak Reservoir dictate that Lucky Peak be kept as full as possible from Memorial Day to Labor Day. This practice forces

Arrowrock Reservoir to be drawn down first, which further reduces power plant generation output. Also, there are some months where Arrowrock flow discharge is null, thus no generation will be possible. This occurs mainly in October.

A. Operations

Under the proposed operations of the Arrowrock hydroelectric project, the weir downstream of the plant will be set at elevation 3022. Minimum operating head is 70 ft at preliminary design stage on the turbines, plus line losses and flow over the weir, yields total minimum head of 75 feet. With Lucky Peak Reservoir drawn down below 3022 such that the weir elevation of 3022 is governing and with one unit running at a minimum flow of 300 cfs allowing for the minimum head water elevation in Arrowrock Reservoir is 3097 feet. As design progresses, some improvements in head operations are possible, so minimum operating elevations should be considered from 3092 to 3097. Below elevations 3092 – 3097, the hydroelectric plant would not operate, and any water released would be released through the Bureau of Reclamation's valves rather than through the turbines in the power plant. In July and August the mean water levels in Lucky Peak are 3051 and 3042, respectively. During mean water years, the minimum operating conditions for the power plant in July and August would be 70 to 70 feet above Lucky Peak elevations, at elevations 3121-3126 and 3112-3117. Considering this minimum operating head, minimum operating conditions for the power plant in July and August are above the 3111 elevation in Arrowrock where entrainment occurs through the valves. See FWS 2005 Biological Opinion on Bureau of Reclamation's Upper Snake Projects (USFWS 2005). Flow velocity near the surface from generation is expected to be imperceptible. It is anticipated that entrainment of fish could result only if the fish are moving deep under the surface. When Lucky Peak elevations drop to 3022 or below and, if the level in Arrowrock Reservoir is below elevation 3092 to 3097, the turbines would not be running. Any fish entrained at the dam under those conditions would pass through Reclamation's Clamshell discharge valves into Lucky Peak Reservoir.

When the power plant is operating, a significant amount of water would continue to be released through the Clamshell gates, reducing fish exposure to the turbines. The power plant at 15 MW capacity would not pass through the turbines all the water released from Arrowrock. A comparison of Arrowrock turbined flow (Appendix 3) with Arrowrock spilled flow (Appendix 4) shows that, in July and August, the mean flows turbined are 1339 cfs and 1336 cfs, respectively, while the spilled flows are 2420 cfs and 1857 cfs, respectively. In this timeframe, on average most of the flow is released through the valves and not through to the power plant. In the non-irrigation season, October through April, roughly 62% of the mean flows are turbined and 38% are spilled, or sent through the Clamshell valves. For the months October – December, the turbined flows are substantially higher, on average, in excess of 90%. This calculation of "spilled flow" refers to all flow that is not released through the power plant, including all flow that is released through the Clamshell discharge valves. The term as used here does not refer only to water spilled over the spillway on the right abutment of the Arrowrock dam during high flow conditions.

The impact of these operational restrictions is that the power plant generally will not be operating at the lowest elevations of Arrowrock when entrainment is most likely to occur and that even when operating at levels where entrainment might occur, not all of the flow will be released through the turbines.

B. Entrainment Conditions

To demonstrate the impact of these restrictions on Arrowrock reservoir operation as it relates to fish entrainment potential, Arrowrock monthly outflow and turbined flow are compared here for different ranges of flows and reservoir elevations. Arrowrock reservoir operation statistics were computed using monthly data of a 73-year period (October 1927 to September 2001) from computer modeling based on the November 2004 "Proposed Action Scenario" of the Bureau of Reclamation. Reclamation has stated that its proposed operation for the next thirty years of its Biological Opinion is based upon the modeling of this historic data over this 73-year period. This data represents the range of conditions Reclamation will operate under during the term of its Biological Opinion.

Table 1 lists for each range of reservoir elevation the number of months that reservoir outflow occurred in each of the tabulated flow ranges under the Proposed Action. "Arrowrock" or "reservoir" outflow are flow releases to be made based on downstream requirements and reservoir operational parameters, i.e., "available flow." Related to the specific conditions where fish entrainment is most likely to occur (outflow greater than 695 cfs and reservoir elevation below 3111 ft) (USFWS 2005), we observe that 25 months (light gray area) over the 876 months included in the period correspond to these conditions (less than 3% of the months).

Using monthly reservoir elevation, we also observe that Arrowrock reservoir drops below 3111 ft in at least one month for 16 years over 73-year period (~22%). This occurs mainly in September and October. Winter discharges from October through April will exceed 695 cfs and the reservoir's elevation will be near or below 3111 in 65% of the years over the 30-year term of the Biological Opinion, although conditions would not be suitable for entrainment 100% of the time in those 65% of years (USFWS 2005). The difference between these figures represents daily data used by the Service in the Biological Opinion compared to average monthly data used in the hydrological evaluations for the power plant. For generation analysis over a 34-year period, monthly data is considered more representative of conditions and therefore has been relied upon in the hydroelectric plant generation analysis. Monthly data likely do not fully represent these drawdowns, which can be of short duration and/or smoothed on a monthly basis. Nevertheless, this monthly analysis should provide a realistic estimate of drawdown events of meaningful duration.

C. Shaping

The Arrowrock proposed power plant will have two Kaplan units, each one having a 700 cfs rated flow and an installed capacity of 7.5 MW. To simulate operation of the power plant within the Arrowrock reservoir operation scheme, similar statistics were computed for instantaneous turbined flow; i.e., flow releases through the turbines, based on machine capability, available

flow, and shaping operations to effectively increase overall energy production.

Distribution of turbined outflow for a specific reservoir elevation range can be different than those for reservoir outflows. These changes are caused by parameters used to represent realistic power plant operation near optimum efficiency, which depend on characteristics of the proposed turbines and may lead to shaping periods at Arrowrock. For Arrowrock, Table 2 provided herein and Appendices 3 and 4 represent the flows of the hydro project, after shaping is considered. The monthly flow rates in this analysis do not necessarily correspond to the Reclamation flow rates because the hydro flow rates are adjusted for shaping. Shaping will not affect the elevation of either Arrowrock or Lucky Peak Reservoir on a daily or monthly basis, but will increase velocities under certain conditions, as described below.

For the power plant operation simulation, when monthly outflow was less than turbine minimum flow capability, the license allows the power plant could operate a part of a day at a different, higher, "shaped" flow and the power plant shut down the remainder of the day. Thus, to account for these flow changes on a given monthly basis, flow releases in this hydrologic analysis have been time-shifted to achieve minimum reasonable turbine generation for a portion of the month, instead of considering no generation at all in the month. No daily analysis has been performed, but again monthly data is considered representative. If monthly reservoir outflow were less than or equal to 500 cfs, turbined flow was set to 500 cfs, which is near optimum efficiency of 1-unit operation. If monthly reservoir outflow were between 500 cfs and 1000 cfs, turbined flow was set to 1000 cfs, which is near optimum efficiency of 2 units. These flows are illustrated on Appendices 3 and 4. The consequence of this adjustment is to show greater likelihood of exceeding the entrainment velocity of 695 cfs in a given month than the Bureau of Reclamation will show, when the flows would have been in the 500 to 1000 cfs range.

For reservoir outflow greater than 1000 cfs, turbined flow was set equal to reservoir outflow and we assume that there is no shaping during such months. Maximum power plant flow rate was also considered in setting turbined flow; it was the lesser of 1) the maximum flow allowed for the net head, or 2) the flow value corresponding to maximum generation of 15 MW.

Table 2 lists for each range of reservoir elevation the number of months that modeled turbine outflow occurred in each of the tabulated flow ranges. We observe that there are 17 months (light gray area) over the 876 months of the period wherein monthly turbined flows correspond to potential conditions for fish entrainment (2% of the months).

For the entire range of reservoir elevations, for turbined outflow compared with reservoir outflow, we observe a greater number of months with flow conditions in the 1000 cfs - 1100 cfs range. As indicated previously, this is caused by operation of the Arrowrock turbines preferably near optimum efficiency (2 units at about 500 cfs each). These shaping periods occur mainly with higher reservoir elevations. Likewise, a shift in the outflows from the 0 cfs - 500 cfs range in Table 1 to the 500 cfs - 600 cfs range in Table 2 reflects power plant operation near the optimum 1-unit condition.

To further evaluate the effects of shaping, one can examine the actual daily releases from Arrowrock over the period of 1994 to 2004. This is the same time period used in the 2005 Biological Opinion, and it provides more detailed information concerning potential entrainment due to shaping operations. Table 3 displays the number of days in each month that the actual releases were between 500 and 1000 cfs.[1] Those conditions mark the potential to shape flows from 500 up to 1000 cfs in a particular day. This table likely overestimates the potential increased velocities in this shaping scenario for several reasons. First, it includes flows as low as 500 cfs, which is the optimum efficiency of a single turbine. It also includes flows as high as 997 cfs. Actually shaping from 997 cfs to 1000 cfs would not likely be undertaken, but, even it were, the velocity differential in the reservoir would be imperceptible.

This data shows that, for the months of April, May, June, and July, there is no shaping between the 500 to 1000 cfs range. A few shaping opportunities occur in a few years during August, but the elevation of Lucky Peak makes entrainment through the turbines unlikely in August because the operational limitations on the turbines listed above. September and October offer greater opportunities for increasing velocity for shaping from 500 to 1000 cfs, but, in those months, the bull trout are just returning to the reservoir and are found mostly in the upper reaches of Arrowrock Reservoir, rather than closer to the dam (USFWS 2005). In November, 41 of 300 days show potential to shape from 500 to 1000 cfs, December 33 of 310 days, January 10 of 310 days, February 30 of 310 days, and March 35 of 310 days. Thus, the overall potential to shape in the winter from 500 cfs up to 1000 cfs appears to occur about 10% of the time.

However, not all of these releases will occur at elevations which are conducive to entrainment. Table 4 shows the days in the same time period as Table 3 when Arrowrock Reservoir is below elevation 3111. In January and February, the reservoir is not below 3111 in any year (excluding the 2003 to 2004 valve repair drawdown). The only years in March when there was an opportunity to shape between 500 to 1000 cfs, the reservoir was above 3111 elevation, and the only March dates (1997) when the elevation was below 3111 elevation, there was no shaping opportunity between 500 to 1000 cfs. Thus, there is no impact to entrainment from shaping from 500 to 1000 cfs in the January through October time period.

In the November 2002 timeframes when shaping would occur, the elevations were 3110 and 3109.96 and velocities were 992.7 and 966.3 cfs, conditions that are not likely to perceptively increase entrainment. For November 2000 conditions, there are 12 days when shaping would increase velocity during entrainment conditions. In those 12 days, the elevations were 3101 through 3102, and velocities were 788 through 883 cfs.

In December, there are four days in this timeframe when shaping operations would take place at elevations below 3111. Those four days occurred in 2002 when elevations were 3109.32 through 3109.66. Velocities were 936.9 through 987.1 cfs. These conditions are not likely to perceptively increase entrainment due to shaping.

[1] The 2003 to 2004 water data is not useful information, as it involves the drawdown of Arrowrock for Reclamation's valve project, which will not be repeated, and that data is not included in this discussion below.

One additional factor to consider is that there is zero risk of entrainment during the portion of the day that the flows are shut down to accommodate shaping.

Based on the actual daily data from Arrowrock, it appears that shaping will not increase the risk of entrainment, except in September and October when few bull trout are near the dam, and in very infrequent circumstances during November and to an even lesser degree in December.

D. Fish Mortality

For fish that are entrained by turbine generation, initial estimates indicate a survival rate in the range of 80%, based on fish mortality studies for Kaplan units ("Evaluation of Fish Mortality through the Chute-Bell Hydroelectric Generating Station," Hydro-Quebec, 2000; and "Fish Entrainment and Turbine Mortality Review and Guidelines," Electric Power Research Institute, 1992, Figure 4-11). Kaplan turbines have been shown to have significantly lower rates of mortality than Francis turbines under similar conditions PRI Table 4-8, p. 4-41; Abstract, p. iii. Kaplan turbines also have decreased mortality at higher heads when compared to Francis turbines. Compare Figure 4-10 with Figure 4-7. Hatchery raised fish experience higher mortality than wild fish (10-30%). Handling fish in these turbines experiments is believed to increase mortality risk as well, and the tests may overestimate actual mortality, as a result. Mortality rate appears to increase as fish size increases.

The Biological Assessment and Biological Opinion for the operation of the Bureau of Reclamation projects (FWS 2005) does not provide sufficient information about the size of fish entrained to compare the data against the existing studies. Bull trout in Arrowrock Reservoir tend to be juveniles or sub-adults and adults. One would expect mortality to be on the upper ranges of mortality through Kaplan turbines because of the larger size of the sub-adult and adult bull trout. As bull trout are native fish, one would not expect the hatchery fish mortality rates to be predictive of bull trout mortality. Based on the available information, it would seem that mortality by way of entrainment through the turbines would be less than 50%. This result is consistent with the prediction of the Service's Incidental Take Statement that a majority of bull trout entrained through the valves would be harassed.

Consequently, mortality of bull trout entrained in the turbines may be slightly higher than mortality through the valves but not sufficient to affect the population in Arrowrock Reservoir.

Table 1 - Number of Months for Different Ranges of Arrowrock Reservoir Outflow and Reservoir Elevation

Reservoir Outflow (cfs)	< 3100 ft	3100 ft - 3111 ft	3111 ft - 3131 ft	3131 ft - 3151 ft	3151 ft - 3216 ft
0	0	0	1	2	0
0 - 500	8	2	18	22	133
500 - 600	0	4	3	14	23
600 - 700	0	0	4	13	13
700 - 800	1	2	1	8	12
800 - 900	1	1	3	18	11
900 - 1000	2	1	1	9	7
1000 - 1100	2	0	1	6	9
1100 - 1200	2	1	1	4	11
1200 - 1300	0	0	2	2	16
1300 - 1400	0	1	4	7	12
> 1400	4	7	14	32	400
All flows	20	19	53	137	647

Table 2 - Number of Months for Different Ranges of Arrowrock Turbined Outflow and Reservoir Elevation

Turbined Outflow (cfs)	< 3100 ft	3100 ft - 3111 ft	3111 ft - 3131 ft	3131 ft - 3151 ft	3151 ft - 3216 ft
0	20	0	1	2	0
500 - 600	0	2	18	22	133
600 - 700	0	0	0	0	0
700 - 800	0	0	0	0	0
800 - 900	0	0	0	0	0
900 - 1000	0	1	0	0	0
1000 - 1100	0	9	13	68	75
1100 - 1200	0	4	1	4	16
1200 - 1300	0	3	4	2	61
1300 - 1400	0	0	16	39	362
0 - 1400	20	19	53	137	647

Table 3

Daily Discharges From 500 to 1000 cfs

Discharge Data from Hydromet

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
January	4	0	6	0	0	0	0	0	0	0	19
February	6	0	1	0	1	0	7	0	15	0	17
March	0	1	0	0	0	0	3	26	4	1	1
April	0	0	0	0	0	0	0	0	0	0	1
May	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0
August	2	0	0	0	0	0	0	17	0	0	4
September	27	0	2	9	1	0	17	9	14	3	8
October	3	0	12	0	2	20	29	0	0	25	0
November	0	0	0	0	0	0	12	0	3	16	26
December	0	0	0	0	0	0	0	0	4	27	29

Shaded area represents 2003 - 2004 one-time valve project draw down

Table 4

Daily Arrowrock Reservoir Elevations <3111 Feet

Elevation Data from Hydromet

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
January	0	0	0	0	0	0	0	0	0	0	31
February	0	0	0	0	0	0	0	0	0	0	29
March	0	0	0	21	0	0	0	0	0	0	16
April	0	0	0	16	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	7	7	0	0
August	0	0	2	1	0	2	8	31	31	24	21
September	0	24	30	30	22	26	30	11	9	30	15
October	0	9	15	20	0	6	31	0	0	31	9
November	0	0	0	0	0	0	20	0	3	30	0
December	0	0		0	0	0	0	0	6	31	0

Shaded area represents 2003 - 2004 one-time valve project draw down

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Section 7
Document 5

Table 5
Daily Discharges from 500 - 700 cfs
Discharge Data from Hydromet

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
January	0	0	5	0	0	0	0	0	0	0	4
February	6	0	0	0	0	0	1	0	14	0	4
March	0	0	0	0	0	0	2	14	2	0	1
April	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	1	0	0	1
September	12	0	2	0	1	0	9	0	0	0	3
October	3	0	10	0	2	16	8	0	0	1	0
November	0	0	0	0	0	0	0	0	0	7	13
December	0	0	0	0	0	0	0	0	0	5	27

Shaded area represents 2003 - 2004 one-time valve project draw down

Table 5 represents actual discharge at Arrowrock Dam and the number of days when actual discharge was between 500 and 700 cfs flow rate. This table, compared to the Arrowrock elevation Table 4, shows that shaping from 500 to 700 cfs flow rate and when Arrowrock elevation is below 3111 feet occurs only in August, September and October over the 11-year period. Examining the daily records shows that, in two days in August, (8/16/2001 and 8/28/2004), both conditions were met. There were a total of 15 days in September when both conditions were met (1996, 1998, 2000, and 2004). In October, there were a total of 20 days over the 11-year period (1996, 1999 and 2000). Thus, over the 11-year period, there were 37 days total when Arrowrock was below 3111 elevation and shaping would have the potential to increase entrainment by increasing the flow rates from below 700 cfs to above that flow rate.

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Document 6

Appendix 3.1 – Arrowrock Turbined Flow (cfs)

Year	October	November	December	January	February	March	April	May	June	July	August	September	Year
1927-1928	500.00	1000.00	500.00	1400.00	1400.00	1400.00	1291.39	1253.87	1378.76	1400.00	1400.00	1354.39	1187.42
1928-1929	1000.00	1000.00	500.00	1299.14	500.00	1000.00	500.00	1348.79	1400.00	1400.00	1400.00	1197.62	1050.18
1929-1930	0.00	1000.00	500.00	1000.00	1011.93	500.00	1017.17	1297.65	1352.93	1400.00	1400.00	1197.62	970.94
1930-1931	0.00	500.00	500.00	1000.00	1000.00	500.00	1400.00	1400.00	1400.00	1400.00	1000.00	1000.00	922.74
1931-1932	1000.00	500.00	500.00	1000.00	500.00	500.00	1400.00	1400.00	1395.43	1400.00	1400.00	1088.26	1010.17
1932-1933	500.00	500.00	1000.00	1000.00	500.00	500.00	1400.00	1400.00	1389.97	1400.00	1400.00	1400.00	1035.34
1933-1934	1000.00	500.00	1000.00	1000.00	500.00	1000.00	1400.00	1348.02	1400.00	1400.00	1400.00	500.00	1042.71
1934-1935	500.00	500.00	500.00	500.00	500.00	1000.00	1187.41	1285.72	1400.00	1400.00	1400.00	1400.00	966.52
1935-1936	1000.00	1000.00	500.00	500.00	1000.00	500.00	1400.00	1369.47	1384.69	1400.00	1400.00	1400.00	1069.30
1936-1937	1147.61	500.00	500.00	1000.00	1000.00	500.00	1400.00	1400.00	1400.00	1400.00	1400.00	1000.00	1054.18
1937-1938	0.00	500.00	1000.00	1400.00	1400.00	1400.00	1400.00	1264.58	1354.20	1400.00	1400.00	1000.00	1125.01
1938-1939	1000.00	500.00	500.00	1400.00	500.00	1000.00	1348.25	1400.00	1400.00	1327.09	1400.00	500.00	1028.18
1939-1940	1000.00	500.00	1000.00	1400.00	1000.00	500.00	1236.02	1331.61	1383.92	1392.17	1400.00	500.00	1055.71
1940-1941	1000.00	500.00	500.00	1000.00	1000.00	500.00	1399.82	1400.00	1400.00	1400.00	1400.00	1304.50	1066.66
1941-1942	1336.56	500.00	1000.00	500.00	500.00	500.00	1243.64	1283.98	1391.26	1400.00	1400.00	1400.00	1041.33
1942-1943	1000.00	1000.00	500.00	1400.00	1400.00	1162.36	1400.00	1167.13	1255.36	1400.00	1400.00	1000.00	1171.99
1943-1944	1400.00	500.00	500.00	1258.48	1000.00	500.00	1352.57	1348.79	1400.00	1400.00	1400.00	1327.66	1116.25
1944-1945	1020.47	500.00	500.00	1000.00	1000.00	500.00	1400.00	1400.00	1383.41	1400.00	1400.00	1400.00	1074.90
1945-1946	1000.00	1000.00	500.00	1192.55	1361.75	1400.00	1277.97	1234.60	1381.81	1400.00	1400.00	1400.00	1210.59
1946-1947	1000.00	500.00	500.00	1400.00	1374.97	1000.00	1385.72	1400.00	1392.89	1400.00	1400.00	1353.12	1174.11
1947-1948	1000.00	1000.00	1000.00	500.00	500.00	1000.00	1400.00	1400.00	1378.32	1400.00	1400.00	1400.00	1117.94
1948-1949	1000.00	500.00	500.00	1000.00	500.00	500.00	1264.10	1314.47	1396.67	1400.00	1400.00	1332.85	1011.94
1949-1950	1207.69	500.00	1000.00	1000.00	1000.00	1003.99	1264.32	1249.87	1388.10	1400.00	1400.00	1000.00	1119.67
1950-1951	1000.00	500.00	1000.00	1400.00	1400.00	1333.08	1266.58	1285.36	1400.00	1400.00	1400.00	1000.00	1198.82
1951-1952	1000.00	500.00	500.00	1400.00	1400.00	1400.00	1318.69	1138.11	1400.00	1400.00	1400.00	1000.00	1153.81
1952-1953	1000.00	500.00	500.00	1000.00	1059.02	1275.11	1294.83	1391.20	1400.00	1400.00	1400.00	1099.45	1110.79
1953-1954	1000.00	500.00	500.00	1277.49	1371.46	1290.89	1225.03	1246.65	1381.18	1400.00	1400.00	1000.00	1131.93
1954-1955	1400.00	500.00	500.00	1304.02	500.00	500.00	1000.00	1400.00	1395.10	1400.00	1400.00	1400.00	1062.68
1955-1956	1000.00	500.00	1000.00	1400.00	1400.00	1400.00	1400.00	1175.52	1277.47	1400.00	1400.00	1056.11	1200.68
1956-1957	1000.00	500.00	500.00	1400.00	1400.00	1358.92	1400.00	1400.00	1400.00	1400.00	1400.00	1133.74	1190.24
1957-1958	500.00	500.00	500.00	1223.61	1281.79	1400.00	1400.00	1293.54	1400.00	1400.00	1400.00	1000.00	1107.18
1958-1959	1000.00	500.00	500.00	1000.00	1000.00	1000.00	1236.24	1299.29	1381.31	1400.00	1400.00	1400.00	1093.44
1959-1960	1000.00	500.00	500.00	1400.00	1000.00	1000.00	1400.00	1400.00	1385.01	1400.00	1400.00	500.00	1075.75
1960-1961	1400.00	500.00	500.00	1255.23	500.00	1000.00	1262.21	1325.10	1348.79	1400.00	1400.00	1000.00	1079.51
1961-1962	500.00	500.00	500.00	1000.00	1000.00	1000.00	1170.83	1363.96	1400.00	1400.00	1400.00	1400.00	1052.62
1962-1963	1000.00	500.00	500.00	1400.00	1000.00	1376.93	1400.00	1400.00	1378.76	1400.00	1400.00	1400.00	1181.23
1963-1964	1000.00	500.00	500.00	1085.13	1000.00	1000.00	1400.00	1387.84	1378.51	1400.00	1400.00	1400.00	1121.42
1964-1965	1000.00	500.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1000.00	1259.18
1965-1966	1400.00	500.00	500.00	1306.90	1000.00	1000.00	1348.25	1400.00	1400.00	1341.91	1400.00	500.00	1093.87
1966-1967	500.00	500.00	1000.00	1000.00	1000.00	500.00	1275.33	1307.40	1384.31	1400.00	1400.00	1000.00	1022.24
1967-1968	1113.88	500.00	500.00	1292.63	500.00	500.00	1355.71	1308.00	1348.79	1400.00	1400.00	1380.54	1053.43
1968-1969	1293.13	500.00	1000.00	1101.72	1220.66	1400.00	1291.72	1214.14	1383.28	1400.00	1400.00	1185.62	1200.21
1969-1970	1369.98	500.00	500.00	1356.52	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1000.00	1210.47
1970-1971	1000.00	500.00	500.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1000.00	1182.74
1971-1972	1297.94	500.00	500.00	1400.00	1242.06	974.52	1400.00	1400.00	1348.31	1400.00	1400.00	500.00	1114.45
1972-1973	1012.46	500.00	500.00	1257.77	1083.06	500.00	1364.02	1400.00	1400.00	1400.00	1400.00	1000.00	1068.01
1973-1974	500.00	1000.00	1000.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1000.00	1223.84
1974-1975	1148.62	500.00	500.00	1151.27	1308.87	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1000.00	1167.25
1975-1976	1400.00	500.00	500.00	1259.51	1287.64	1257.33	1223.57	1245.79	1381.50	1400.00	1400.00	1400.00	1187.80
1976-1977	1000.00	500.00	500.00	1206.44	500.00	1000.00	1293.34	1400.00	1400.00	0.00	0.00	0.00	734.52
1977-1978	0.00	1000.00	500.00	1000.00	1170.01	1108.35	1316.93	1377.94	1400.00	1400.00	1400.00	1400.00	1086.69
1978-1979	500.00	500.00	500.00	1232.46	500.00	1000.00	1134.43	1399.75	1400.00	1400.00	1400.00	1000.00	1001.18
1979-1980	500.00	500.00	1000.00	1000.00	1000.00	1102.53	1242.12	1244.98	1383.73	1400.00	1400.00	1089.57	1072.70
1980-1981	1000.00	500.00	500.00	1400.00	1000.00	1000.00	1400.00	1400.00	1400.00	1400.00	1400.00	1263.48	1139.74
1981-1982	1288.16	500.00	1000.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1282.56
1982-1983	1250.22	500.00	500.00	1400.00	1242.06	0.00	0.00	1400.00	1400.00	1400.00	1400.00	1017.76	959.36
1983-1984	1400.00	500.00	1000.00	1400.00	1400.00	1400.00	1400.00	1268.69	1355.59	1400.00	1400.00	1046.40	1248.19
1984-1985	1400.00	500.00	500.00	1245.68	1133.02	1000.00	1259.44	1342.68	1400.00	1400.00	1400.00	1400.00	1165.61
1985-1986	1000.00	500.00	500.00	1400.00	1400.00	1400.00	1400.00	1242.57	1372.53	1400.00	1400.00	1000.00	1167.11
1986-1987	1000.00	500.00	500.00	1180.42	500.00	500.00	1367.36	1348.43	1400.00	1400.00	1400.00	500.00	970.45
1987-1988	500.00	500.00	500.00	1000.00	1000.00	500.00	1356.01	1293.44	1400.00	1378.64	1400.00	1000.00	984.70
1988-1989	1000.00	500.00	1000.00	1104.61	1302.80	1178.11	1400.00	1400.00	1397.98	1400.00	1400.00	1400.00	1206.53
1989-1990	1063.92	500.00	1000.00	1000.00	500.00	500.00	1400.00	1400.00	1400.00	1400.00	1400.00	1273.69	1073.68
1990-1991	0.00	1000.00	500.00	500.00	1000.00	1000.00	1400.00	1400.00	1400.00	0.00	0.00	0.00	677.81
1991-1992	0.00	0.00	1000.00	500.00	1000.00	1141.69	1400.00	1400.00	1242.06	0.00	0.00	0.00	637.14
1992-1993	0.00	0.00	0.00	500.00	1000.00	1377.40	1400.00	1241.90	1378.95	1400.00	1400.00	1400.00	922.92
1993-1994	0.00	500.00	500.00	1056.81	500.00	500.00	1400.00	1400.00	1400.00	1400.00	1400.00	1000.00	923.18
1994-1995	0.00	500.00	500.00	1042.19	1400.00	1400.00	1294.05	1238.03	1365.75	1400.00	1400.00	1000.00	1042.14
1995-1996	1000.00	500.00	1000.00	1400.00	1400.00	1400.00	1339.72	1244.98	1377.31	1400.00	1400.00	1000.00	1205.22
1996-1997	1000.00	500.00	1000.00	1330.37	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1000.00	1219.29
1997-1998	1347.82	500.00	500.00	1400.00	1400.00	1400.00	1306.75	1344.39	1385.33	1400.00	1400.00	1301.15	1223.44
1998-1999	500.00	500.00	500.00	1400.00	1400.00	1400.00	1262.69	1245.61	1384.18	1400.00	1400.00	1000.00	1114.58
1999-2000	1000.00	1000.00	500.00	1000.00	500.00	1000.00	1243.10	1350.77	1400.00	1365.00	1400.00	1400.00	1099.68
Mean	879.43	561.64	642.47	1152.34	1028.10	999.19	1301.61	1337.87	1383.88	1339.79	1336.99	1069.91	1086.65
Minimum	0.00	0.00	0.00	500.00	500.00	0.00	0.00	1138.11	1242.06	0.00	0.00	0.00	637.14
Maximum	1400.00	1000.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1400.00	1282.56

Section 7
Document 7

Appendix 3.2 – Arrowrock Spilled Flow (cfs)

Year	October	November	December	January	February	March	April	May	June	July	August	September	Year
1927-1928	0.00	0.00	0.00	476.54	669.81	157.74	1777.47	7214.10	3016.22	2344.92	1654.01	0.00	1451.60
1928-1929	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2384.76	2940.25	2819.76	1399.56	393.08	834.87
1929-1930	806.42	0.00	0.00	0.00	0.00	0.00	0.00	1936.76	2513.12	2295.92	1721.64	432.62	816.32
1930-1931	1013.07	0.00	0.00	0.00	0.00	0.00	252.15	1487.96	2550.15	824.76	0.00	0.00	512.79
1931-1932	0.00	0.00	0.00	0.00	0.00	0.00	2768.74	3679.24	3934.45	2769.41	2556.11	0.00	1315.73
1932-1933	0.00	0.00	0.00	0.00	0.00	0.00	318.72	2248.85	5204.78	2445.67	1498.15	101.19	988.26
1933-1934	0.00	0.00	0.00	0.00	0.00	0.00	333.17	1734.04	2418.00	1098.72	672.16	0.00	523.80
1934-1935	0.00	0.00	0.00	0.00	0.00	0.00	1447.54	3689.77	3501.86	2393.06	1499.77	97.83	1058.84
1935-1936	0.00	0.00	0.00	0.00	0.00	0.00	3963.63	5013.57	3378.78	2201.59	1488.39	95.83	1350.57
1936-1937	0.00	0.00	0.00	0.00	0.00	0.00	74.47	1464.63	2282.30	1051.49	1375.27	0.00	524.21
1937-1938	0.00	0.00	0.00	369.35	1545.77	1038.57	3645.15	6265.65	5206.99	2729.34	2660.88	0.00	1955.68
1938-1939	0.00	0.00	0.00	78.15	0.00	0.00	2619.25	2514.84	1647.44	1113.11	1606.38	0.00	801.88
1939-1940	0.00	0.00	0.00	190.79	0.00	0.00	2468.47	3920.13	2390.39	1212.24	1642.26	0.00	990.94
1940-1941	0.00	0.00	0.00	0.00	0.00	0.00	157.72	2931.90	2636.66	2212.61	1608.70	0.00	803.24
1941-1942	0.00	0.00	0.00	0.00	0.00	0.00	2560.87	1857.28	4067.33	2330.61	1660.52	68.54	1047.13
1942-1943	0.00	0.00	0.00	2482.28	2401.02	2489.53	6951.47	7084.60	6890.26	4077.22	2204.58	0.00	2879.36
1943-1944	1117.37	0.00	0.00	0.00	0.00	0.00	57.33	2155.00	2499.16	2093.83	2221.32	0.00	854.54
1944-1945	342.62	0.00	0.00	0.00	0.00	0.00	393.77	3407.98	4099.05	2337.94	1645.88	291.66	1050.14
1945-1946	0.00	0.00	0.00	0.00	0.00	158.22	5133.31	6387.36	4211.36	2385.12	1652.39	147.47	1679.01
1946-1947	0.00	0.00	0.00	327.94	0.00	0.00	2439.61	4580.54	3287.41	2162.54	1633.10	0.00	1209.97
1947-1948	0.00	0.00	0.00	0.00	0.00	0.00	1856.09	3192.29	5044.93	2429.00	1657.27	362.72	1215.20
1948-1949	0.00	0.00	0.00	0.00	0.00	0.00	3134.74	5257.08	3185.41	2131.31	1638.08	0.00	1286.10
1949-1950	0.00	0.00	0.00	0.00	0.00	0.00	3438.09	5499.21	5602.36	3006.06	2242.56	0.00	1655.88
1950-1951	0.00	0.00	0.00	410.30	413.40	726.04	5340.67	7681.21	4374.66	2719.20	2329.35	0.00	2007.90
1951-1952	0.00	0.00	0.00	770.49	873.39	1091.02	5818.41	8928.75	6034.66	2701.02	2443.93	0.00	2394.63
1952-1953	0.00	0.00	0.00	0.00	0.00	76.03	3208.94	2791.79	6142.75	3259.46	2428.12	0.00	1495.26
1953-1954	0.00	0.00	0.00	0.00	0.00	187.98	3432.51	5935.52	3753.79	2746.59	2169.16	0.00	1528.24
1954-1955	24.29	0.00	0.00	0.00	0.00	0.00	0.00	3020.06	4297.97	3075.39	1434.16	345.79	1023.24
1955-1956	0.00	0.00	0.00	1183.61	1632.88	1489.98	5463.89	7833.32	7120.84	2696.58	2430.14	0.00	2487.41
1956-1957	0.00	0.00	0.00	395.79	214.94	0.00	4200.84	7442.34	4342.96	2766.32	2422.19	0.00	1825.09
1957-1958	0.00	0.00	0.00	0.00	0.00	237.32	2756.70	8142.30	6259.64	2839.23	2424.51	0.00	1899.82
1958-1959	0.00	0.00	0.00	0.00	0.00	0.00	2193.03	2053.60	4396.90	2356.89	1669.12	72.91	1063.98
1959-1960	0.00	0.00	0.00	389.39	0.00	0.00	3770.03	756.32	3787.81	1989.41	1449.81	0.00	1010.60
1960-1961	471.71	0.00	0.00	0.00	0.00	0.00	0.00	1649.98	2654.64	1800.89	1457.24	0.00	675.11
1961-1962	0.00	0.00	0.00	0.00	0.00	0.00	3354.62	4427.49	3643.15	2388.55	1452.72	529.71	1320.98
1962-1963	0.00	0.00	0.00	273.62	0.00	19.07	892.65	3286.31	4262.31	2332.92	1463.99	290.52	1074.02
1963-1964	0.00	0.00	0.00	0.00	0.00	0.00	2068.04	2967.84	4507.55	2303.69	1513.69	320.79	1143.10
1964-1965	0.00	0.00	331.13	2966.15	2649.86	2547.43	5966.21	7671.76	6768.42	3898.06	2277.29	0.00	2922.42
1965-1966	1054.41	0.00	0.00	0.00	0.00	0.00	1638.19	2892.34	1911.43	1114.27	2100.33	0.00	899.98
1966-1967	0.00	0.00	0.00	0.00	0.00	0.00	396.57	4204.81	5847.70	2789.63	2699.43	0.00	1336.54
1967-1968	0.00	0.00	0.00	0.00	0.00	0.00	283.24	1544.20	2988.27	3040.13	1382.33	0.00	775.65
1968-1969	78.93	0.00	0.00	0.00	0.00	81.79	5665.06	8074.97	4509.64	2324.64	1657.22	0.00	1873.93
1969-1970	0.00	0.00	0.00	0.00	283.86	442.75	2450.72	5812.56	4080.49	3221.40	2740.53	0.00	1596.22
1970-1971	0.00	0.00	0.00	3310.54	2860.55	2756.48	4455.44	8085.13	6432.62	3779.11	2862.37	0.00	2880.38
1971-1972	0.00	0.00	0.00	2788.86	2865.92	3646.10	2809.20	6956.51	6343.74	3190.36	2934.29	0.00	2629.68
1972-1973	0.00	0.00	0.00	0.00	0.00	0.00	570.50	2721.43	2438.20	1742.84	1546.27	0.00	757.78
1973-1974	0.00	0.00	0.00	1282.82	2106.05	3529.20	4247.76	8052.60	6693.39	3341.44	2728.56	0.00	2668.98
1974-1975	0.00	0.00	0.00	0.00	0.00	1500.18	3288.01	5938.54	5243.27	3953.81	2317.59	0.00	1865.62
1975-1976	796.02	0.00	0.00	0.00	308.13	149.17	3516.09	6272.13	3567.10	2267.36	1625.59	451.87	1586.57
1976-1977	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1104.44	2808.53	2681.68	975.81	796.45	700.74
1977-1978	372.25	0.00	0.00	0.00	0.00	0.00	3210.32	3532.58	3719.91	3062.40	2233.56	326.01	1377.84
1978-1979	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1915.60	2048.90	1530.23	1411.07	0.00	580.91
1979-1980	0.00	0.00	0.00	0.00	0.00	0.00	3296.17	5112.14	4408.89	2509.23	2404.12	0.00	1484.77
1980-1981	0.00	0.00	0.00	66.30	0.00	0.00	316.08	2686.11	3150.39	2024.51	1704.64	0.00	835.40
1981-1982	0.00	0.00	0.00	1033.53	1519.97	2553.46	3376.79	7710.28	5767.27	3578.94	2137.56	845.66	2382.68
1982-1983	0.00	0.00	0.00	3323.49	3528.51	4108.88	5516.39	6218.89	6133.63	3643.78	2475.29	0.00	2907.34
1983-1984	826.73	0.00	0.00	1951.41	1984.38	1529.89	3535.77	6362.13	5564.10	3182.34	2197.38	0.00	2263.30
1984-1985	18.77	0.00	0.00	0.00	0.00	0.00	3102.83	3449.26	2349.24	1635.62	1650.06	472.14	1060.52
1985-1986	0.00	0.00	0.00	2269.39	2700.78	3113.89	4355.40	5536.33	5169.82	2659.60	2451.18	0.00	2351.56
1986-1987	0.00	0.00	0.00	0.00	0.00	0.00	121.78	1431.83	2390.49	1061.23	1521.17	0.00	547.42
1987-1988	0.00	0.00	0.00	0.00	0.00	0.00	450.33	1710.05	2532.30	747.24	1550.25	0.00	585.51
1988-1989	0.00	0.00	0.00	0.00	0.00	0.00	2439.38	1932.66	2864.14	2286.91	1775.91	115.10	954.57
1989-1990	0.00	0.00	0.00	0.00	0.00	0.00	360.30	1513.42	2295.66	1961.43	1537.73	506.59	685.66
1990-1991	497.14	34.04	0.00	0.00	0.00	0.00	256.42	1580.28	3484.65	3251.21	1187.83	1004.84	946.33
1991-1992	1100.12	321.64	0.00	0.00	0.00	0.00	339.34	1083.62	2632.21	953.48	412.15	404.48	605.37
1992-1993	392.71	467.63	78.06	0.00	0.00	0.00	393.09	5396.40	3716.67	2268.19	1367.11	1137.35	1276.76
1993-1994	0.00	0.00	0.00	0.00	0.00	0.00	54.50	1486.50	2273.71	572.97	610.23	0.00	418.10
1994-1995	0.00	0.00	0.00	0.00	32.99	580.63	2703.13	4910.24	4328.40	3453.32	2509.45	0.00	1553.24
1995-1996	0.00	0.00	0.00	2004.17	1772.22	1819.38	4264.16	7169.22	5010.43	3006.16	2665.96	0.00	2313.62
1996-1997	0.00	0.00	0.00	3720.44	4485.46	4117.81	5732.43	7941.35	5538.93	2771.05	2532.09	0.00	3061.09
1997-1998	0.00	0.00	0.00	342.63	487.19	180.55	2733.34	5788.15	4596.37	2592.02	2322.49	0.00	1593.24
1998-1999	0.00	0.00	0.00	573.13	719.71	1117.04	3908.69	5499.13	5000.34	2828.15	2598.58	0.00	1858.96
1999-2000	0.00	0.00	0.00	0.00	0.00	0.00	3147.27	3181.77	2111.57	1340.43	1448.51	694.80	996.44
Mean	122.09	11.28	5.61	451.80	493.93	567.76	2427.30	4319.23	4038.48	2420.65	1857.25	141.18	1409.46
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	756.32	1647.44	572.97	0.00	0.00	418.10
Maximum	1117.37	467.63	331.13	3720.44	4485.46	4117.81	6951.47	8928.75	7120.84	4077.22	2934.29	1137.35	3061.09

Section 7
Document 8

PROJECT SUMMARY

We have developed a plan for the installation of hydroelectric power at Arrowrock Dam that we believe is economical, and technically and financially feasible.

Whereas previous concepts for hydro power installation involved tunneling through the dam, the recommended approach involves tapping into the existing Outlet Conduits No.1 and No. 2 near their downstream end, just upstream of the newly installed Clamshell Gates, for conveyance of flow to the powerhouse containing two 7.5 MW units for a total of 15 MW capacity. The arrangement of installation of the required bifurcations is such that the two outlet conduits can be operated for irrigation releases when the powerhouse units are inoperable. However, this will seldom be necessary, since hydro power equipment is very reliable, requiring very little planned outage compared with thermal generating units. Also, at Arrowrock there are some months when because of hydrological conditions no generation takes place, providing ample time for scheduled outages and repairs. This plan of utilizing the outlet conduits for conveyance of flow to the units requires modification to the recently completed gate structure of the outlet conduits. These required modifications are shown on the enclosed drawings.

The powerhouse would be located on the left bank (looking downstream) on the basalt rock bench that is seasonally flooded and then re-emerges when the Lucky Peak Lake (immediately downstream reservoir) recedes in the fall. The powerhouse would be a reinforced concrete structure approximately 80 ft high above its foundation. This results from the submergence requirement for the turbines and from the required flood protection when the Lucky Peak Lake reaches its maximum level in the summer recreational season. Because of the height of the powerhouse, an elevator would be provided to facilitate access.

One important aspect of the plan is the turbine selection for the very wide hydraulic head variation at the project. The head variation for the full output conditions can vary from about 180 feet to less than 50 feet. Hydraulic turbines operate efficiently and free from cavitation over a limited range of head variation. We investigated various turbine types for this application, including vertical axis Francis turbines, horizontal axis Francis turbines, Francis turbines with double runners, and Kaplan turbines. The Kaplan alternative proved most attractive, considering the equipment costs, the cost of civil works construction, and the energy output. After extensive hydro power operation studies, we focused on Kaplan type turbines. The turbines would be double regulated with moveable runners and adjustable wicket gates for maximum efficiency of operations. For the specific conditions of Arrowrock, this type of turbine provides satisfactory operation over most of the significant operating conditions to be encountered.

In addition to the powerhouse structure and generating equipment, project facilities will include:

- Balance of power plant equipment, including one main power transformer.

- Modification and bifurcations at existing irrigation outlet pipes.
- Two 55-inch diameter steel penstocks, expanding to 114-inch diameter unit inlet valves.
- Tailrace channel with tailwater control weir.
- New 34.5 kV transmission, length = 5.5 miles.

The deep setting of the powerhouse also requires a deep excavation for the tailrace channel. The tailrace channel slopes up and leads to a weir that controls the tailwater elevation for periods when the Lucky Peak Lake is drawn down. This weir reduces the head variation at the project and increases the operating conditions for the turbines.

The penstocks will be encased in concrete and the area will be backfilled to provide a space for the switchyard.

Section 7
Document 9

EMAIL FROM JOHN TIEDEMAN (RECLAMATION) 7/19/2005

Al. Sorry for not getting back to you sooner, but attached are two files. The first file (Blast) gives the criteria Reclamation looks at in regards to blasting near/on our facilities. On the first page, please note the last two sentences. On the second page, the table criteria for "Historically significant, Sound condition" would most likely apply.
And on the third page in Table 13-2, the material would be Sound igneous rock or *Water saturated materials.

The second is a file from our Denver office that has some interesting information on pressure effects on fish and all is related to sheet pile driving. Merely the angle of the sheet pile changes the pressure and negative pressures are sometimes created. Even thou this is not exactly what your project is about, it does describe a study which give some recent information.

Hope this helps out. JohnT

of safety when these conditions are present. Install an approved lightning warning device capable of detecting atmospheric conditions that could produce lightning on the jobsite. Warning devices must be acceptable to the COR or office head before installation.

24.1.8 **Vibration and Damage Control**. Take precautions to minimize earth vibration, air blast, and thrown fragments. Where vibration and blast damage is possible, include a vibration and damage control section in the site blasting plan. Establish a means of accurately measuring and documenting earth vibration and effects on nearby facilities or structures. The maximum peak particle velocity as recorded at the designated structure or location must not exceed 1 inch per second. Control the airblast so that it does not exceed 128 decibel linear-peak at designated locations or structures.

24.1.9 **Warning Signs**. Post warning signs at access points to blasting areas.

24.1.10 **Destruction of Explosives**. Deteriorated or damaged explosives, blasting agents, blasting supplies are prohibited. Destroy and remove these and all excess explosives from the site in accordance with the specific written instructions of the manufacturer.

24.1.11 **Empty Explosive Containers**. Destroy empty boxes and combustible packing materials which have contained explosives in accordance with the manufacturer's disposal procedures. If disposal is through burning, all personnel must remain at least 100 feet from the burning site once the material has been ignited and until no visible flames or smoke have been detected for 1 hour.

24.1.12 **Fire**. If a fire begins that involves explosives, or where the danger of the fire contacting explosives is imminent, do not fight the fire. All personnel must seek safe shelter; guard the fire area to prevent intruders.

24.2 Radio and Electromagnetic Radiation

Take adequate precautions to prevent accidental discharge of electric blasting caps from current induced by radar, radio transmitters, powerlines, and similar sources of electromagnetic radiation.

24.2.1 **Mobile Radio Transmitters**. Mobile radio transmitters or cellular telephones within 100 feet of electric blasting caps or delays not in their original containers are prohibited unless de-energized and effectively locked. Post warning signs at least 36 by 42 inches in size, stating BLASTING ZONE--TURN OFF 2-WAY RADIOS AND CELLULAR TELEPHONES, on all public roads within 1,000 feet of blasting operations, using electronic detonators.

Table 02305A- Maximum Peak Particle Velocity Permitted at Structures

Structure Type	Vibration frequencies (cycles/second)	Peak particle velocity (inches/second)
Relatively new residential with wallboard walls	Below 40 Above 40	0.75 2.0
Older residential with plaster walls	Below 40 Above 40	0.5 2.0
Historically significant:		
Precarious condition	--	0.2
Sound condition	--	0.5
Industrial (more substantial than residential)	--	2.0
Government-owned concrete or steel structures, or grouted or treated foundations	--	4.0

END OF SECTION

Table 13-1.—Determining moduli and ratios for typical velocities of earth materials from refraction surveys

V_p = Compressional wave velocity	(ft/s) (m/s)
V_s = Shear wave velocity	(ft/s) (m/s)
E = Young's Modulus	(lb/in^2) (MPa)
G = Shear Modulus	(lb/in^2) (MPa)
K = Bulk Modulus	(lb/in^2) (MPa)
μ = Poisson's Ratio	
ρ = Density (in situ)	(lb/ft^3) (kg/m^3)

Shear Modulus: $G = \rho V_s^2$
Young's Modulus: $E = 2G(1+\sigma)$
Bulk Modulus: $K = \rho(V_p - 4/3V_s^2)$
Velocity Ratio: V_p/V_s
Poisson's Ratio: $\mu = (.05)\,[V_p/V_s]^2 - 2/[V_p/V_s]^2 - 1\backslash$

material dynamic properties. Compressional waves and shear waves are generated in one drill hole, and the seismic wave arrivals are received in companion drill hole(s). The seismic source(s) and receiver(s) are located at equal depths (elevations) for each recording. Drill hole deviation surveys are performed in each drill hole to accurately determine the distances between each of the drill holes at all recording intervals. For typical seismic velocities of earth materials, see table 13-2.

Surface Wave Surveys

Purpose.—Surface wave surveys produce and record surface waves and their characteristics. Surface waves have lower frequencies and higher amplitudes than other seismic waves. Surface waves result from the constructive and destructive interference of refracted and reflected seismic waves. Surface waves that travel along the boundaries of a body are called Stanley waves. Surface waves are the slowest type of seismic

Table 13-2.—Typical velocitie

Material	(feet
Dry silt, sand, loose gravel, loam, loose rock, talus, and moist fine-grained topsoil	6
Compact till, indurated clays, gravel below water table*, compact clayey gravel, sand, and sand-clay	2,
Weathered, fractured, or partly decomposed rock	2,(
Sound shale	2,5
Sound sandstone	5,(
Sound limestone, chalk	6,(
Sound igneous rock	12,
Sound metamorphic rock	10,
*Water (saturated materials should have velocities equal to or exceeding that of water)	

wave, traveling along the bounc
materials. The characteristics
addition to recording the waves.
are filtered out of seismic data o
"ground roll," in the oil explo
surface waves. Special care is ta
surveys to filter out surface w
interfere with desired reflection
surface waves and their characte
in figure 13-2.

Section 7
Document 10

EMAIL FROM LEN GARRITY (SHAW STONE & WEBSTER) 8/27/2005

This is to summarize and confirm the discussion of Thursday, August 25, 2005 between Shaw/ Stone&Webster [SSW], Len Garrity and Gary Wiseman, the Bureau of Reclamation [BOR] Boise and Denver offices and representatives of Superior Blasting, Gerald Dilley and Jack Kieker. BOR participants included John Tiedeman, Steve Jarsky and Greg Scott

Stone & Webster opened the discussion stating that it was in the process of developing an EPC price for the Arrowrock Hydroelectric Project and need to discuss and if possible arrive at an agreement for the blasting levels to be assumed for the project in order to develop the cost for the blasting/excavation at the site. Superior Blasting explained that it planned to pre split all final walls.

Blasting levels that might be considered ranging from 0.5 in/sec to 10in/sec depending on distances etc. were discussed at some length.

It was determined that a blasting level of 4in/sec was acceptable to the BOR at the toe of the dam and a blasting level of 2in/sec was acceptable to the BOR at the valve works AND stairway structure on the downstream face of the dam.

The BOR stressed that BEFORE any blasting took place it would have to receive AND approve the blasting plan for the excavation. The blasting plan would have to pay particular attention to the approach to be used in excavating for the installation of the new penstocks at the face of the dam. The blasting plan would have to consider and address the existing [now abandoned] diversion tunnel and the downstream plug in the tunnel. Location of the powerhouse and associated excavation should consider relative position to the existing diversion tunnel.

The blasting plan should include a preblast assessment with photographs, seismic monitoring etc. and a shot plan within 50 ft of the dam.

SSW confirmed that it would work closely with the BOR on aspects of the blasting and excavation.

It was pointed out by the BOR that most of the approvals for the blasting would be worked thru Denver office of the BOR which is not far from SSW's Denver office.

We appreciate the BOR's efforts and cooperation in this matter and look forward to working with the BOR personnel on this project.

Regards,

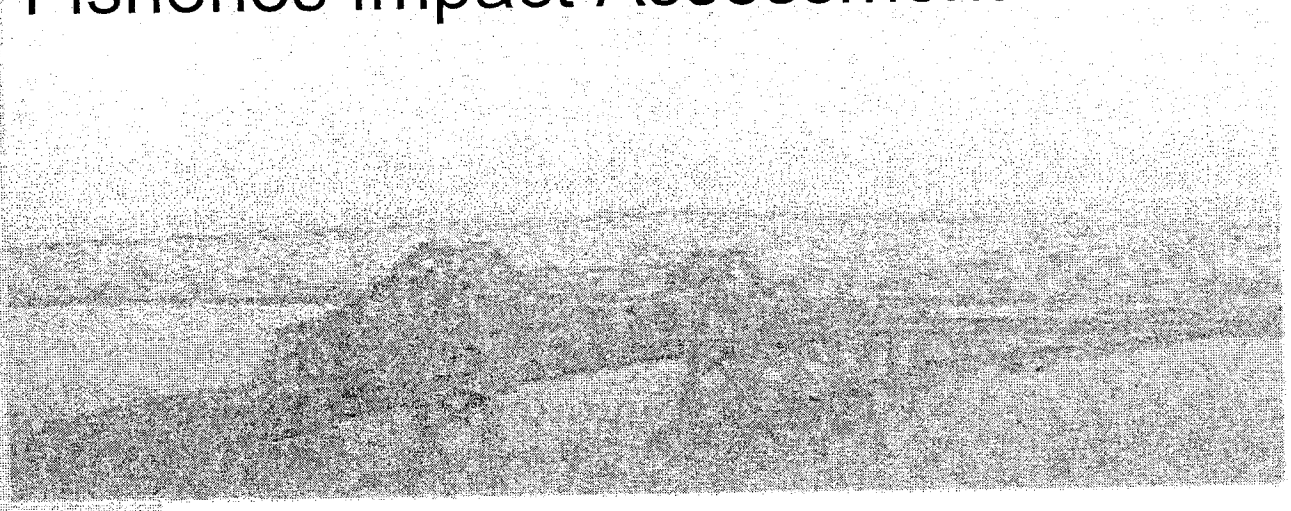
Len Garrity

Section 7
Document 11

San Francisco – Oakland Bay Bridge
East Span Seismic Safety Project

Pile Installation Demonstration Project

Fisheries Impact Assessment



August 2001

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Caltrans Contract 04A0148
Task Order 205.10.90

PIDP 04-ALA-80-0.0/0.5

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EXECUTIVE SUMMARY

This report provides an assessment of impacts to fisheries resources in San Francisco Bay during a Pile Installation Demonstration Project (PIDP) for the San Francisco-Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project (East Span Project). This report includes a discussion of regulatory issues and the results of the PIDP fish monitoring and experimental program.

The PIDP was conducted in the central San Francisco Bay between October 23 and December 12, 2000 to evaluate engineering and environmental factors associated with installing large steel piles that would support a replacement structure or with installing piles as an element of retrofitting the existing bridge between Yerba Buena Island and the City of Oakland. The PIDP involved driving three steel pipe piles using two types of hydraulic hammers, one with a maximum energy rating of 500 kilojoules (kJ) (referred to as the small hammer) and one with a maximum rating of 1700 kJ (referred to as the large hammer). The PIDP also tested two different types of in-water sound attenuating equipment, an air bubble curtain and a proprietary fabric barrier system with an aerating mechanism, in addition to driving one pile without sound attenuating devices. As such, the PIDP was a demonstration project to investigate construction requirements, identify potential problems, make modifications to equipment, and examine effectiveness of sound attenuation devices for the East Span Project. Overall, the PIDP included a total of 12 hours and 51 minutes of pile driving for all segments.

Fisheries monitoring activities conducted during the PIDP included:

- Observations on predation by gulls
- Observations on the presence and distribution of schools of fish with a fathometer
- Examination of injured fish collected from the water
- Experiments using shiner surfperch held in cages at different distances

The fisheries monitoring program documented near-term fish mortalities and the likelihood of a high rate of delayed mortality of differing sizes and species of fish that have swim bladders. During installation of Pile 1 without sound attenuation, fish started floating to the surface almost immediately after the start of pile driving using either the small or large hammer. Gulls usually arrived within minutes, feeding on fish floating up to the surface near the pile and up to 500 meters (1,640 feet) down current. The predation rate as indicated by gull foraging behavior varied from approximately 0 to 7 fish per minute.

The predation rate was generally lower when sound attenuating mechanisms were in operation. An air bubble curtain was used during the installation of Pile 2, and a proprietary fabric barrier system with an aerating mechanism (essentially an air bubble curtain surrounded by an additional bubble curtain enclosed by two fabric layers) was used during installation of Pile 3. Both systems reduced but did not eliminate fish mortality related to pile driving.

Surveys with a fathometer before, during, and after pile driving indicated that fish schools did not move away from the PIDP site and suggested that the PIDP barge tended to aggregate fish. Internal examination of the fish collected at the surface of the

water near the construction site indicated injuries to the kidneys and liver as a result of the contraction and expansion of the swim bladder. Attempts to recover fish that may have sunk to the bottom were unsuccessful. Observations on where stunned fish surfaced indicated that the Immediate Mortality Zone (IMZ) is approximately 10-12 meters (33-39 feet) from a pile being driven with either the small or large hammer without sound attenuation.

Permanent injury to the inner ear and lateral line organ will result in a reduced ability to orient in the water column, capture prey, avoid predators and delayed mortality. For the purposes of this report, a Delayed Mortality Zone (DMZ) has been defined as the zone in which the peak sound pressure level and impulse are not great enough to result in immediate death but result in mortality several hours to several days later. Based on acoustic measurements and experiments using shiner surfperch held in cages, the DMZ for pile driving using the large hammer without attenuation is estimated to extend out at least about 150 meters (about 500 feet) and possibly up to about 1,000 meters (3,280 feet) from the pile. The size of the IMZ and DMZ will vary with the species, size, physiological condition of the fish and environmental conditions. Fish without swim bladders will probably not be as adversely affected as those with swim bladders. The IMZ and DMZ are presented as estimates only. There is simply an inadequate amount of experimental data on pile driving impacts to draw more than general conclusions.

The impacts of pile driving on different species of fish in San Francisco Bay could vary depending on the time of year. For example, pile driving operations in the summer and early fall could result in the mortality of anchovies, but the quantities killed would not be significant compared to the commercial fishery for anchovies in the Bay. Pile driving operations in the winter months could result in the mortality of some steelhead, salmon and herring. Pile driving at any time throughout the year could result in the mortality of several species of surfperch and a number of federally managed species including brown rockfish and sardines. Losses of federally managed species are not expected to have a population level impact since the main biomass of the federally managed species is in the Pacific Ocean outside San Francisco Bay. The rate of mortality of surfperch due to pile driving is also not expected to amount to a population level impact.

The 1999 Section 7 consultation with the National Marine Fisheries Service (NMFS) requires the utilization of sound attenuation devices, such as an air bubble curtain, during the period January 1 through May 31 to protect salmon and steelhead during the juvenile outmigration period or no pile driving would be permitted. Since sound attenuation devices may not completely eliminate fish mortality, consultation with NMFS for an incidental "take" statement for salmon and steelhead (which are federally listed endangered and threatened fish) is under way.

Mitigation for the East Span Project will be implemented to minimize impacts to herring. Construction activities that occur during the peak herring spawning season, generally January to March, would be monitored by a qualified biologist to watch for the presence of spawning herring. If the biologist (or CDFG) observes spawning in the area, in-water construction activities such as pile driving and dredging would be suspended within 200 meters (660 feet) of observed spawn. In-water construction activities would not resume at that location for a period of up to 14 days (as determined by a qualified biologist), allowing herring eggs to hatch and larvae to disperse.

1.0 INTRODUCTION

This report provides an assessment of impacts to fisheries resources in San Francisco Bay during a Pile Installation Demonstration Project (PIDP) for the San Francisco-Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project (East Span Project). This report includes a discussion of regulatory issues and the results of the PIDP fish monitoring and experimental program.

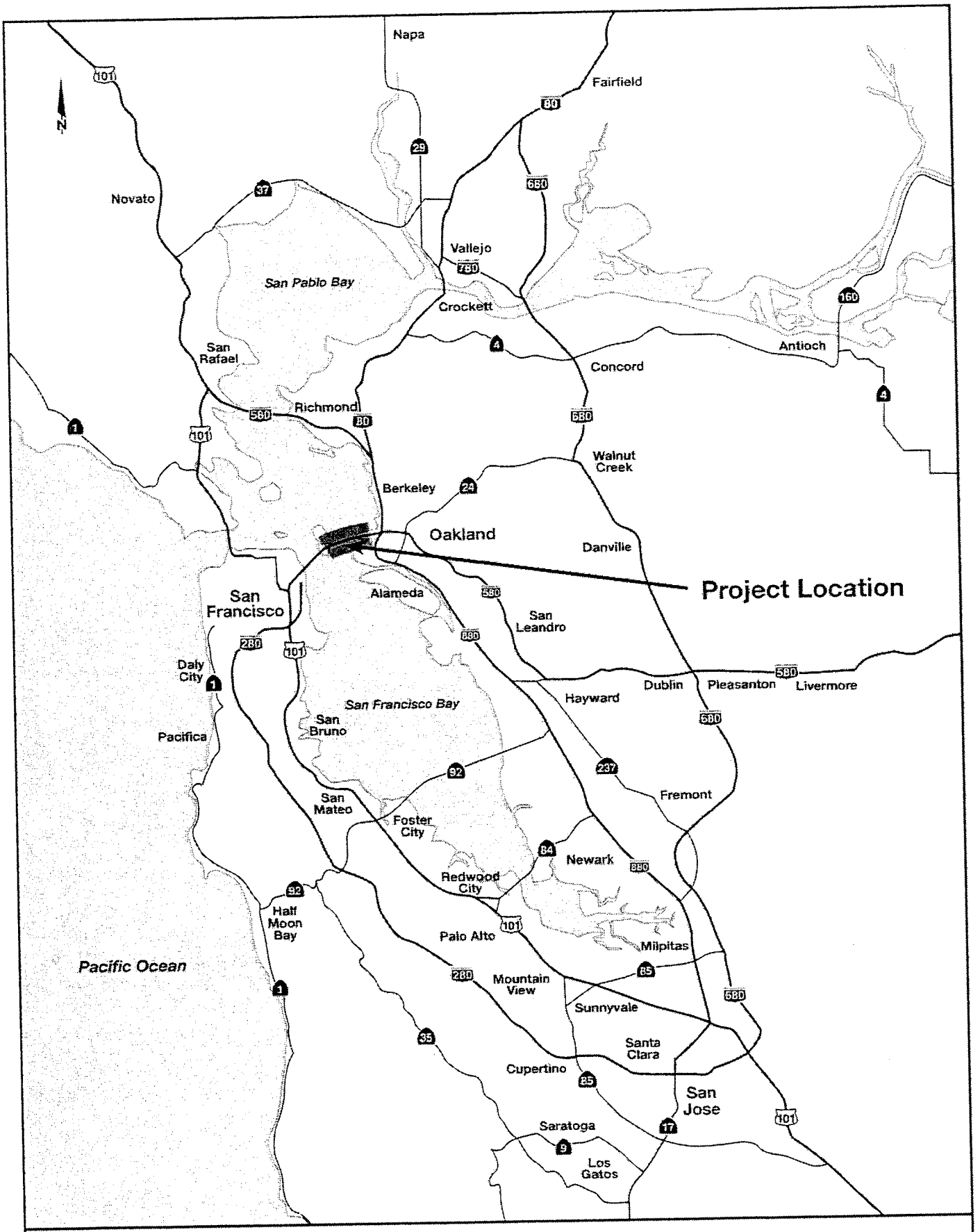
1.1 Project Description

The PIDP was conducted in the central San Francisco Bay between October 23 and December 12, 2000 to evaluate engineering and environmental factors associated with installing large steel piles that would support a replacement structure or with installing piles as an element of retrofitting the existing bridge between Yerba Buena Island and the City of Oakland. Figure 1-1 indicates the project vicinity within San Francisco Bay and Figure 1-2 indicates the PIDP study area.

The PIDP study involved driving three piles, with two different sizes of hammers and the use of two different methods of underwater sound attenuation. The test piles, labeled 1, 2 and 3 were made of steel pipe 2.4 meters (8 feet) in diameter. Pile 1 was driven straight down and did not use any sound attenuation.

Pile 2 was a battered pile angled 1h:6v to the east and used an air bubble curtain. The air bubble curtain provides a curtain of air around the pile to attenuate noise from driving activities. Bubbles emerged from a submerged piping system that surrounded the pile template (used to hold the hammer/pile in place). The piping system was comprised of three 10.2-centimeter (4-inch) diameter perforated polyvinyl chloride (PVC) pipes attached to a steel frame, forming a 30.5-meter (100-foot) diameter octagonal ring. Two rows of 0.1-centimeter (0.04-inch) diameter holes were drilled into the PVC pipes. The bubble curtain system was fabricated and assembled off-site, then transported to the pile-driving site using a barge-mounted crane. The piping system ring was then submerged to the bay floor to encircle the pile template. Air was supplied from a 1600 cubic feet-per-minute (cfm) compressor located on the PIDP barge. Though Pile 2 was driven at an angle, the bubbles streamed straight up to the water surface, potentially providing less attenuation near the surface than at greater depths. A similar system was used by Würsig et al. (2000) for attenuating noise received by dolphins during pile driving activities for an airport expansion.

Pile 3 was a battered pile angled 1h:6v to the west and was surrounded by a proprietary method of sound attenuation referred to as a fabric barrier system with aerating mechanism. The fabric barrier system consisted of an in-water, double-layer fabric curtain with a single 7.6-centimeter (3-inch) diameter pipe between the two fabric sheets and three 7.6-centimeter (3-inch) diameter pipes between the inner fabric layer and the pile. The fabric curtain was made of water-permeable material which enclosed the pile template. The top of the curtain attached to the pile template at a level a few meters above the surface of the water. The bottom was attached with beams to the bottom of the template.

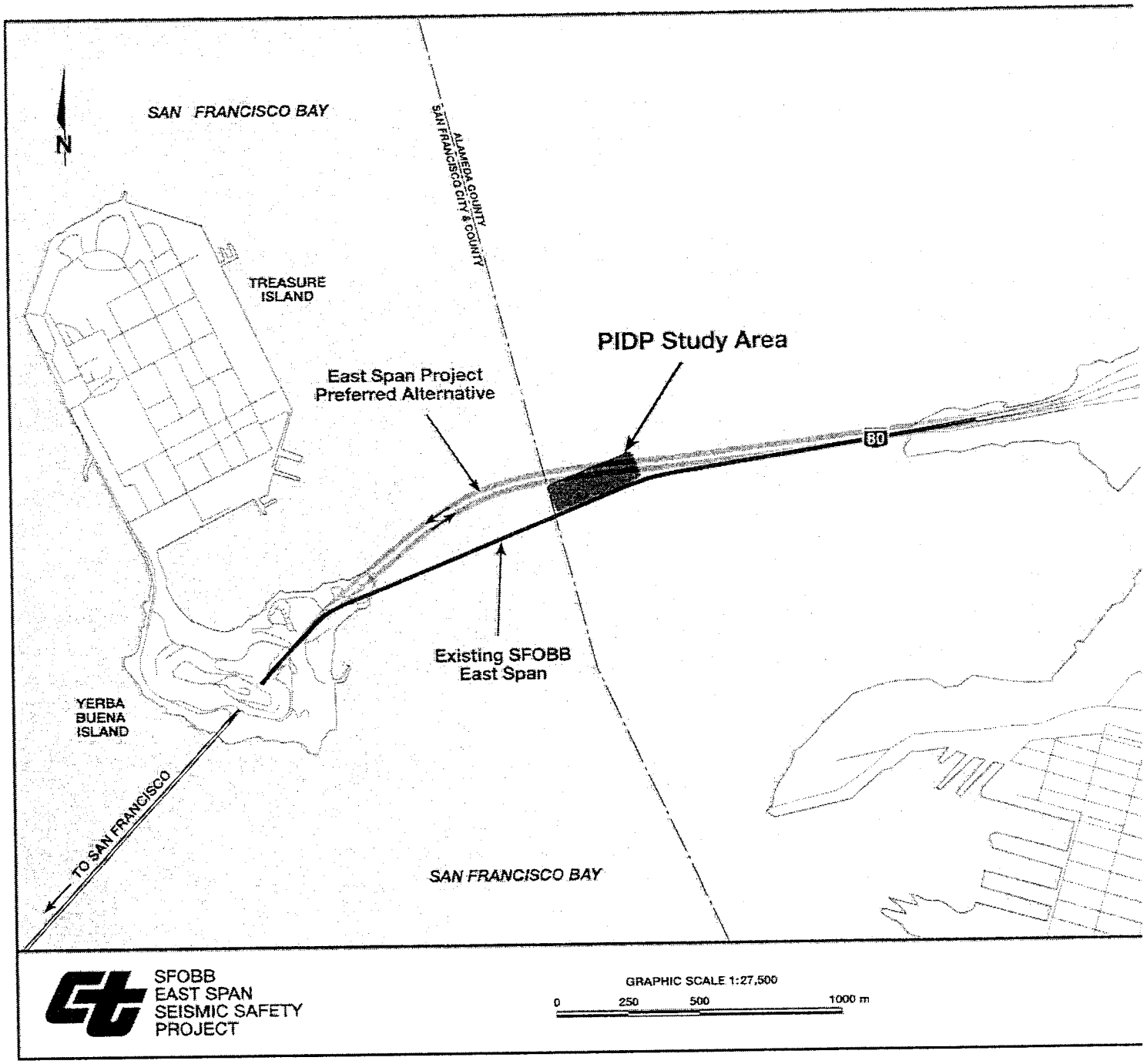


SFOBB
EAST SPAN
SEISMIC SAFETY
PROJECT

Project Location

Figure 1-1

3/30/99

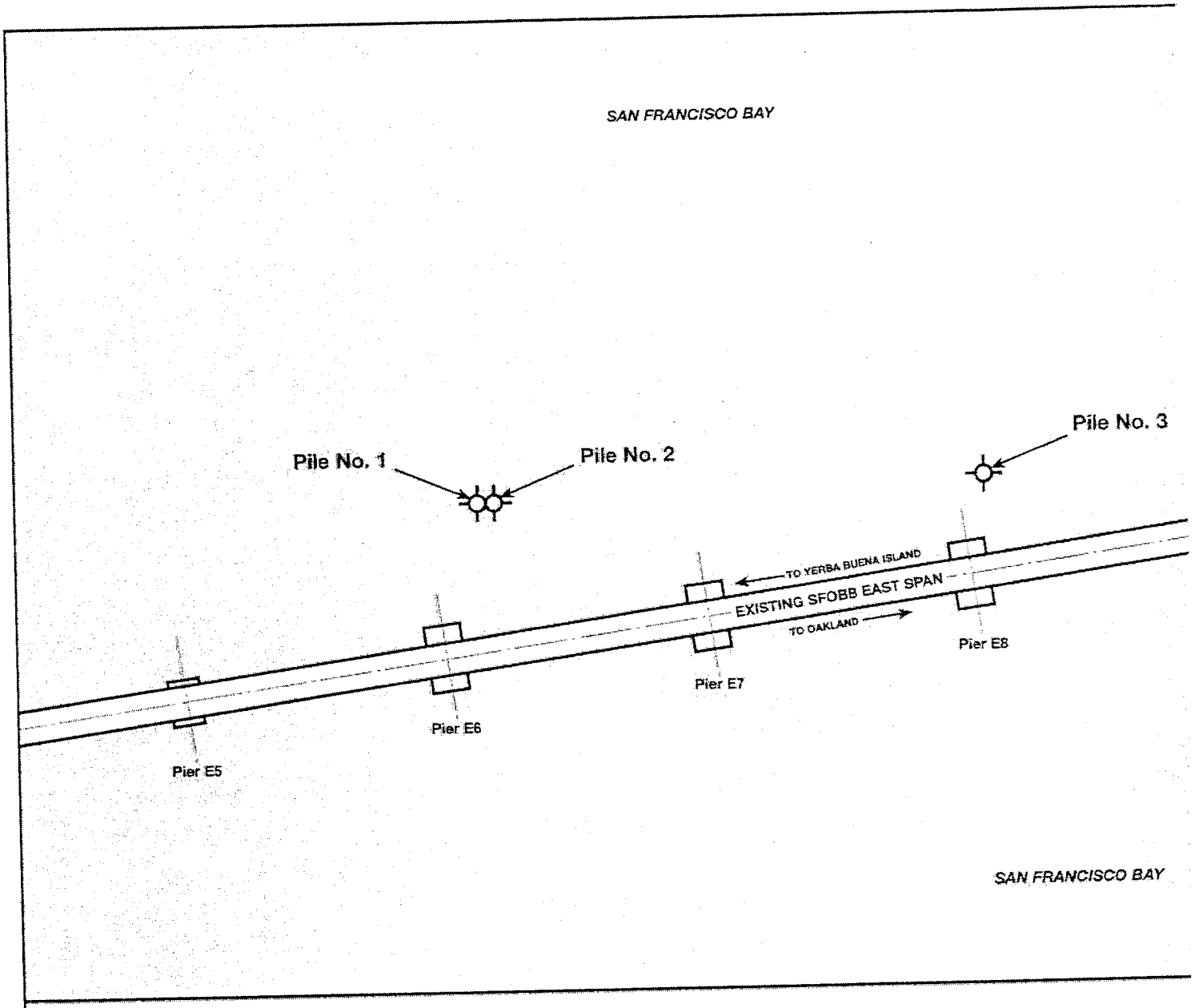

SAN FRANCISCO BAY
N
ALAMEDA COUNTY
SAN FRANCISCO CITY & COUNTY
TREASURE ISLAND
PIDP Study Area
East Span Project Preferred Alternative
80
Existing SFOBB East Span
YERBA BUENA ISLAND
TO SAN FRANCISCO
SAN FRANCISCO BAY
SFOBB
EAST SPAN
SEISMIC SAFETY
PROJECT
GRAPHIC SCALE 1:27,500
0
250
500
1000 m

The fabric barrier system with aerating mechanism had a 10.7-meter by 22.9-meter (35-foot by 75-foot) rectangular footprint. This proprietary fabric barrier system with aerating mechanism was assembled and attached to the template off-site. The template/air bubble and fabric barrier was transported by barge to the Pile 3 location. Air was supplied from the same 1600 cfm compressor that was used on Pile 2; however, air was supplied to four pipes which were arranged in a smaller footprint than for the air bubble curtain, thereby providing a higher density of air bubbles around the pile.

Each pile was made up of four 33-meter (108-foot) long sections labeled sections A through D, which were driven and welded together in succession until the full length of the pile was achieved. The first section, Section A, generally required relatively little pounding. The weight of the pile with a moderate level of pounding was enough to drive it down through the soft mud on the bottom of the Bay. Pile Sections B through D required progressively more energy to drive the piles into hard mud and soft rock. Two types of Menke hydraulic hammers were employed to drive the piles; a small hammer rated at 500 kilojoules (kJ), and a large hammer rated at 1,700 kJ. It took approximately ¾ of an hour to several hours to drive one section. There were many work stoppages to weld new sections and make measurements and repairs. The first few hammer strikes were irregular in timing and typically at a lower energy. Once all systems were operating properly, there were typically 25-30 strikes to the pile per minute. Over the two-month period between October 23 and December 12, 2000, pile driving was conducted for a total period of 12 hours and 51 minutes.

The piles were installed at two locations adjacent to the existing SFOBB East Span (Figure 1-3). Piles 1 and 2 were installed north of East Span pier E6, where the water is approximately 9 meters (30 feet) deep. Pile 3 was installed north of East Span pier E8, where the water depths range between approximately 7 meters (25 feet) to the west of the pile and 5 meters (17 feet) deep to the east of the pile. The barge from which pile driving equipment was operated was held in place next to the test pile by a system of anchors and pilings that could be adjusted as needed. A schematic of the PIDP study area is shown in Figure 1-4. Photos of the PIDP barge and the large and small hammers are shown in Figures 1-5 and 1-6. Photos of the air bubble curtain in operation and the fabric barrier system are shown in Figures 1-7 and 1-8.

During the PIDP, several monitoring efforts were undertaken to study the environmental impacts of pile driving. This report summarizes observations on the impact of the PIDP on fisheries resources in central San Francisco Bay, along with a discussion of regulatory issues, results of the fish monitoring and experimental program, and the effectiveness of the sound attenuation devices in terms of effectiveness at reducing noise, costs, and operational/deployment difficulties for the East Span Project.



SFOBB
EAST SPAN
SEISMIC SAFETY
PROJECT

GRAPHIC SCALE 1:3,500

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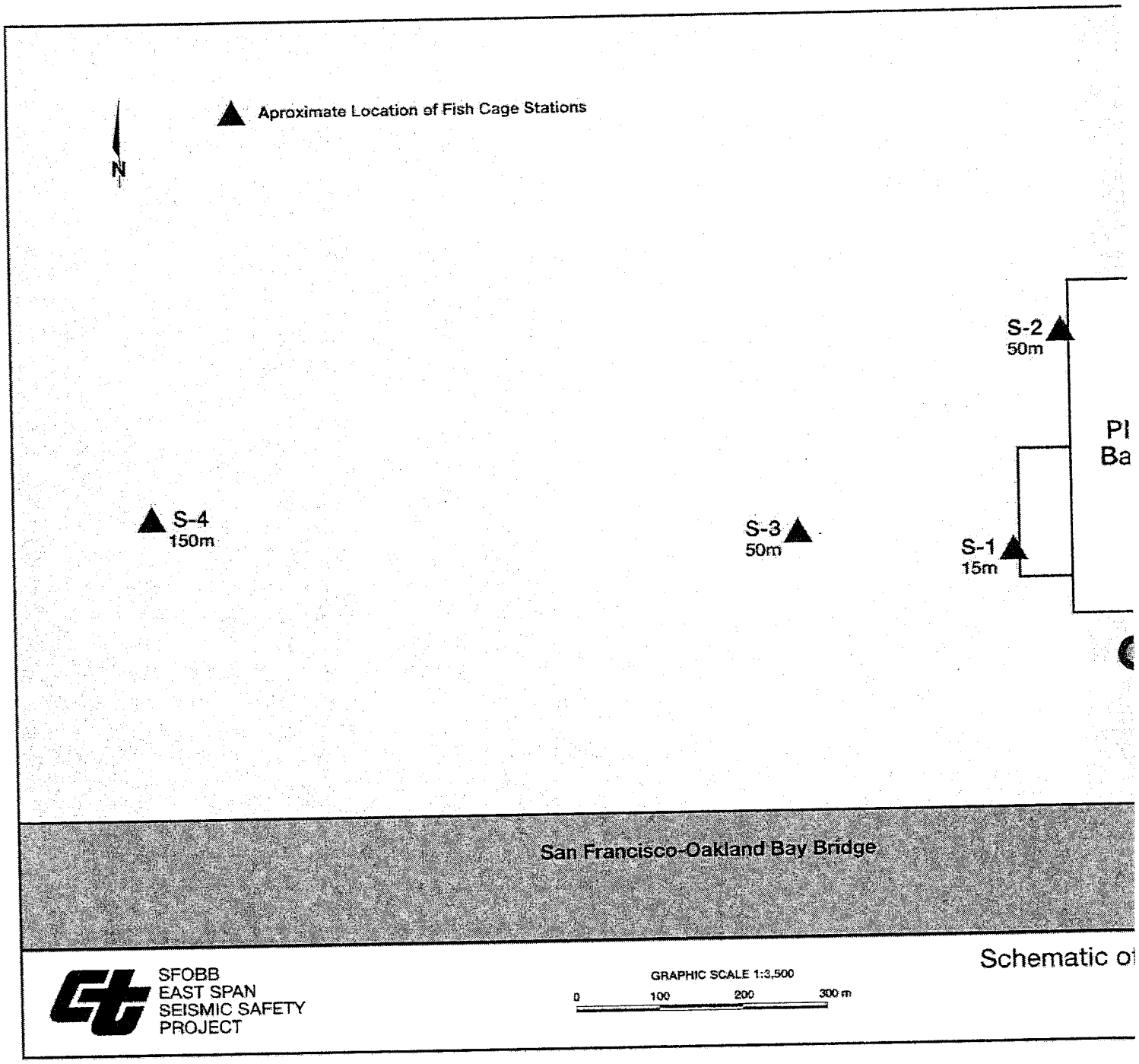

SFOBB
EAST SPAN
SEISMIC SAFETY
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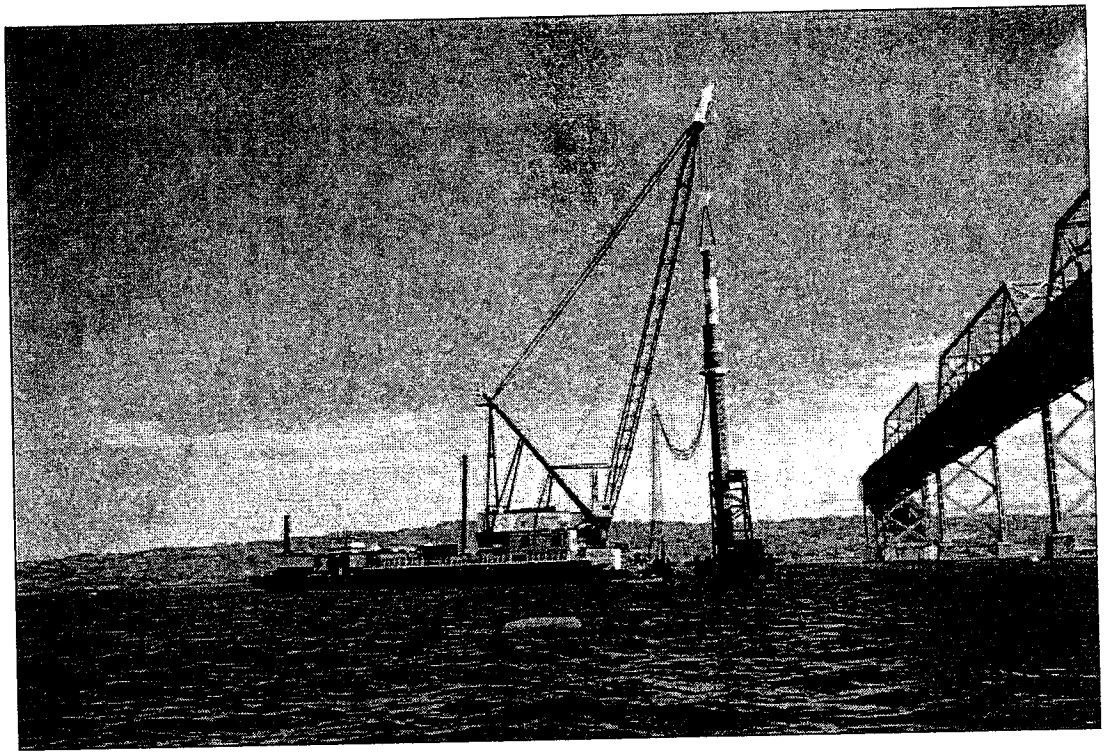


Figure 1-5. PIDP Barge and Large Hammer. (Note: Buoy in the foreground was used to support underwater sound monitoring instruments.)

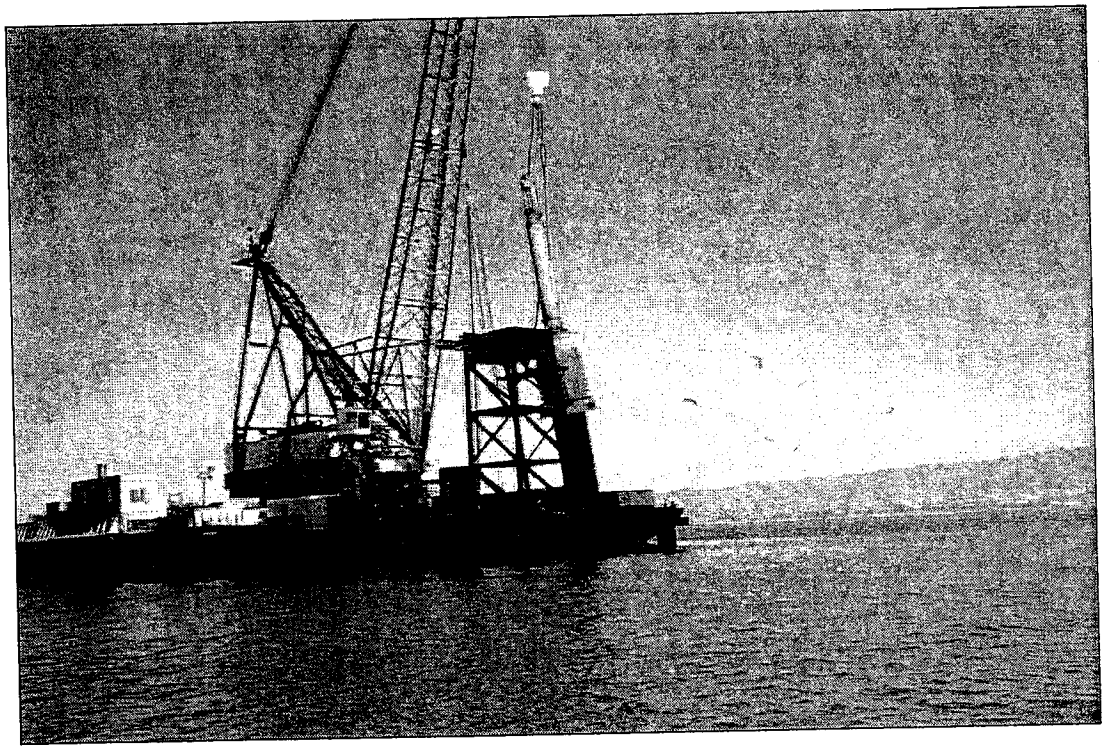


Figure 1-6. PIDP Barge and Small Hammer. (Note: Birds circling the area.)

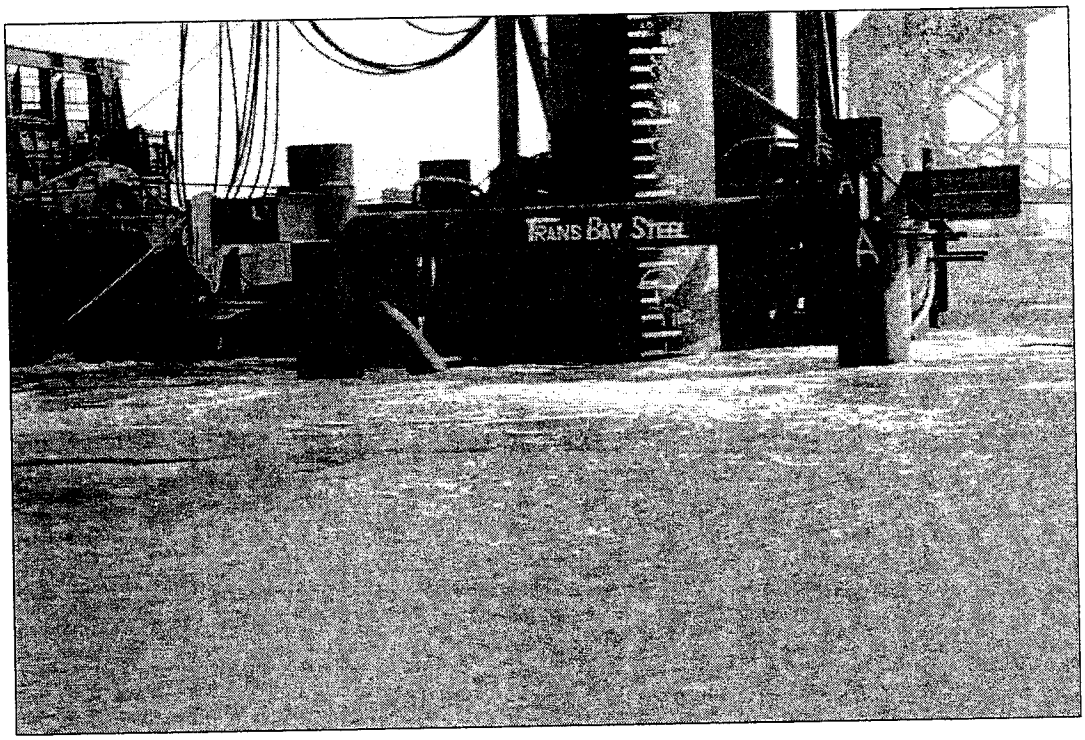


Figure 1-7. Air Bubble Curtain in Operation.

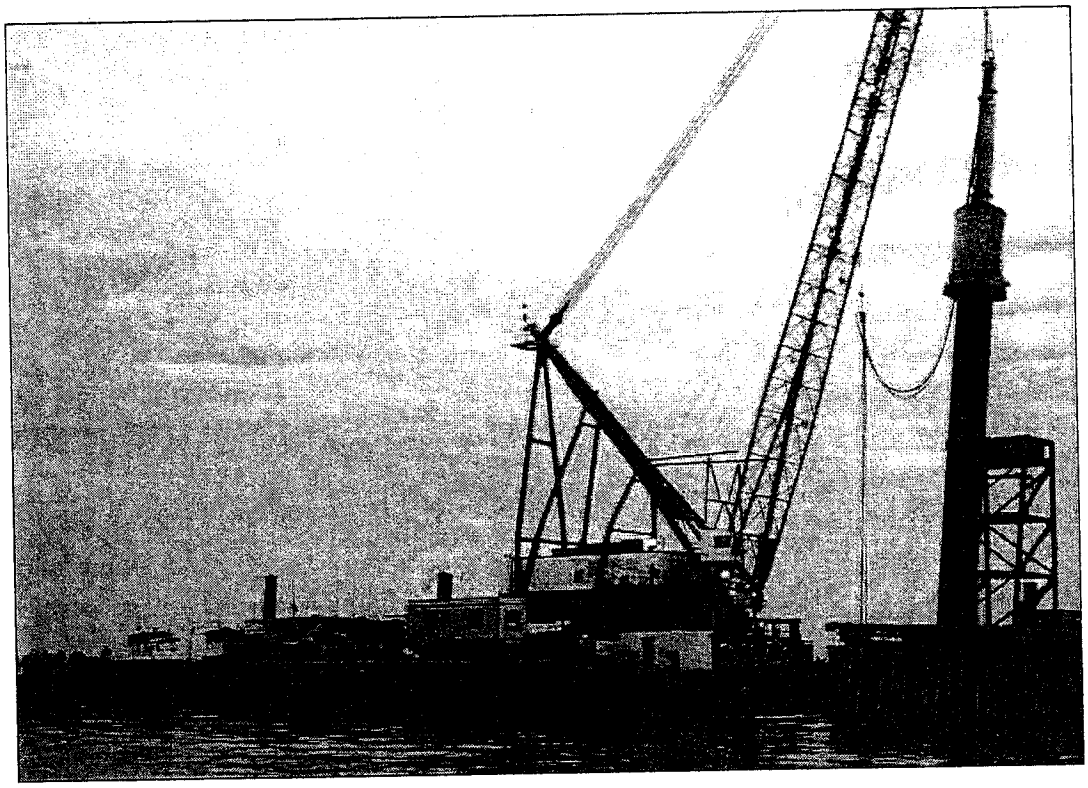


Figure 1-8. Fabric Barrier System with Aerating Mechanism (lower right corner of figure).

1.2 Regulatory Environment for Fisheries Resources in San Francisco Bay

The main regulatory agencies concerned with potential impacts on fisheries resources are the National Marine Fisheries Service (NMFS) and California Department of Fish and Game (CDFG). The NMFS is charged with management of the Federal Endangered Species Act (FESA) for salmon and steelhead, and for coastal fisheries resources under the Essential Fish Habitat (EFH) mandate of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). The CDFG is responsible for management of the California Endangered Species Act (CESA) and for regulation and conservation of fisheries resources.

1.2.1 National Marine Fisheries Service

The California Department of Transportation (Caltrans) and the Federal Highway Administration concluded initial consultation with the NMFS for the FESA and EFH in September 1999. The NMFS stated that, pertaining to federally listed salmon and steelhead, "noise insulating devices will be used to reduce sound pressure and impulse levels" if pile driving activities occur during the juvenile outmigration period of January 1 through May 31. The following section reviews and updates the regulatory status of fisheries resources in San Francisco Bay.

1.2.1.1 Threatened, Endangered and Special Concern Species

The California Natural Diversity Data Base (CNDDB) was consulted for both federally and state listed endangered and threatened species, and species of special concern (Table 1-1). Federal and state resource agencies were consulted to determine the scope of special status species that could be within the project areas and susceptible to potential pile driving impacts. Winter-run chinook salmon (*Oncorhynchus tshawytscha*) are federally and state listed as endangered. Spring-run chinook salmon are federally and state listed as threatened. Though neither chinook salmon race inhabits tributaries to San Francisco Bay, adults and juveniles can be found in the project area during upstream migration to natal streams in the upper Sacramento River and during juvenile downstream migration to the ocean. San Francisco Bay is part of their essential fish habitat.

Natural spawning chinook salmon of the California coastal Evolutionarily Significant Unit (ESU) are federally listed as threatened and may be found in San Francisco Bay, but their presence in the project area may be considered transitory and incidental since they primarily spawn in coastal streams. There are three creeks flowing into South San Francisco Bay that have small annual chinook salmon migrations: Alameda Creek, Coyote Creek, and the Guadalupe River (Hsueh 1999, Leidy 1984).

The Central Valley fall/late fall-run chinook salmon ESU is a federal candidate species. Fall/late fall-run chinook spawn in the Sacramento and San Joaquin Rivers and their tributaries, and migrate through San Francisco Bay. Late fall-run chinook salmon are listed by the CDFG as a "California Special Concern Species" and by the United States Forest Service as a "Sensitive" species. San Francisco Bay is part of their essential fish habitat though their presence in the project area may be considered transitory and incidental since they are primarily migrating directly between the Pacific Ocean and the Sacramento-San Joaquin Delta.

Central California Coast ESU steelhead and Central Valley ESU steelhead are federally listed as threatened. Some Central California Coast ESU steelhead and California coastal ESU chinook salmon may migrate through the area enroute to East Bay and South Bay

tributaries including Alameda Creek, Coyote Creek, Guadalupe River and Stevens Creek (Hsueh 1999, Leidy 1984). Both salmon and steelhead have swim bladders.

The green sturgeon (*Acipenser medirostris*) is federally listed as a species of special concern. Green sturgeon are much less common than white sturgeon (*A. transmontanus*) in San Francisco Bay but they are found throughout the Bay and are commonly called "golden sturgeon" by recreational fishermen. Sturgeons have swim bladders (Conte personal communications 2001).

Table 1-1 Summary of Threatened, Endangered and Special Concern Species

Common Name	Scientific Name	Comments
Winter-run chinook salmon	*Oncorhynchus tshawytscha*	Federal endangered, State endangered
Spring-run chinook salmon	*O. tshawytscha*	Federal threatened, State threatened
Chinook salmon-California coastal ESU	*O. tshawytscha*	Federal threatened
Chinook salmon-Central Valley ESU fall/late fall-run	*O. tshawytscha*	Federal candidate species, California special concern species
Steelhead-Central California Coast ESU	*O. mykiss*	Federal threatened
Steelhead-Central Valley ESU	*O. mykiss*	Federal threatened
Green sturgeon	*Acipenser medirostris*	Federal special concern species

Source: The California Natural Diversity Data Base, January and April 2001.

1.2.1.2 Definitions of Take, Harass, Harm and Critical Habitat

The purpose of the Federal Endangered Species Act (FESA) is to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved (FESA Section 2). Accordingly, the FESA prohibits the "take" of any listed species within the United States (FESA Section 9). Take is defined as "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or to attempt to engage in any such conduct" (FESA Section 3). Harass is defined as "an intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavioral patterns which include, but are not limited to, breeding, feeding or sheltering" (50 CFR §17.3). Harm is defined as "an act which actually kills or injures fish or wildlife. Such an act may include significant habitat modification or degradation which actually kills or injures fish or wildlife by significantly impairing essential behavior patterns, including, breeding, spawning, rearing, migrating, feeding or sheltering" (50 CFR part 222). Critical habitat is defined as " (1) the specific areas within the geographical area occupied by the species, at the time it is listed in accordance with the provisions of Section 4 of the Act, on which are found those physical or biological features (constituent elements): (a) essential to the conservation of the species and (b) which may require special management considerations or protection" (FESA Section 3 (5)(A)). The 4(d) rule for steelhead listed many examples of "take" that are "likely" to kill or injure salmon and steelhead (Federal Register 1999). Examples include: land use activities that adversely affect salmonid habitat, urban development and altering habitat that makes listed

salmonids more susceptible to predation. Central California Coast steelhead critical habitat includes all of San Francisco Bay and its tributaries (Federal Register 2000b).

Underwater shock waves generated by explosives are known to affect the aquatic environment and result in injury and death to fish and wildlife (Keevin et al. 1999). FESA Section 7 consultations are commonly required for the use of explosives in coastal waters such as for the removal of off-shore petroleum platforms and construction (Howorth 1999). Pile driving is known to also produce underwater shock waves (Würsig et al. 2000).

1.2.1.3 Essential Fish Habitat

The amended Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), also known as the Sustainable Fisheries Act (Public Law 104-297), requires all Federal agencies to consult with the Secretary of Commerce on activities, proposed activities, authorized, or funded or undertaken by that agency that may adversely affect essential fish habitat (Office of Habitat Conservation 1999). The Essential Fish Habitat (EFH) provisions of the Sustainable Fisheries Act are designed to protect fisheries habitat from being lost due to disturbance and degradation. EFH is defined as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The term "waters" is defined to include "aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate." The term "necessary" is defined as the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and spawning, breeding, feeding, or growth to maturity to cover a species' full life cycle.

The MSFCMA requires that EFH must be identified for all federally managed species including all species managed under the Pacific Fisheries Management Council (PFMC). The PFMC is responsible for managing commercial fisheries resources along the coast of Washington, Oregon, and California. Managed species are covered under three fisheries management plans:

- Coastal Pelagics Fishery Management Plan
- Pacific Groundfish Fishery Management Plan
- Pacific Salmon Fishery Management Plan

Most of the federally managed species are not found in central San Francisco Bay. The NMFS published on the web a listing of "Fisheries Management Plan" (FMP) species in San Francisco Bay. FMP species that may be found in the project area include species that are found in the South-Central and Central parts of San Francisco Bay. See Table 1-2.

Table 1-2 Federally Managed Species Found in San Francisco Bay

Name	Scientific Name	Swim Bladder (Yes/No)	Presence in the Project Area
Northern anchovy	*Engraulis mordax*	Yes	Present, Most abundant species in the project area
Pacific sardine	*Sardinops sagax*	Yes	Present, but not common
Jack mackerel	*Trachurus symmetricus*	Yes	Present, but not common
Chinook salmon	*Oncorhynchus tshawytsscha*	Yes	Present
Leopard Shark	*Triakis semifasciata*	No	Present
Soupfin shark	*Galeorhinus zyopterus*	No	Present
Spiny Dogfish	*Squalus acanthias*	No	Present
Big Skate	*Raja binoculata*	No	Present
Brown Rockfish	*Sebastes auriculatus*	Yes	Abundant
Lingcod	*Ophiodon elongatus*	Yes	Present
Pacific Sanddab	*Citharichthys sordidus*	No	Present
English Sole	*Parophrys vetulus*	No	Abundant
Starry Flounder	*Platichthys stellatus*	No	Abundant
Curlfin Sole	*Pleuronichthys decurrens*	No	Present
Sand Sole	*Psettichthys melanostictus*	No	Present
Cabezon	*Scorpaenichthys marmoratus*	Yes	Few
Pacific whiting (hake)	*Merluccius productus*	Yes	Present
Kelp greenling	*Hexagrammos decagrammus*	Yes	Present
Bocaccio	*Sebastes paucispinis*	Yes	Rare

Source: Helfman, et. al., 1997 and Southwest Regional, National Marine Fisheries Service, National Oceanographic and Atmospheric Administration website, www.swr.nmfs.noaa.gov, November 2000.

1.2.2 California Department of Fish and Game

The historical responsibility of the CDFG has been to manage fisheries resources for a maximum or optimum sustainable yield. As the fisheries resources of California have declined, the role of CDFG has increasingly turned towards conservation and restoration-oriented management. The management emphasis has been shifting from maximizing long-term commercial and sport fishing yields to the adoption of the Precautionary Principal that is focused around a conservative approach to resource management.

Many species of fish are not formally listed as threatened or endangered, but are tightly managed to limit fisheries impacts or the loss of essential habitat. Species such as striped bass, sturgeon, and herring are all rigorously managed by CDFG, which sets specific limits on the size and number that can be taken in any year. The population status of the group of fish collectively called surfperch has become a matter of concern and CDFG is in the process of developing a management plan to protect this group from further decline (Ota personal communication 2001).

1.2.2.1 Herring

The Pacific herring commercial fishery in San Francisco Bay is unique in that it is the only commercial fishery in the United States that is conducted entirely within an urban setting. It is also one of the most tightly regulated fisheries in the nation. Last year's quota was set at 5,377 tonnes (5,925 tons) (Martin 2000). Herring have swim bladders. Herring schools form into large prespawning aggregations that pulse throughout the deeper parts of San Francisco Bay, including the channel between Yerba Buena Island and Oakland. When conditions are right, the herring surge into shallow water to lay their eggs on aquatic plants such as eelgrass or kelp, but the eggs may end up on virtually all surfaces above the bottom sediments (Suer 1987). Known spawning areas include Treasure Island and eelgrass beds from Richmond to Alameda. Figure 1-9 shows the location of the December 1990-January 1991 herring spawn.

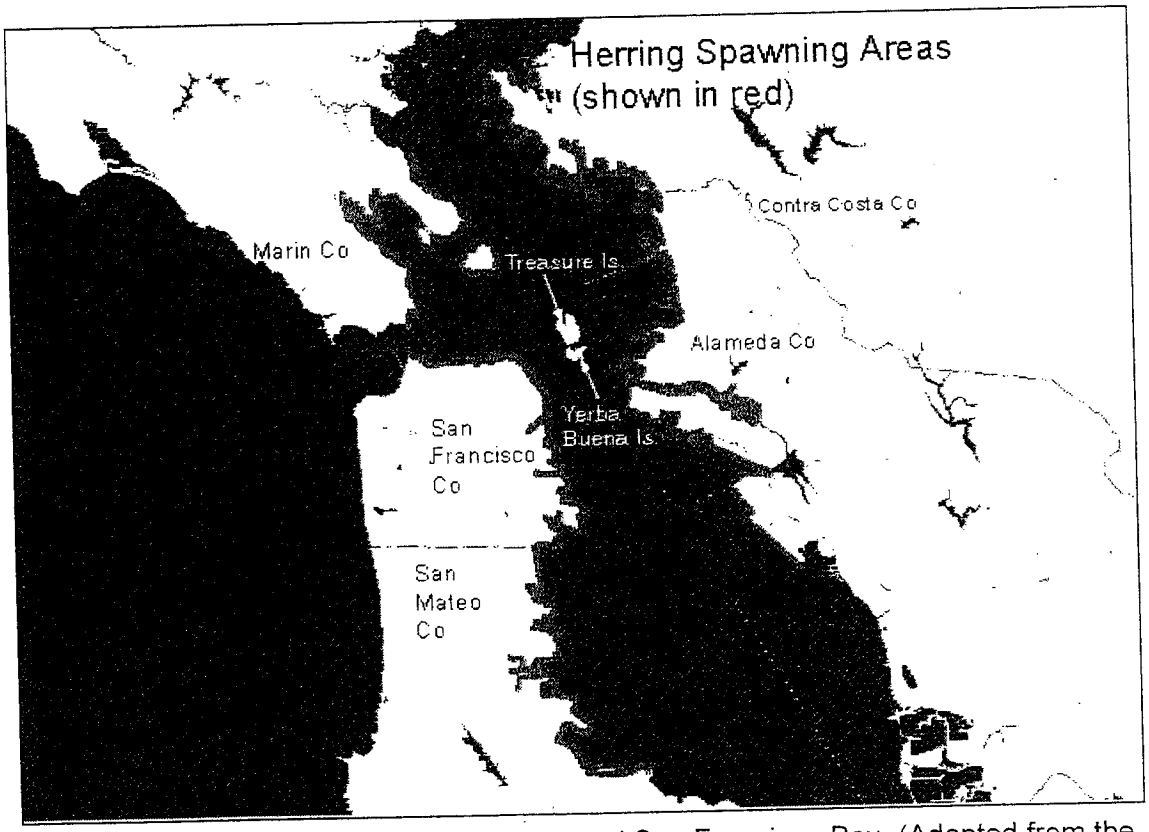


Figure 1-9. Known Spawning Areas in Central San Francisco Bay. (Adapted from the California State Lands Commission website.)

1.2.2.2 Surfperch

Fourteen species of the surfperch family (*Embiotocidae*) are regularly found in San Francisco Bay (Orsi 1999). All surfperch have swim bladders. They are characteristically found in shallow water using a variety of habitats such as rocky areas, emergent vegetation, surf, kelp forest, and structures such as pilings and piers. They all bear their young alive in shallow areas. CDFG is increasingly concerned about the population status of some species of surfperch and measures to increase their protection are under consideration (Ota personal communication 2001).

1.2.2.3 Northern Anchovy

The northern anchovy (*Engraulis mordax*) has the largest biomass and is the most abundant fish in San Francisco Bay (as cited in San Francisco Bay Area Wetlands Ecosystem Goals Project 2000). Although northern anchovy can be found in the Bay throughout the year, their seasonal peak is generally April to October. Females can produce up to 130,000 eggs per year in batches of about 6,000. They spawn oval, pelagic eggs in channels, while larvae seek out shallow water (San Francisco Bay Area Wetlands Ecosystem Goals Project 2000). A commercial fishery for anchovies that are used as live bait by the recreational and charter sport fishing industry exists in San Francisco Bay (Kuljis personal communication 2001). Anchovies are sold by the "scoop" which may have as many as 400 fish per scoop (depending on the size). A single commercial sport fishing boat may take as many as 20-30 scoops for a full day sport fishing charter (Howorth 1996). All anchovies have swim bladders.

2.0 MATERIALS AND METHODS

Fish monitoring was conducted on eight of the 14 days of pile driving, including representative days when the small and large hammer were used without sound attenuation, with the air bubble curtain, and with the fabric barrier system. The following section describes the approach for monitoring and assessing the effects of the PIDP on fish in the project area.

2.1 Access to Site and Sample Stations

Access to the project study area was facilitated by a 7-meter (22-foot) 'Boston Whaler'. This support vessel was used to transport observers and equipment to the project area and the monitoring stations located some distance off the PIDP barge. The support vessel was equipped with an Interphase Echo 600 depth sounder or fathometer and had sufficient open work-space on the deck to carry nets, cages, experimental fish, ice chests, and monitoring equipment. Two people were on the support vessel at all times. A U.S. Coast Guard-licensed skipper operated the support vessel while a fisheries scientist made observations. The boat was permanently moored at the Sausalito Bay Adventures dock in Sausalito, a distance of approximately 13 kilometers (8 miles) north of the study site. Each sampling day, the crew departed from the marina in Sausalito a minimum of 2 hours before pile driving was scheduled to commence. Access to the site was usually gained in approximately 30-40 minutes. Field notes were taken throughout the day. Numerous photographs were taken of the pile driving operations, bird behavior and fish collected.

2.2 Observations of Fish Impacts

The impacts on fish were assessed by means of fathometer transect surveys, observations of bird behavior and predation on injured fish, examination of injured fish collected from the Bay and experimental studies with fish held in cages.

2.2.1 Transect Surveys

Transect surveys were conducted by observing the appearance of schools of fish on the fathometer at known distances from the pile. Transects were conducted prior to, during, and immediately following driving operations in order to assess any changes in fish distribution patterns. Counts were made of fish schools appearing on the screen of the fathometer while the boat slowly covered areas at pre-established distances from the pile. Schools appeared as dense black spotted areas in an otherwise clear gray screen between the seabed and seafloor, both of which were always clearly indicated. A note was taken of the schools' locations (bottom, mid-water or surface), and schools were designated as small, medium or large and diffuse or compact.

Transects were usually conducted in straight lines, traveling in a square formation, northwest to northeast to southeast to southwest, around the pile. Transects were conducted at distances of between 5 meters (16 feet) and 300 meters (984 feet) from the PIDP barge. Distance estimates were initially made based on a best estimate of the distance with reference to buoys placed at known distances from the pile to mark the location of underwater sound monitoring equipment. Later in the project, a Bushnell Yardage pro® compact 800 optical distance measurement device was employed to measure the distance.

2.2.2 Gull Behavior

Upon arrival at the site, a note was made of the birds present in the area, usually within 500 meters (1,640 feet) of the PIDP barge station. At intervals before, during and after pile driving operations, a note was made of the number and species of birds present in the immediate area and their activity. During pile driving, birds were observed to dive into the water preying on moribund fish. The number of dives was monitored and the number of fish removed by diving birds was counted for discreet time periods, usually 1-minute intervals, providing an estimate of the mortality rate for fish that drifted to the surface. The location of fish being taken by the sea gulls varied and was closely related to ambient tidal currents. Moribund fish were found to be carried by the current to distances of up to 500 meters (1,640 feet) from the pile before they surfaced.

2.2.3 Fish Mortalities

Attempts were made to collect fish that were killed or stunned by pile driving. Gull diving behavior was usually a clear indicator of where the fish were surfacing. Personnel on the support vessel attempted to collect moribund fish from the water using long handled dip nets while the boat was allowed to drift or else slowly circled in the area. Attempts were also made to capture any fish that may have drifted down to the bottom of the Bay. One method employed a 75-centimeter (29.5-inch) diameter ring-net shrimp trap which was cast over the side, allowed to sink to the bottom and then quickly hauled to the surface. A cast net was also employed to try to catch any fish in the water column. A third method employed a seine net (4 meters length by 1 meter depth) [13 feet by 3.3 feet] suspended from the PIDP barge and designed to capture any moribund fish floating mid-water in the tidal current. The long handled dip nets proved to be the only successful method for collecting fish, although only 13 fish were captured in this way. The low collection rate was due to the fact that the birds moved in quickly and were observed to take fish more than 0.3 meter (1 feet) below the surface. Therefore they were usually able to remove fish from the water before they became visible to the observer on the support vessel.

Once moribund fish were collected, they were immediately placed into a bucket of fresh seawater and their condition and behavior were noted. The status of the fish was noted as (a) swimming normally, (b) buoyancy impaired or swimming head down, (c) moribund, lying on the bottom of the bucket with some gill movement or (d) dead. The fish were allowed to remain in the bucket for a minimum of 15 minutes in order to assess recovery, if any. Then each fish was placed in a separate labeled plastic bag and stored on ice, in an ice-chest located on board the support vessel.

2.3 Caged Fish Experiments

Shiner perch (*Cymatogaster aggregata*) were purchased from a local bait shop and maintained in an aerated tank on board the support vessel. Approximately 60 to 80 fish were purchased on each monitoring day; however, not all fish were used for experiments. Experimental subjects were selected from the tank and examined for injuries, parasites, behavior and size. Unsuitable fish were released once the support vessel returned to dock in Sausalito. Though the fish were in generally good condition, many had frayed tail fins from being held in a cage at the bait vendor's float, and most harbored parasitic copepods around their gills.

The experimental procedure involved placing the shiner perch in small live bait holding cages (Memphas Net and Twine Collapsible wire fish bag stock No. cw 81) at predetermined distances from the pile being driven. The cages consisted of an oval shaped black plastic-coated, wire mesh, measuring approximately 45 centimeters (18 inches) in length and approximately 30 centimeters (12 inches) wide at the widest part. The cages were equipped with a spring-hinged door on the top and bottom permitting easy access to the fish. Figure 2-1 shows a cage with a model fish to illustrate the relative size of the fish and the cage. Figure 2-2 is a photograph of a shiner surfperch prior to dissection.

The following is a summary of the primary locations where fish cages were positioned (see Figure 1-4). These locations were adjusted depending on tidal currents and other conditions near the PIDP barge.

Station 1 Southwest corner of the PIDP office barge, approximately 15 meters (49 feet) northwest of the pile.

Station 2 Northwest corner of the PIDP barge, approximately 50 meters (164 feet) northwest of the pile

Station 2.5 Northeast corner of the PIDP barge, approximately 60 meters (196 feet) northeast of the pile. This station was used as a control when there was no driving to see if there were any swim bladder injuries due to handling and transportation to the project site.

Station 3 Approximately 50 meters (164 feet) to the west of the pile.

Station 4 Approximately 150 meters (492 feet) to the west of the pile.

Station 5 Near the eelgrass bed in the cove between Treasure Island and Yerba Buena Island approximately 1,100 meters (3,608 feet) west of the pile.

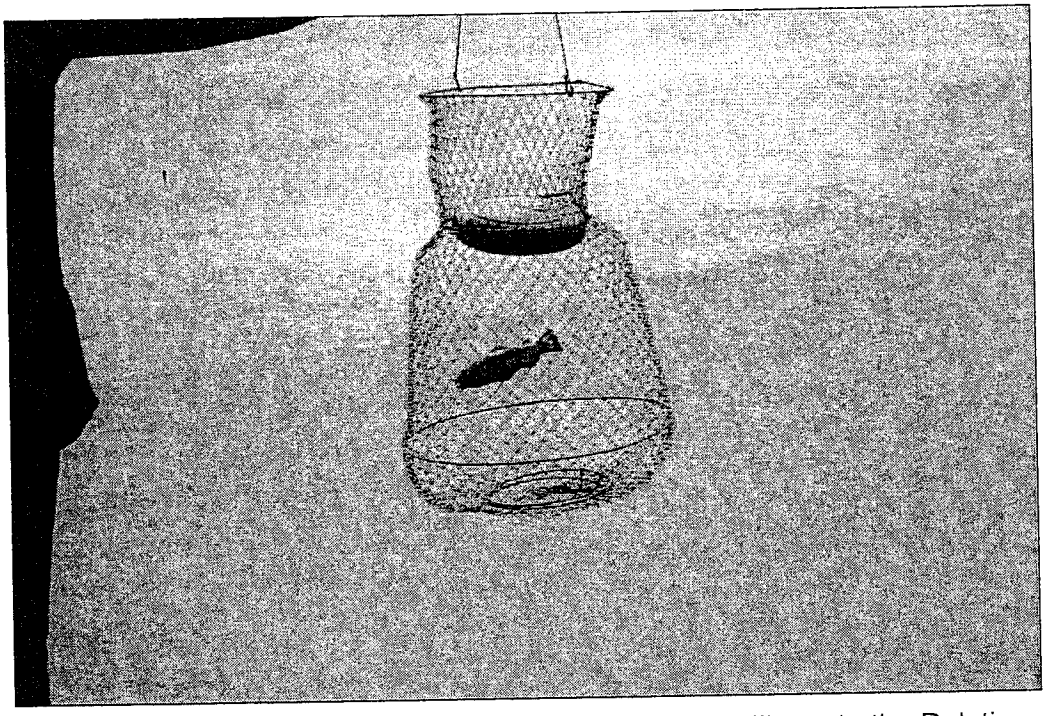


Figure 2-1. Experimental Fish Cage With Model Fish to Illustrate the Relative Size of the Fish and Cage.

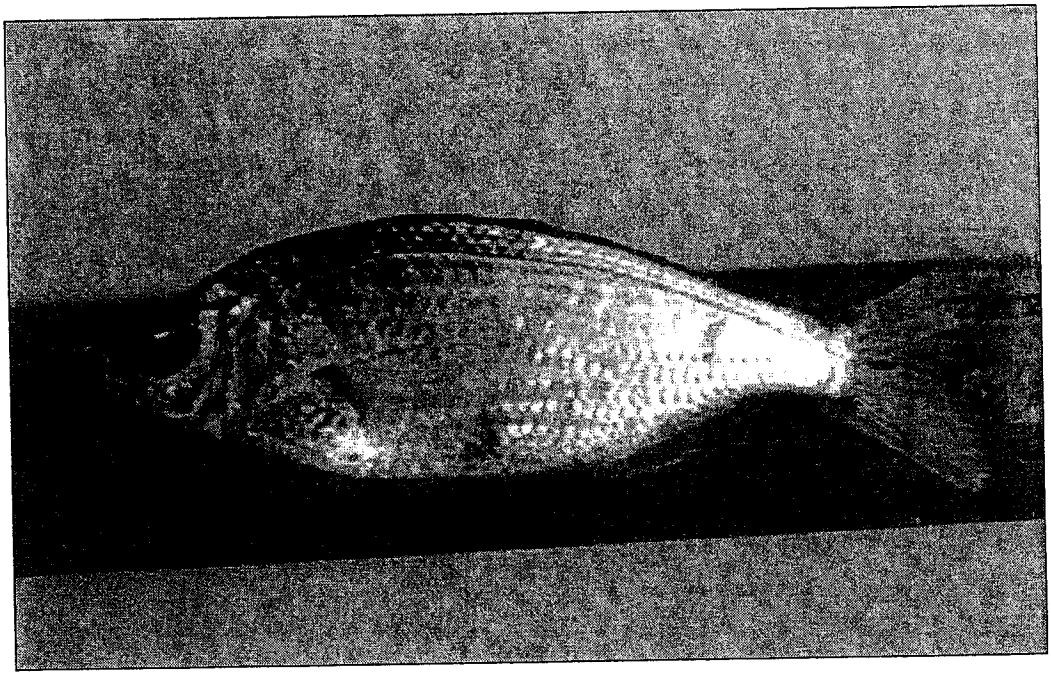


Figure 2-2. Shiner Perch Used in Experiments.

Each cage was weighted by two spherical 900-gram (2-pound) weights attached to the bottom of the cage to help hold the cage approximately vertical in the water column in the strong tidal currents. A 1-centimeter (0.4-inch) diameter nylon rope tied to the top of the cage was used to suspend it from a floating buoy or cleat on the PIDP barge.

The cages were suspended at various depths but were never more than 10 meters (33 feet) from the surface. The project area was generally less than 10 meters (33 feet) deep. The cage was submerged into the baitfish holding tank and a maximum of five fish were then placed in the cage. The cage was then quickly lifted overboard and lowered to depth. The cage was attached by its rope to either a floating buoy in the case of stations 3 and 4, or to a mooring cleat on the PIDP barge for stations 1, 2 and 2.5.

A note was taken of the time the fish were placed in the water. After a measured period of time during which the fish were exposed to pile driving sound pressure, the cages were pulled up and the fish removed. Care was taken to haul the cages slowly to the surface so as not to inflict any additional damage to the fish. Once on the surface the fish were removed and placed into a bucket of fresh Bay water located on board the support vessel or on the PIDP barge for the last few trials. The time that the fish were removed from the water was noted. The status of the fish was assessed according to the same scale noted previously for the fish collected from the Bay. The fish were allowed to remain in the bucket for a minimum of 15 minutes in order to assess recovery, if any. Finally, each fish was placed in a separate labeled plastic bag and stored on ice until later examination in the laboratory.

2.4 Environmental Parameters

Temperature, salinity and Secchi depth readings (a measure of water visibility) were taken on each sample day. A note was also made of the ambient weather conditions, including tidal status.

2.5 Laboratory Procedures

All fish samples were returned to the laboratory for analysis within 24 hours. In each case, the fish were removed from the plastic bag, measured for length and examined for external signs of damage. Notes were taken of any damage to the external body surface of the fish, including the mouth, eyes, vent, fins and gills. A representative number of fish were also photographed. The fish were then dissected by means of a longitudinal slit along the ventral surface from the vent to the gills. The body cavity and its contents were then examined and damage assessed according to the following numerical scale as used by Hubbs *et. al.* (1960), and Gaspine *et. al.* (1976):

(0) No damage.
(1) Only light hemorrhaging, principally in the tissues covering the kidney.
(2) Gas bladder intact, but with light hemorrhaging throughout the body cavity, with some damage to the kidney.
(3) No external indication of damage but the gas bladder usually burst. Hemorrhaging and organ disruption less extreme than in (4) or (5), but with gross damage to the kidney.

(4) Incomplete break-though the body wall, but with bleeding around the anus. The gas bladder almost always broken and the other organs damaged as noted under (5).

(5) Rupture of the body cavity. The break is usually a slit just to the side of the mid-ventral line. Associated with this severe damage is a burst gas bladder and gross damage to the other internal organs. The abdominal contents are often completely lost or homogenized.

3.0 FACTORS INFLUENCING PILE DRIVING IMPACTS ON FISH

To understand the impact of the PIDP on fish in the project area, it is necessary to understand some of the main characteristics of underwater sound and how fish detect and respond to underwater sounds and shock waves. This explanation is followed by a discussion of the nature and degrees of impacts of pile driving on fish.

3.1 Characteristics of Underwater Sound

The aquatic environment is a rich matrix of acoustic and hydrodynamic activity (Urick 1986). Accordingly, fish have evolved with a remarkable set of hydrodynamic-acoustic detection mechanisms that allow them to discern disturbances and patterns of underwater sound that facilitate survival. The following section briefly describes some of the characteristics of underwater sound and the physiological and morphological mechanisms that enable fish to detect and respond to it. There are several attributes of underwater sound that determine the degree of its impact on fish including; frequency, sound pressure level, acoustic impulse, near-field effect, cavitation, distance from the source, and sound scattering.

3.1.1 Frequency

Frequency, which is measured in cycles per second (cps) or Hertz (Hz), describes the pitch (high or low) of a sound. Fish generally detect only relatively low frequency sounds <400 Hz (Popper 1997). Optimum sound detection for salmon and steelhead is below 200 Hz (Abbott 1973, Popper 1997). Humans and marine mammals hear sounds as high as 20,000 Hz (Fiest et. al. 1992, Popper and Carlson 1998). Most pile driving acoustic energy is relatively low frequency (<2000 Hz). Analysis of frequency spectra for each pile condition indicates that most noise energy from the PIDP was in the range of 80 to 1250 Hz (Illingworth & Rodkin 2001). The relationship between sound frequency and injury to fish was not studied as part of the PIDP.

3.1.2 Sound Pressure Level

The conventional way to quantify underwater sound is in terms of the pressure, as in pounds per square inch (psi), atmospheres (atm) or Pascals (Pa). The relative loudness of the sound is conventionally defined in terms of a reference pressure such as one micro-Pascal (μPa) and expressed using the decibel (dB) scale. The decibel scale, which is logarithmic, is used because the pressures of interest range over many orders of magnitude, from just barely detectable to the threshold of pain and injury. Sound pressure is what is detected by hydrophones and underwater pressure transducers and converted into voltages. The voltages are then converted to sound pressure levels (SPL) in decibels by reference to a transducer calibration curve. Underwater SPLs are presented in terms of "dB re 1 μPa".

3.1.3 Acoustic Impulse

Experimental studies with explosives indicate the acoustic impulse (*I*) or time integral of the pressure is a better method to predict tissue damage than the SPL (Yelverton et. al. 1973). The acoustic impulse for explosives is reported in pressure-millisecond units such as psi-msec. The acoustic impulse reflects the shape of the sound pulse (e.g.,

slow rise and fall or sharp rise and fall). Large fish are able to withstand a much larger impulse than small fish. Table 3-1 illustrates the acoustic impulse associated with a 50-percent mortality (LD50) response to underwater blasts for different size fish. Although the characteristics of underwater sound generated by pile driving and explosives are not the same, acoustical information related to explosives is presented because of the relative similarity of a pile driving shock wave and explosives and the lack of literature on pile driving acoustic properties and impacts. The data expressed in psi-msec in the table was extrapolated from published response curves for illustrative purposes only, showing that larger fish are much less susceptible to underwater sounds than small fish.

Table 3-1. The 50-Percent Mortality Response to Underwater Blasts Based on Impulse

Size of Fish by Weight (grams)	Impulse	
	psi-msec[1]	dB-msec[2]
0.1	2	203
1.0	5	211
10	15	220
100	25	225
500	40	229
1000	50	231

Sources: [1] Adapted from Yelverton et. al. 1975.
[2] Caltrans Office of Environmental Engineering (Jones personal communication 2001).

Explosives have a very brief almost instantaneous rise time and high positive peak lasting 5-10 milliseconds (Helweg 1998). The acoustic signature of a pile driving strike is much longer by comparison, lasting 300 to 500 milliseconds (Illingworth & Rodkin 2001).

Recently the NMFS has used the root-mean-square (RMS) pressure during the pulse as the criteria for reaction thresholds for marine mammals (Illingworth & Rodkin 2001). This value is the square root of the energy divided by the duration, which represents the average pulse pressure. It is presented in this report as the RMS impulse and is expressed in dB re 1 μPa. Table 3-1 shows the RMS impulse that corresponds to a 50-percent mortality response for different size fish, based the impulse data reported in psi-msec (see Section 6.0 for the conversion factor).

3.1.4 Near-Field Effect

The extent of the near-field effect, or molecular displacement, is directly correlated with the frequency of the sound. Low frequency sounds have larger near-field effects than high frequency sounds. The component of underwater sound detected at very low frequencies (<20 Hz) is particle acceleration. The motion of a fish through the water will result in a near-field effect as water is pushed aside. Fish use near-field vibrations for detecting objects in the water such as a predator moving towards them or other fish in their school. The spectral analysis of the PIDP shows sound pressure levels at 150 dB RMS re 1 μPa at 50 Hz (Illingworth & Rodkin 2001). This suggests a strong near-field effect extending at least one meter outward from the pile.-

3.1.5 Cavitation

Cavitation occurs as a pressure wave is followed by a rarefaction wave that tears the water into tiny bubbles (Christian 1973). Cavitation will only occur near the epicenter of the acoustic source such as on the water surface just above a depth charge or underwater explosive. Cavitation results in instantaneous production of small air bubbles in the water and presumably in fish tissue. The shear and strains on tissues can be expected to be fatal to fish whether or not they have a swim bladder (Craig and Hearn 1998). The water near the pile tended to appear whitish at times, suggesting the presence of many tiny air bubbles and that cavitation was occurring around the pile-driving site even with the use of the small hammer.

3.1.6 Sound Pressure Levels and Distance

The sound pressure level of a spherically spreading underwater sound wave, such as would emanate from a large hollow pipe pile being driven by a hammer, drops off or attenuates over distance. However, many factors increase the rate of attenuation, such as the presence of air bubbles which scatter sound. Also, high frequency sounds attenuate much faster than low frequency sounds (Meyers and Holm 1969).

Because the sound pressure drops off with distance there has been considerable work by the US Navy to define the "safe zone" or safe distance for people, marine mammals and fish (Yelverton 1973, Young 1991). Safe zones have been defined for a certain size organism relative to the impulse from a given size explosive. No comparable safe zones have been defined relative to the impulse from a given size pile driving hammer.

3.1.7 Sound Scattering and Attenuation

The rate of sound propagation is directly related to the density and compressibility of the material through which the sound is traveling. Water is almost incompressible. A small volume of air in the water column increases the compressibility of water by several orders of magnitude above bubble free water, reducing the rate of underwater sound propagation and absorbing the sound energy (Keevin 1997). Underwater sound attenuates or decreases depending on many environmental factors such as the temperature, salinity and hydrostatic pressure. Air bubbles in the water column also tend to scatter or reflect the sound wave in all directions reducing the amount of energy propagated outward. Scattering can also occur due to the irregular surface of the water from wave action.

Bubble curtains have been used to protect underwater structures from damage caused by demolition blasting. They have also been shown to be successful in protecting fish and marine mammals (Keevin 1997, Würsig et al. 2000, Salomi personal communication 2000, Wright personal communication 2000).

3.2 The Acoustico-Lateralis System of Fish

Fish detect underwater sound through the acoustico-lateralis system which includes the swim bladder, lateral line organ and the inner ear (Popper and Carlson 1998). The swim bladder is an air-filled sack that is generally located near the center of gravity between the dorsal kidney and the liver and other internal organs below. Most pelagic fish such

as herring, salmon, anchovies, striped bass, surfperch and sardines have swim bladders. Many bottom fish such as brown rockfish also have swim bladders but some such as flatfish, bat rays and sharks do not have swim bladders. Fish without swim bladders are generally much less susceptible to injury from explosives than fish with swim bladders (Gaspin 1975, Goertner et al. 1994). Increased pressure compresses the swim bladder and decreasing pressure results in its expansion. All fish used in the experiments and collected floating on the surface near the PIDP had swim bladders. It is not known if fish without swim bladders suffer the same degree of damage to their lateral line organs as fish with swim bladders for the same sound pressure level.

All fish, with or without swim bladders, have lateral line organs. The lateral line organ runs the length of the body of the fish. It consists of fluid filled canals with microscopic sensory hairs that respond to vibrations in the water. The inner ear is comprised of three symmetrically paired sets of chambers containing small bony otoliths. The chambers are lined with fine sensory hairs. Hearing in fish is affected by the differential displacement of the bony otoliths against the sensory hairs and the vibration of the sensory hairs along the lateral line organ. The proper functioning of the inner ear and lateral line organ are essential for avoiding predators, feeding and maintaining position in a school.

3.3 Previous Studies on the Impacts of Acoustics on Fish

Studies have been performed in both laboratory and field settings to assess acoustic impacts on fish. In a laboratory study, it was found that goldfish experience temporary hearing loss when exposed to a continuous 140 dB re 1μPa sound level for four hours. The sensory hairs of oscars (*Astronotus ocellatus*) were damaged by continuous sound pressure levels of 180 dB re 1 μPa for one hour (Hastings et. al. 1996). This kind of damage may not be immediately lethal, but it results in the fish not being able to swim normally, detect predators, stay oriented relative to other fish in the school, feed or breed successfully.

Sound spectral measurements at a fish farm in Korea indicated the loudest underwater sounds were in the 2,000 to 3,000 Hz frequency range and that the underwater noise, airborne noise and ground vibrations levels at 90 meters (295 feet) from the pile driving operation were 36 dB re 1 μPa, 23 dB re 0.0002 μbar and 5.9 μmeters above pre-operation or ambient levels (Shin 1995). Fish increased their swimming speed and buried themselves in the pond bottom mud.

Underwater acoustic measurements from the demolition pounding of a "hoe ram" on Baldwin Bridge piers, Connecticut, were recorded by Dolat, 1997. The ram struck the pier approximately four times per second creating loud pulsed sine waves with each blow. The underwater sound pulse had a duration of 20 milliseconds. The frequency of the peak energy was near 500 Hz with a secondary peak between 1,500 and 2,000 Hz. Peak sound pressure levels were estimated for 30 meters (98 feet) from source of the sound. The maximum instantaneous sound pressure level was equivalent to the peak sine wave of 190 dB re 1μPa. Each strike was equivalent in energy to a 20 millisecond sine wave with an SPL of 180 dB re 1μPa. Four strikes per second was equivalent to a continuous 170 dB re 1μPa. Based on these estimates of the peak SPL, the report concluded that fish less than 30 meters (98 feet) away could experience permanent auditory system damage, temporary and possibly permanent loss of equilibrium or

complete incapacitation. The report included a brief discussion of previously unreported studies that show that beyond a brief startle response associated with the first few acoustic exposures, fish do not move away from areas of very loud noises and can be expected to remain in the area unless they are carried away by the river currents.

Pile driving operations have been reported to disrupt juvenile salmon behavior in Puget Sound, Washington (Feist et. al. 1992). Though no underwater sound measurements are available from that study, comparisons between juvenile salmon schooling behavior in areas subjected to pile driving/construction and other areas where there was no pile driving/construction indicate that there were fewer schools of fish in the pile driving areas than in the non-pile driving areas. The results are not conclusive but there is a suggestion that pile driving operations may result in a disruption in the normal migratory behavior of the salmon in that study, though the mechanisms salmon may use for avoiding the area are not understood at this time.

3.4 Mortality and Injury Criteria

The effects of underwater sounds created by pile driving on fish may range from a brief acoustic annoyance to instantaneous lethal injury depending on many factors including:

- Size and force of the hammer
- Distance from the pile
- Depth of the water around the pile
- Depth of the fish in the water column
- Amount of air in the water
- The texture of the surface of the water (amount of waves on the water surface)
- The bottom substrate composition and texture
- Size of the fish
- Species of fish
- Physical condition of the fish

3.4.1 Mortality

The main cause of mortality for examined fish was the rapid expansion and contraction of the swim bladder. The criterion for mortality is the cessation of all gill movements. Shock waves result in injuries to the swim bladder, kidney and liver at a macroscopic level (Yelverton et. al.1975). A fish floating on the surface or sinking to the bottom may be easily categorized as a mortality. However, experiments with explosives indicate that many fish with injuries do not die immediately. Studies on fish exposed to detonation shock waves indicate that 90 percent die within four hours (Yelverton et. al. 1975). However, there is some indication that fish may die up to five days after an exposure to a shock wave. The delayed mortality study was not conducted with predators in the immediate environment. Few injured fish live more than a few hours in a natural setting with a balanced community of predators.

3.4.2 Injury

Any macroscopically discernable injury or change in behavior is likely to result in excessive predatory pressure and near term mortality even though many fish might be

able to recover in a protected environment. No standard criterion for fish injury or harassment exists at this time (Keeven personal communication). The FESA criteria for harm pertain to all listed species including fish. The rupture of the swim bladder, the loss of function of the lateral line organ and inner ear are equivalent to the loss of a body organ and would constitute a "take" under the FESA.

3.4.3 Acoustic Discomfort

The criteria for "acoustic discomfort" is not defined for fish in the literature, but for purposes of this study may be defined as the level of acoustic energy that elicits a startle response. The startle response is a quick burst of swimming that may be involved in avoidance of predators (Popper 1997). It is associated with the Mauthener cell in the base of the brain. A fish that exhibits a startle response is not in any way injured, but it is exhibiting behavior that suggests it perceives acoustic stimuli indicating potential danger in its immediate environment. Fish do not exhibit a startle response every time they experience a strong hydro-acoustic stimulus. The startle response extinguishes after a few repeated exposures. A startle response for fish was not monitored in the field.

3.4.4 Sinking vs. Floating

Most pelagic fish such as anchovy, sardine and herring sink when they die even though some may flounder on the surface for a few minutes (Kuljis personal communication 2001). Observations of fish mortalities after underwater explosions indicate a good deal of variability in floating versus sinking between species of fish injured, the type of explosive, and circumstances of the explosion; however, a general conclusion is that approximately 50 percent of the fish sink to the bottom immediately (Fitch and Young 1948, Gitschlag 1994). Fish closest to the explosion tend to have the air from the swim bladder forced out of their body and sink (Hempen personal communication 2001). The same factors probably apply to pile driving.

4.0 RESULTS OF PILE INSTALLATION DEMONSTRATION PROJECT MONITORING

4.1 Oceanographic Conditions

A decline in water temperature was recorded during the five-week duration of this study from a maximum of 14.3° Celsius (C) [57.7° Fahrenheit (F)] in early November to a minimum of 11.7°C (53.1°F) on the last sample date (December 11). Salinity was relatively consistent at 30 °/oo to 31 °/oo, while Secchi depth varied slightly with a maximum visibility of just 1.4 meters (4.6 feet) recorded. Winds were generally from a northwest direction and usually between 9.3 and 18.5 kilometers/hour (5 and 10 knots), although wind speeds of up to 46.2 kilometers/hour (25 knots) occurred occasionally. Full moons occurred on November 11 and December 10-11 and there were very strong tidal currents in the area making it difficult to set and retrieve the experimental cages. Table 4-1 summarizes conditions that occurred during the survey period.

Table 4-1. Summary of Environmental Parameters Collected During Survey Period

Date	Temp. °C (°F)	Salinity (°/oo)	Secchi Depth centimeters (inches)
11/03	14.3 (57.7)	30	137 (54)
11/04	14.4 (57.9)	30	114 (45)
11/09	13.2 (55.8)	30	91 (36)
11/11	13.2 (55.8)	30	122 (48)
11/12	13.0 (55.4)	N/A	122 (48)
11/19	N/A	31	91 (36)
11/20	N/A	31	91 (36)
12/03	12.5 (54.5)	30	137 (54)
12/11	11.7 (53.1)	30	91 (36)

N/A = Not available

4.2 Presence and Behavior of Fish Populations in Study Area

Transect surveys of the fish populations in the project area were conducted with a fathometer on three occasions, including two surveys conducted while pile driving was in progress (November 3, 2000 and November 12, 2000). See Table 4-2 for details. On November 4, 2000, transect surveys around the PIDP barge prior to driving operations indicated the presence of numerous fish and fish schools from a distance of 300 meters (984 feet) out from the pile to within 5 meters (16 feet) of the barge. The species of fish observed was not determined but it is likely that most fish observed were northern anchovy (*Engraulis mordax*), Pacific herring (*Clupea harengus*), Pacific sardine (*Sardinops sagax caeruleus*) and various species of surfperch. These species are commonly found in this area at this time of year (Orsi 1999). The presence of large numbers of fish in the area close to the PIDP barge suggests that the structure may attract some species of fish, such as surfperch that are naturally found close to harbor jetties and pier pilings. Objects floating in the water tend to aggregate fish very quickly. For example, a fairly large community of perch could be expected to be in the barge area within 24 hours. During driving operations on November 12, an abundance of fish was observed in the area within 300 meters (984 feet) of the PIDP barge and as close

as 50 meters (16 feet) from the pile during pile driving. Observations indicate fish in the area before pile driving stayed in the area after pile driving started. There was no indication of fish moving out of the area during pile driving operations. No transect surveys were made for Pile 3.

Table 4-2. Fathometer Indication of Fish Schools in the Project Area

Date	Time	Pile Section	Monitoring Condition	Distance meters (feet)	Number of Fish Schools and Size *
11/03/00	10:25 am	2A	Before Pile Driving	60 (197)	1c
	10:45 am		During Pile Driving	80 (262)	1b
11/04/00	12:40 pm	1C	Before Pile Driving	300 (984)	3a, 3c
	12:55 pm		Before Pile Driving	150 (492)	3a, 3b, 1c
	1:02 pm		Before Pile Driving	50 (164)	3a, 2m, 2c
	1:06 pm		Before Pile Driving	5 (16)	2a, 2c
11/12/00	10:55 am	2B	During Pile Driving	50 (164)	2c, 2a, 1b
	11:00 am		During Pile Driving	150 (492)	1d, 2a
	11:03 am		During Pile Driving	300 (984)	Numerous-d
	11:40 am		After Pile Driving	50 (164)	5d

* a = small, b = medium, c = large school, d = size not determined

4.3 Bird Behavior as Indicative of Impact on Resident Fish

The principal bird species recorded in the area were gulls, the California gull (*Larus californicus)* and Herring gull (*Larus argentatus*). A number of Brandt's cormorants (*Phalacrocorax penicillatus*) were also observed, although this species was usually present at a considerable distance from the PIDP area and they were never observed taking fish from the water. A few brown pelicans (*Pelecanus occidentalis*) were also noted in the area, but only one was observed to dive for floating fish and only at a considerable distance [>300 meters (>984 feet)] away from pile driving operations.

In general, few gulls were recorded in the area prior to pile-driving operations. Usually, there were only 3-6 gulls to be seen in the area with no more than 20 gulls either overhead, on the water or sitting on the piers of the SFOBB. However, as soon as pile driving commenced, the gulls quickly gathered in the project area, with many birds landing on the water a distance of up to 500 meters (1,640 feet) from the pile, and flocks of birds in the air immediately surrounding the PIDP barge. On November 4, 2000, between 100 and 150 birds were observed flying, diving and sitting on the water, although many of them were observed to not be actively feeding. Similar observations were made on other occasions. Subsequently, observations on bird activity were limited to counting only the birds that appeared to be actively foraging as indicated by diving, flying in tight circles and plunging their heads into the water. Birds sitting on the water were not observed to be feeding on fish.

Diving for moribund fish was observed in the area immediately around the pile within a few minutes after the first blow of the hammer (See Figure 4-1). Gulls were seen to take fish from the water in the area immediately around the pile for a short time after the

beginning of driving and then spread out. Thereafter, depending on tidal current strength and direction, the gulls were observed to gradually move away from the PIDP barge and concentrate on removing moribund fish surfacing up to 500 meters (1,640 feet) from the pile.

Figure 4-1. Gulls Preying on Fish Near the PIDP Site.

Gull foraging activity was examined in detail on five different dates. For every fish actually removed, there were many dives by birds that appeared to be unsuccessful. Only dives where fish were seen to be removed from the water were recorded. However, it was difficult to observe very small fish in the gulls' mouths. Therefore, the rate of predation noted below is likely to be underestimated. The results of these observations are summarized in Table 4-3. Data on bird predation rates were collected in one-minute intervals when other types of monitoring activity were not being conducted. The number of one minute counts (n) over a period of time is noted along with the average number of birds foraging and the average number of fish taken for each set of counts conducted. Observations were made at various times during pile driving sessions; therefore, the time period during which counts were conducted does not necessarily correspond to the entire pile-driving period.

The predation rate data for November 12 and 19, 2000 suggest the air bubble curtain is effective in reducing fish mortalities during pile driving using the small hammer. The data for November 20, 2000 during pile driving using the large hammer are not consistent with data for November 12 and 19, 2000 during pile driving with the small hammer, however other factors discussed below may have affected the gull activity in the area. The fabric barrier system when used in conjunction with aerating mechanism seemed to be effective in reducing fish mortalities during pile driving with either the small and large hammer. During driving of Pile 3B with the small hammer and during driving

of Pile 3D with the large hammer, when the aerating mechanism was on, gulls were present in the area but none were observed diving for fish. When the aerating mechanism was turned off during driving of Pile 3D with the large hammer, however, birds were observed diving and removing fish from the water.

Irregularities in sample size, data sequences, time of data collection, and the non-normal distribution of gulls over time and space and non-normal distribution of fish over time and space preclude a rigid interpretation of this gull predation data. Tides, seasonal cycles, and time of day all affect distribution of birds and fish. There could be times when the gulls moved out of the area to follow a fishing boat or a boiling bait school. There could also be many gulls in the general area but relatively few fish in the area to be stunned and float up. At other times, most injured fish may have sunk to the Bay bottom instead of floated to the surface. The data is presented acknowledging that use of fish mortality counts due to bird predation is probably very limited as a monitoring tool unless it is done with many more cycles of air on/air off in the same time frame.

Table 4-3. Fish Predation Rate by Gulls During Pile Driving With and Without Sound Attenuation

Date	Pile Number and Hammer Size	Air On/Off	Time Period of Gull Observations	Number of 1-Minute Counts (n)	Mean Number of Birds Foraging	Mean Number of Fish Removed per Minute
11/12/00	2B small	Off	10:37-11:06 am	13	20	1
	2B small	On	11:26-11:30 am	3	6	0
11/19/00	2D small	On	9:40-9:46 am	7	12	0.1
	2D small	Off	10:35-10:51 am	17	30	3
11/20/00	2D large	On	9:22-10:27 am	54	12	1
	2D large	Off	11:10-11:27 am	14	3	0.3
12/03/00	3B small	On	11:25-11:45 am	2	25*	0
	3B small	Off	12:20-12:45 pm	3	10*	0
	3B small	On	1:20-1:21 pm	1	10*	0
12/11/00	3D large	On	12:20-1:10 pm	8	3*	0
	3D large	Off	2:11-2:16 pm	4	18	2
	3D large	Off	2:27-2:31 pm	5	14*	0

* These birds were present in the area, but none were observed diving for fish.

The predation rate also varied considerably within each driving period where hammer size, energy and driving rate appeared consistent. An examination of the data from November 20, 2000 illustrates this more clearly. Table 4-4 below provides details of the number of fish observed being taken by the gulls per minute, continuously over a 30-minute period. On this occasion, the large hammer was used and the air bubble curtain was in operation throughout.

Table 4-4. Fish Predation by Birds on November 20, 2000 With Air Bubble Curtain in Operation

Time	Number of Birds	Number of Fish Taken	Time	Number of Birds	Number of Fish Taken
9:22 am	0	0	9:39	8	0
9:23	0	0	9:40	11	0
9:24	4	0	9:41	12	2
9:25	6	0	9:42	15	1
9:26	13	0	9:43	10	0
9:27	10	0	9:44	6	0
9:28	15	1	9:45	7	0
9:29	20	0	9:46	6	0
9:30	20	0	9:47	15	7
9:31	20	1	9:48	30	6
9:32	15	1	9:49	30	2
9:33	10	0	9:50	35	5
9:34	10	1	9:51	20	1
9:35	10	0	9:52	20	0
9:36	15	1	9:53	12	0
9:37	10	2	9:54	10	1
9:38	10	0			

While the overall average number of fish taken per minute for the entire time period was 0.97, the actual predation rate varied from zero on many occasions to a maximum of 7 fish per minute at 9:47 a.m. Data indicate that a total of 21 moribund/dead fish appeared at the surface during a 5 minute time period, from 9:47 to 9:51 a.m. This was accompanied by an increase in the number of gulls in the immediate area. The cause of this sudden increase in fish mortality is unclear, but it may be due to a school of fish moving into the area immediately around the pile due to tidal currents, foraging or predator avoidance.

4.4 Collection and Examination of Floating Fish

A total of 13 fish were removed with dip nets from the area around the pile and PIDP barges. These fish were later identified as six anchovy, three herring, one sardine, one pile perch, one white surfperch and one shiner surfperch (Table 4-5). Other species of fish may have been injured during pile driving, however only a limited number of fish were collected using dip nets. Most fish were retrieved within 50 meters (160 feet) from the pile, with the exception of the sardine which was found floating in the water about 180 meters (591 feet) north of the barge on November 20, 2000. In some cases, the fish were still alive on capture but their ability to maintain an upright orientation in the water was severely impaired, and most fish were bleeding from the vent and had varying degrees of bleeding on the head and around the eyes. Two anchovies had lesions on the flank, with the internal organs exposed. Examination of the internal organs indicated that nine fish had burst gas bladders and the internal organs were severely damaged.

Table 4-5. Summary of Injuries to Moribund Fish Collected in the Project Area

Date	Pile	Hammer Size	Species	Length cm (in)	Status	External Damage	Gas Bladder	Damage Value*
11/19/00	2D	S (+A)	A	8.2 (3.2)	moribund	flank	burst	5
			A	9.2 (3.6)	moribund	flank	burst	5
			A	9.0 (3.5)	moribund	vent, head	burst	4
			A	9.2 (3.6)	moribund	vent, head	intact	4
			H	10.5 (4.1)	moribund	vent, head	intact	3
11/20/00	2D	S (+A)	H	9.4 (3.7)	moribund	vent, head, eyes	intact	3
			H	7.1 (2.8)	dead	vent, gills	burst	4
			S	-	moribund	extensive predator damage	burst	3
11/20/00	2D	S (-A)	A	9.3 (3.7)	moribund	vent, head, eyes	intact	4
			A	9.3 (3.7)	moribund	vent, head, eyes	burst	4
12/11/00	3D	L (-A)	PP	25.4 (10.0)	moribund	none	burst	3
			WS	29.2 (11.5)	moribund	none	burst	3
			SP	10.2 (4.0)	moribund	none	burst	3

Species: A=Anchovy, H=Herring, S=Sardine, PP=Pile surfperch, WS=White surfperch, SP=Shiner Surfperch
Drive Conditions: S= small hammer, L= large hammer, (+A) = with air bubble curtain, (-A) = no air bubble curtain
* See Section 2.5 for damage assessment scale.

A number of fish were photographed to illustrate the varying degrees of damage observed. See Figures 4-2 through 4-7.

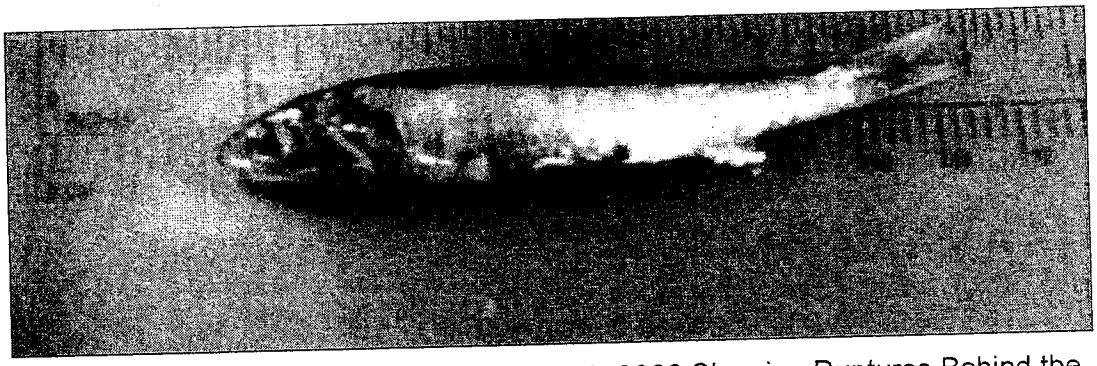


Figure 4-2. Anchovy Collected November 19, 2000 Showing Ruptures Behind the Gill Plate and at the Vent.

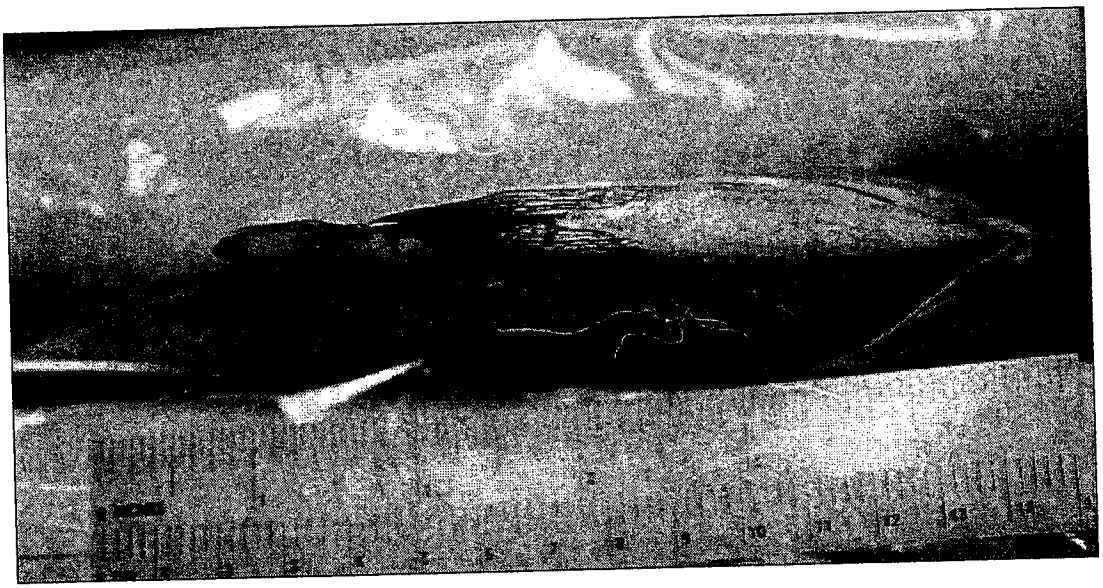


Figure 4-3. Ventral Surface of a Surfperch Showing Areas of Redness Where Blood Vessels Were Ruptured.

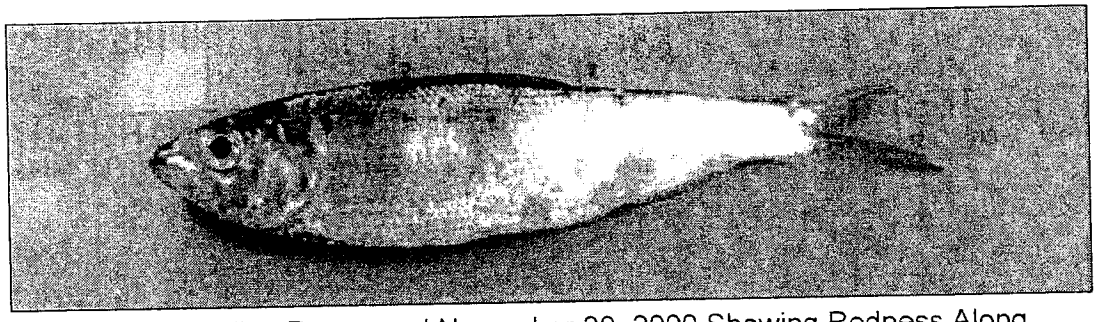


Figure 4-4. Sardine Recovered November 20, 2000 Showing Redness Along Ventral Surface

Figure 4-5 Surfperch With Broken Blood Vessels in the Eye

Figure 4-6. Ruptured Swim Bladder of a Pile Surfperch.

Figure 4-7. Ruptured Swim Bladder of a White Surfperch.

4.5 Caged Fish Experiments

The following discussion of the experimental exposure of surfperch held in cages is very preliminary. There are no examples from the literature on the use of fish held in cages to study the impact of pile driving, though there is a considerable body of literature on the use of fish held in cages to study the impact of explosives (Christian 1973, Teleki and Chamberlain 1978, Yelverton 1975, 1978, McAnuff and Booren 1997, Keevin, Hempen and Schaeffer 1997). Though pile driving is mechanically quite different from an explosion, the available information indicates that the resulting underwater acoustics of pile driving and small explosive charges are similar in many respects.

Conditions under which these fish were experimentally exposed to underwater sounds from pile driving were highly variable, making it difficult to interpret the results. Nevertheless some patterns did seem consistent with the field observations on bird predation of moribund fish and the literature on the impact of underwater explosives.

4.5.1 Controls

A series of control experiments were conducted to assess if there were injuries to the experimental fish just from the handling alone. On November 11, 2000, two groups of fish were placed in cages at Station 2, lowered 5 meters (16 feet) and then retrieved after 10 minutes without any exposure to pile driving. All the fish were found to swim normally on removal from the cages. On later dissection, 70 percent of the fish were observed to exhibit no injury to the internal organs, while 30 percent showed very slight erythma or reddening of the internal organs. This indicates that there may be a small negative impact on the fish caused solely from handling. The slight reddening of the internal organs observed may be associated with the pummeling each fish gets from its neighbor as they are crowded together and scooped up in a net by the baitfish dealer.

4.5.2 Data Summary

The results of the experiments on fish held in cages are summarized in Table 4-6. To the extent possible, the cages were all lowered to the same depth (5 meters) [16 feet] but the distance from the surface was not consistent due to the cages being pushed upwards by the strong tidal currents. The conditions under which the experimental fish were exposed to pile driving were highly variable. Hammer size and driving energy varied as well as the duration of exposure and distance from the pile. In many cases, the same fish were exposed to pile driving both with and without the use of an air bubble curtain or fabric barrier system. In many instances, the driving rhythm also varied making it difficult to assess the exact degree of exposure. The different monitoring stations used also had confounding factors. Stations 1 and 2 were located at the PIDP barge. These large metallic structures may have acted to either amplify the sound or reduce the exposure level depending on whether or not the currents were pushing the cages up under the barge or away from them. In some cases the cages may have been in an acoustic shadow due to the complex of structures underneath the barge required to stabilize them in the face of strong tidal currents.

Table 4-6. Summary of Results of the Caged Fish Experiments

Date	Pile	Hammer Size (* = with air)	Distance m (ft)	Duration (mins)	% Injured	% Seriously injured[a]
Nov 4, 2000	1C	Small	15 (49)	1	0	0
"	"	Small	15 (49)	6	80	80
Nov 9, 2000	1D	Large	15 (49)	5	100	60
"	"	Large	20 (66)	3	80	60
"	"	Large	30 (98)	7[b]	50	0
"	"	Large	50 (164)	67	70	40
"	"	Large	150 (492)	84	60	40
"	"	Large	500 (1,640)	84	10	0
Nov 11, 2000	1D	Large	15 (49)	10	70	20
"	"	Large	50 (164)	10	30	0
Nov 12, 2000	2B	Small	15 (49)	36	60	40
"	"	Small	40 (131)	46	10	0
"	"	Small*	50 (164)	10	22	0
"	"	Small	50 (164)	46	0	0
"	"	Small*	150 (492)	12	40	0
"	"	Small	150 (492)	36	16	0
Nov 19, 2000	2D	Small*	15 (49)	57	50	0
"	"	Small*	20 (66)	57	60	0
"	"	Small	20 (66)	32	60	0
"	"	Small*	30 (98)	57	80	0
"	"	Small*	50 (164)	57	80	20
"	"	Small*	150 (492)	34	0	0
"	"	Small + Large[c]	15 (49)	29	100	50
"	"	Small + Large[c]	30 (98)	24	80	20
"	"	Large	15 (49)	5	75	0
"	"	Large	30 (98)	5	30	0
Dec 3, 2000	3B	Small	15 (49)	17	40	0
"	"	Small	15 (49)	23	20	0
"	"	Small	15 (49)	40	40	0
"	"	Small	15 (49)	42	40	40
"	"	Small	15 (49)	64	60	40
"	"	Small	30 (98)	17	40	0
"	"	Small	30 (98)	23	20	0
"	"	Small	30 (98)	40	40	0
"	"	Small	30 (98)	46	40	0
"	"	Small	30 (98)	64	50	25
Dec 11, 2000	3D	Large*	15 (49)	6	80	20
"	"	Large	15 (49)	53	100	100
"	"	Large	15 (49)	64	100	100
"	"	Large*	30 (98)	19	60	0
"	"	Large*	30 (98)	28	100	20
"	"	Large	30 (98)	36	100	0
"	"	Large	30 (98)	44	40	0
"	"	Large	30 (98)	64	40	0

a. Damage value 2 or greater. See Section 2.5
b. Sporadic driving period, therefore exposure likely to be less than this figure
c. Fish in cages were exposed to pile driving with the small hammer, remained in the water for a period of time and exposed to pile driving with the large hammer, which was used for only for a period of about 5 minutes on November 19, 2000.

4.5.3 Hammer Size

Overall, the effects of pile-driving to fish were greater when exposed to sound pressure by the large hammer compared to the small hammer. Comparing the results of two experiments, both at equal distance from the pile (15 meters) [49 feet] and for the same duration (5 to 6 minutes), 80 percent of the fish exposed to sound pressures by the small hammer were injured (November 4, 2000) and had serious injuries (damage value of 2 or greater), while all fish in cages exposed to the large hammer (on November 9, 2000) exhibited injuries but only 60 percent had serious injuries. When the large hammer was used with the fabric barrier in place and aerating mechanism in operation, the percentage of injured fish was 80 percent and only 20 percent of the fish showed signs of serious injuries (December 11, 2000). Comparable data for the air bubble curtain is not available.

4.5.4 Distance

Experiments conducted on November 9, 2000 and November 12, 2000, showed fish with damage to their internal organs in cages as far away as 150 meters (492 feet) from the pile with or without sound attenuation. On November 9, when the large hammer was used without sound attenuation, 60 percent of the fish at 150 meters (492 feet) were injured, and 40 percent exhibited major tissue damage. On November 12, when the small hammer was used with the air bubble curtain in operation, 40 percent of the fish exposed to pile driving at this distance were damaged, but only minor hemorrhaging was observed. In general, the greatest impacts were observed within a 30-meter (98-foot) radius of the pile, and later experiments were concentrated within this zone. On December 3 and 11, cages were deployed and retrieved at Station 1 (15 meters [49 feet] from pile) and Station 2 (30 meters [98 feet] from pile) at approximately the same time, thereby exposing the fish to almost identical pile-driving conditions. It is evident from Table 4-6 that the fish located nearest the pile suffered significantly greater damage. For example, on December 3, during pile driving using the small hammer, fish exposed to pile driving for 64 minutes at Station 1 experienced more injuries than those exposed for the same duration of time at Station 2. The data indicate that approximately 60 percent of the fish at Station 1 were injured and 40 percent had serious injuries, while 50 percent of the fish at Station 2 were injured and 25 percent had serious injuries.

4.5.5 Duration of Exposure

In the first survey conducted, it appeared that there was an increase in the degree of damage and number of fish impacted with increasing duration of exposure. On November 4, all fish exposed to driving for one minute were unaffected, while 80 percent of the fish exposed for six minutes exhibited significant tissue damage. This trend was observed in later surveys, although it was not always as distinct. In the experiment conducted on December 3, a greater proportion of fish were damaged at longer exposure times than for the shorter exposure times. Only fish exposed 40 minutes or longer were seriously injured. However, in the experiment on December 11, 100 percent of the fish exposed for 36 minutes were injured while only 40 percent of fish exposed for 64 minutes showed signs of damage. This result is confounded by the use of the large hammer in conjunction with the irregular use of the aerating mechanism for the fabric barrier system. There was no macroscopic evidence for a cumulative effect on the fish

tissues examined. Tissues from fish with ruptured gas bladders from short exposures were similar to those from fish that were exposed for longer periods of time.

4.6 Underwater Acoustic Measurements

Underwater acoustic measurements were made using a calibrated LC-10 hydrophone manufactured by Celesco Transducer Products. A Larson Davis Model 3100 real time analyzer was used to pick up the signal and stored it on a Sony Model TC-D5M Stereo Cassette Recorder. The system was field calibrated using a Bruel & Kjaer Type 4220 Pistonphone calibrator with a pistonphone adaptor. The calibration signal was 150 dB re 1uPa (Illingworth & Rodkin 2001).

Table 4-7 provides a summary of noise measurements taken during driving of the last segment of each pile. Noise levels reported were root-mean-square (RMS impulse) and Linear Peak Level (LPL).

Table 4-7. Root-Mean-Square (RMS Impulse) and Linear Peak Level (LPL) Noise Measurements

Date	Pile	Hammer Energy Level kJ	Sound Attenuation	Distance m (ft)	RMS Impulse dB re 1 µPa	LPL Sound Pressure dB re 1 µPa	Depth m (ft)
11/9/00	1-D	900-1,000	None	103 (338)	185	197	1 (3.3)
"	"	"	"	"	196	207	6 (19.7)
"	"	"	"	358 (1,175)	167	181	1 (3.3)
"	"	"	"	"	179	191	6 (19.7)
11/19/00	2-D	500	Bubble Curtain on	200 (656)	184	197	1(3.3)
"	"	"	"	"	189	201	3 (9.9)
"	"	"	"	"	181	197	6 (19.7)
11/20/00	2-D	900-1,000	Bubble Curtain on	206 (676)	187	199	1 (3.3)
"	"	"	"	"	190	201	3 (9.9)
"	"	"	"	"	188	199	6 (19.7)
12/11/00	3-D	900	Fabric Barrier – Aerating Mechanism on	95 West (312)	175	188	1 (3.3)
"	"	900	Fabric Barrier – Aerating Mechanism on	100 East (328)	172	186	1 (3.3)
"	"	1,400	Fabric Barrier – Aerating Mechanism off	100 East (328)	179	193	1 (3.3)
"	"	1,600	Fabric Barrier – Aerating Mechanism on	500 North (1,640)	160	170	1 (3.3)
"	"	1400	Fabric Barrier – Aerating Mechanism off	95 West (312)	184	197	1 (3.3)

Source: Illingworth & Rodkin, 2001.

The RMS impulse levels calculated for the PIDP study provide a conservative measure of RMS sound pressure. RMS sound pressure is the root square of the energy divided by the duration of the impulse, or average pulse pressure. The 5 percent of energy at the start of the rise of the pulse and the 5 percent at the end of the pulse are excluded from the averaging process. Since most of the energy from a pile driving strike occurred within the first 30 to 50 milliseconds, a 1/32 second time constant was used in the calculation of the RMS impulse (Illingworth & Rodkin 2001). By using a standard 1/32

second time constant instead of a varying time constant, the RMS impulse yields an accurate and conservative measure of the RMS sound level. The linear peak sound level indicates the maximum instantaneous SPL during the pile driving period.

The NMFS issued an Incidental Harassment Authorization (IHA) with a Marine Mammal Safety Zone (MMSZ) that included all areas where the RMS sound pressure level was equal to or exceeded 190 dB re 1 μPa. The estimated extent of the 190 dB MMSZ (based on RMS impulse levels), assuming no excess attenuation, for different degrees of pile driving hammer energy is summarized in Table 4-8. Numerous factors in the environment would tend to attenuate underwater sound propagation in shallow water. Attenuation may be the result of microbubbles in the water column resulting from phytoplankton growth, absorption of the sound in soft Bay mud, scattering of the sound by the surface waves, bubbles in the water from turbulence and the reflection of sound waves off objects such as the SFOBB piers, the PIDP barges and irregularities on the bottom. Estimated excess attenuation was approximately 0.02 dB per meter (Illingworth & Rodkin 2001). Therefore, the values presented in Table 4-8 are conservative, since excess attenuation may be expected to reduce the sound pressure levels at these distances.

Table 4-8. Estimated Distance to 190 dB RMS (Impulse) Level For Different Sound Attenuation Systems

Hammer Energy kJ	Estimated Distance (Meters) to the 190 dB RMS (impulse) Levels Assuming No Excess Attenuation		
	No Sound Attenuation	Bubble Curtain System	Fabric Barrier with Aerating Mechanism Operating
750	185	185	<100
1000	215	215	<100
1250	240	240	<100
1500	265	265	<100
1750	285	285	<100

Note: The bubble curtain changed the shape of the impulse and attenuated higher frequency noise, but did not change the overall sound pressure level. It is recommended that the distance to the 190 dB contour should not be assumed to be less than 185 meters regardless of hammer energy or hammer size.

Source: Illingworth & Rodkin, 2001.

The limited amount of data gathered with the bubble curtain in place indicated that there was no reduction in the overall linear sound pressure level (Illingworth & Rodkin 2001). The bubble curtain was apparently effective in attenuating the higher frequency component of the noise (above about 800 Hz), as shown in Figure 4-8 (Illingworth & Rodkin 2001). The correlation between sound frequency and injury to fish was not studied as part of the PIDP. The air bubble curtain also changed the shape of the impulse, resulting in a more gradual accumulation of energy at the start of pile driving (see Figure 4-9). As mentioned in Section 3.1.3, acoustic impulse may be a more appropriate indicator for predicting tissue damage than the SPL and has been shown to correlate with the size of fish that may be injured due to underwater shock waves (Yelverton et. al. 1973).

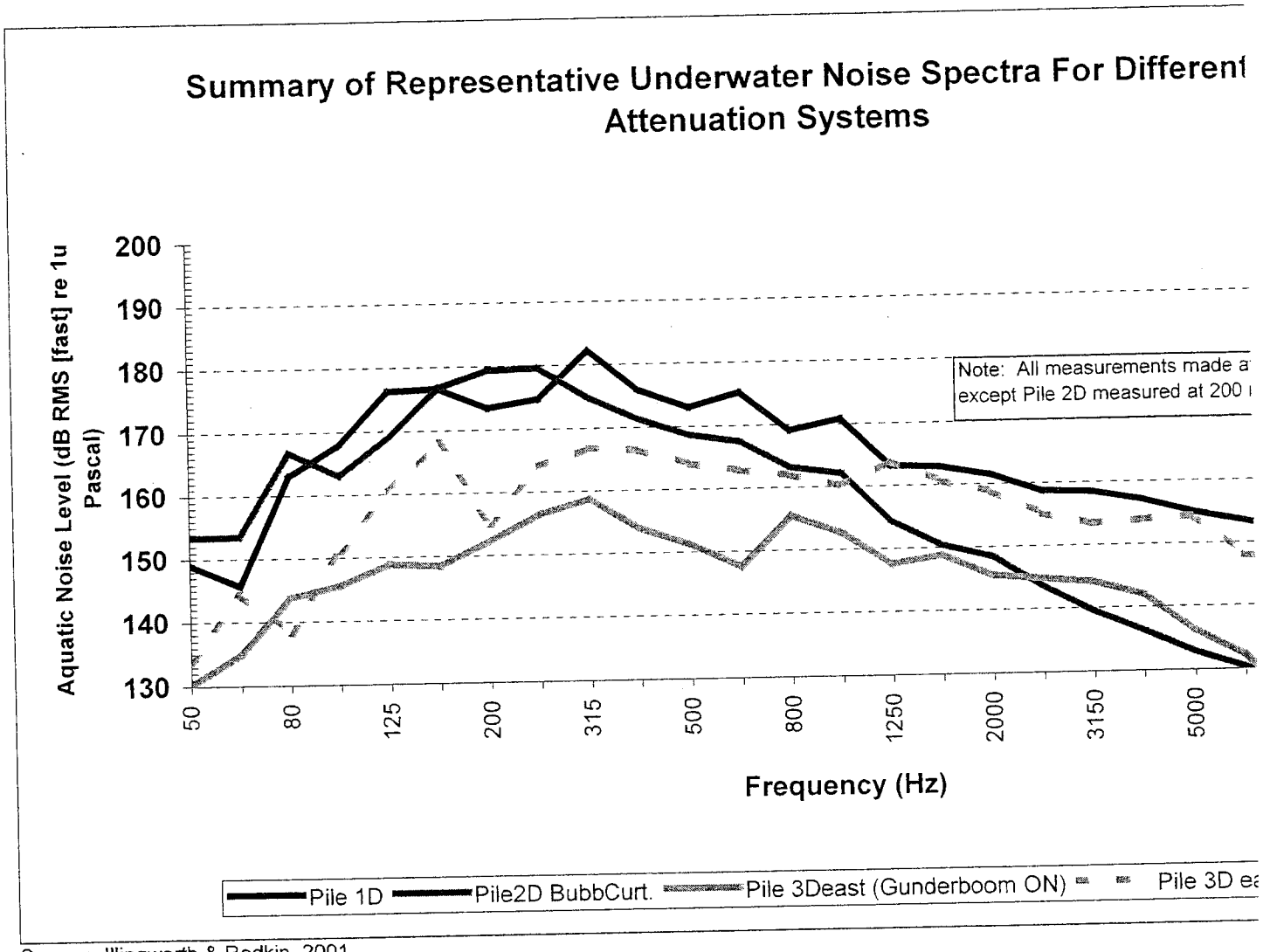
Although there was not a measurable reduction in sound pressure levels recorded when the air bubble curtain system used for the PIDP was in operation, other studies on the use of air bubble curtains have shown that they are effective in reducing underwater sound pressure levels. Bubble curtains are recommended in the Blasters Handbook by E. I. du Pont de Nemours because they reduce sound pressure levels (E.I. du Pont de Nemours 16th edition). Bubble curtains are standard recommended procedures by the Canadian Government because they reduce sound pressure levels from explosives (Wright, 1997). Three states (New Jersey, Oregon and Washington) require bubble curtains to protect natural resources from the sound pressure and shock wave from explosives (Keevin, Hempen and Schaeffer 1997). Recently bubble curtains were shown to reduce pile driving sound pressure levels 3-5 dB in a project near Hong Kong, China (Würsig, Green and Jefferson 2000).

The effectiveness of bubble curtains depends on many factors. The State of Alaska rescinded a bubble curtain requirement because so many were used improperly (Hempen personal communication 2001). Bubble curtains may be more effective where there is less current, the water is shallower and with different pile driving substrates. Bubble curtains that are operating very snugly around the pile may be more effective than a bubble curtain further away from the pile.

Previous data, research and publications indicate that the effectiveness of bubble curtains to reduce sound pressure levels due to explosives and pile driving appears to depend heavily on the configuration of the system and actual field conditions.

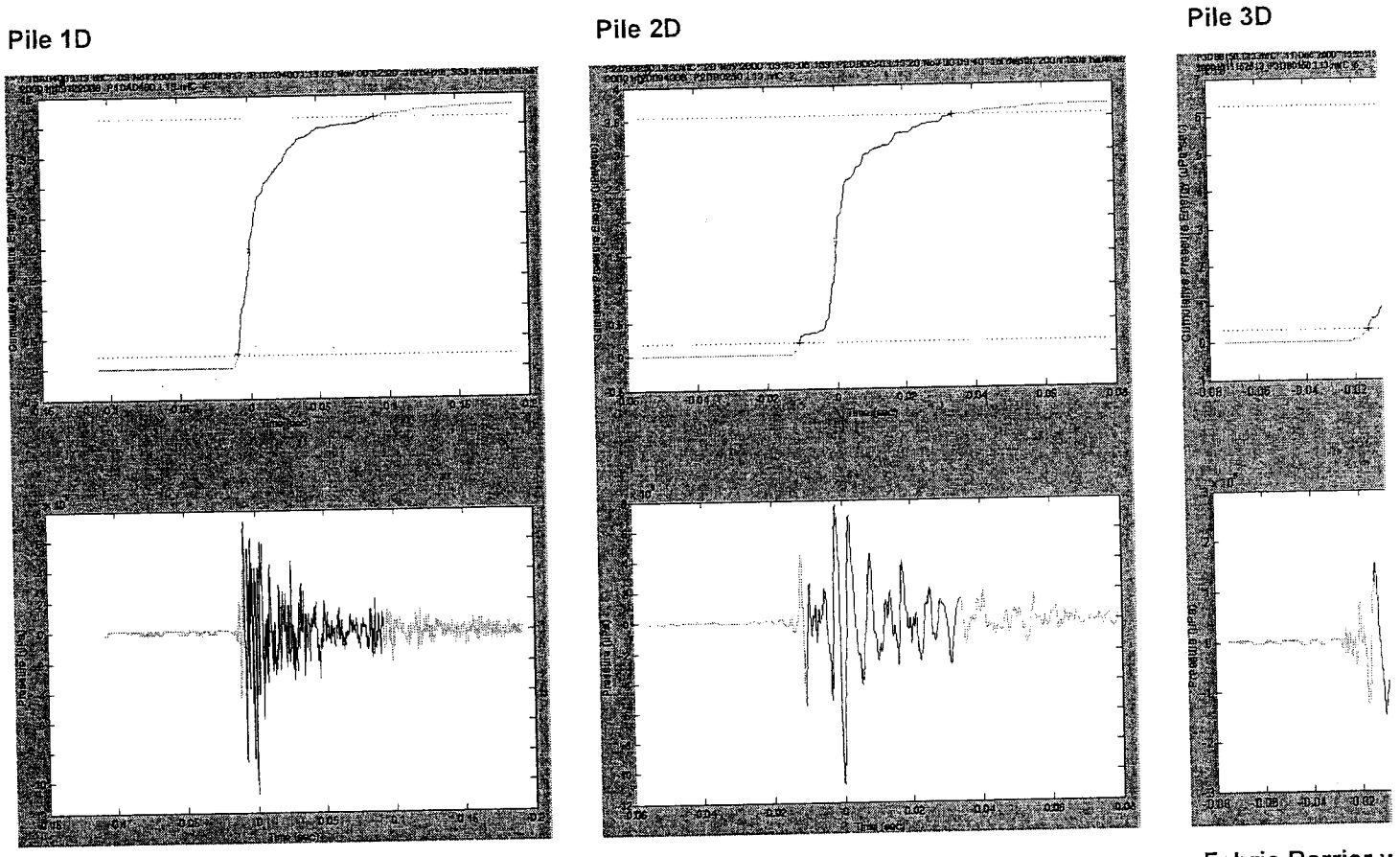
The fabric barrier system effectively reduced the RMS impulse sound pressure (Illingworth & Rodkin 2001). Acoustic data collected indicate that the distance to the 190 dB RMS (impulse) level was always less than 100 meters (328 feet) with the fabric barrier system with aerating mechanism in operation. It is not possible from the measured data to estimate the distance more accurately than to say that it is less than 100 meters (328 feet) with the fabric barrier system with aerating mechanism in operation. Figures 4-8 and 4-9 show that the fabric barrier system with aerating mechanism also reduced the higher frequency component of pile driving noise (above about 800 Hz) and changed the shape of the acoustic impulse.

Figure 4-8



Source: Illingworth & Rodkin, 2001.

Figure 4-9 Comparison of Cumulative Energy and Impulse During Driving of Pile Segments 1D, 2D an



No Attenuation Mechanism1 meter deep @ 358 meters

Bubble Curtain 1 meter deep @ 200 meters

Fabric Barrier w 1 meter deep @

Source: Illingworth & Rodkin, 2001.

5.0 CONCLUSIONS

The PIDP fisheries impact assessment documented near-term fish mortalities and the likelihood of a high rate of delayed mortality of differing sizes and species of fish with swim bladders.

5.1 Fish Mortality

Observations on bird predation indicate many fish with swim bladders that were near active pile driving operations were stunned or killed and drifted up towards the surface where they were quickly consumed by gulls. Observations of gull predation on stunned fish suggested that 0 to 7 fish per minute were killed during pile driving operations. The mortality was undoubtedly much larger since many pelagic fish sink when they die, and many very small juvenile fish would not have been seen by observers. Some critically injured fish may have stayed in the water column or drifted down to the bottom but there is no direct evidence to indicate the number of fish critically injured that did not come to the surface. A review of the literature suggests at least as many fish sink as come to the surface.

Fish survey transects using a fathometer indicated schools of fish did not move away from the pile being driven or the general area of the pile driving barges during pile driving operations. The barges appeared to act as a focus for fish aggregation, especially for those species of fish, such as surfperch, that are attracted to vertical structures.

External examination of stunned fish collected from the water near pile driving operations showed a full range of injuries from no external indication of injury to a complete rupture of the body cavity. The type and range of injury are very similar to the injuries caused by underwater explosives.

Internal examination of stunned fish collected from the water revealed a range of injuries from slight reddening of the dorsal surface of the liver to a complete rupturing of the swim bladder and massive internal bleeding due to the rapid contraction and expansion of the swim bladder.

Unattenuated hammering from both the small hammer and the large hammer resulted in fish mortalities. Based on the sample of fish collected from the water, the larger hammer resulted in mortalities to larger fish. The largest fish recovered was a 29.2-centimeter (11.5-inch) long white surfperch (*Phanerodon furcatus*).

Experiments with fish held in cages close to pile driving operations indicated that many exposed fish may not be stunned or killed immediately, but they may sustain life threatening injuries such as a ruptured swim bladder or limited damage to their internal organs and the inner ear and lateral line organs. Fish with these types of injuries would still be able to swim upright but with their head down and thus they would not typically drift to the surface. In the field, fish with these types of injuries would likely be eaten by predators in subsequent days.

Preliminary results indicate the longer the duration of exposure, the more likely the swim bladder of the fish will be ruptured or that the fish will become moribund and float to the surface or sink to the bottom.

The general impression is that pelagic fish were entrained in the tidal currents and passively drifted into the zone of high acoustic pressure.

5.2 Estimated Radius Of Impact

There are no observations of fish floating to the surface outside the width of the barges. The main barge was 24.4 meters (80 feet) wide. This observation suggests the immediate stun/kill radius or Immediate Mortality Zone (IMZ) at the PIDP site is on the order of 10-12 meters (33-39 feet) for either the small or large hammer without sound attenuation.

Permanent injury to the inner ear and lateral line organ will result in a reduced ability to orient in the water column, capture prey, and avoid predators, thereby leading to delayed mortality. An effort was therefore made to establish the likely radius of the Delayed Mortality Zone (DMZ) for most fish less than several inches long. Results from Hastings et al. (1996), underwater acoustic sound pressure measurements for the PIDP, and results from the experimental fish cages used in the PIDP were considered in this effort.

For the purposes of this report, the DMZ has been defined as the zone in which the peak sound pressure level and impulse are not great enough to result in immediate death but result in mortality several hours to several days later. It is assumed that the rate of mortality and injury drops off with distance in relation to the decrease in sound pressure levels. The DMZ could not be defined as a zone with a precise radius. The analysis below indicates its possible boundaries.

5.2.1 Hastings et al. (1996)

Hastings et. al. (1996) reported that sensory hairs of oscars (*Astronotus ocellatus*) were damaged by continuous sound pressure levels of 180 dB re 1 μPa for one hour. This was the highest sound pressure level applied to the fish in their study. They also applied two lower sound pressure levels (100 dB and 140 dB re 1 μPa), which did not result in injury. They note that extrapolation of their results to other signals and other species should be done with caution. They also note that their findings cannot be interpreted to indicate that sound of shorter duration or lower intensity is not damaging. Nevertheless, their study suggests a possible threshold for continuous sound pressure levels that may result in injury to small fish.

The sound pressure levels that would have resulted in delayed injury to small fish during the PIDP cannot be directly extrapolated from Hastings et. al. (1996). For the PIDP, delayed mortality would have occurred as a result of variable and intermittent sound pressure levels rather than continuous sound pressure levels. Since their study does not identify a threshold that can be applied to the PIDP, underwater acoustic measurements and the results of the experimental fish cages from the PIDP were also considered in defining the DMZ.

5.2.2 Underwater Acoustic Data

The underwater acoustic sound pressure measurements for the PIDP were used to determine the distances at which certain sound pressure levels may be expected at the PIDP site. The data show RMS impulse sound pressure levels as high as 196 dB re 1 μPa at 103 meters (338 feet) from the pile, during driving of Pile 1D using the large hammer without sound attenuation on November 9, 2000 (Illingworth & Rodkin 2001). This was the highest sound pressure level reported. Sound pressure levels drop off at the rate of approximately 6 dB for every doubling of the distance (Illingworth & Rodkin 2001). Table 5-1 presents the estimated RMS sound pressure levels at different distances.

Table 5-1 Estimated RMS Impulse Sound Pressure Level Contours Based on Data for Pile Driving Using the Large Hammer Without Sound Attenuation on November 9, 2000

RMS Impulse Sound Pressure Level (dB re 1 μPa)	Distance meters (feet)
196	103 (338)
190	206 (676) *
184	412 (1,352) *
178	824 (2,703) *

* Estimated distance based on approximate sound pressure level decrease of 6 dB with every doubling of the distance. Not adjusted for excess attenuation.

As discussed in Section 4.6, numerous factors in the environment would tend to attenuate underwater sound propagation in shallow water. Attenuation may be the result of microbubbles in the water column resulting from phytoplankton growth, absorption of the sound in soft Bay mud, scattering of the sound by the surface waves, bubbles in the water from turbulence and the reflection of sound waves off objects such as the SFOBB piers, the PIDP barges and irregularities on the bottom. Estimated excess attenuation was approximately 0.02 dB per meter (Illingworth & Rodkin 2001). Therefore, the values presented in Table 5-1 are conservative, since excess attenuation may be expected to reduce the sound pressure levels at these distances.

5.2.3 Results From Caged Fish Experiments

During the PIDP, shiner surfperch held in cages were positioned at varying distances and depths, for different pile segments. The results of the fish cage experiments were used to help determine a range for the DMZ. At about 150 meters (about 500 feet) away from pile driving operations, 60 percent of experimental fish in cages sustained injuries, and 40percent were seriously injured. This was during the driving of Pile 1D, using the large hammer without sound attenuation (See Table 4-6). Based on this data, the Delayed Mortality Zone (DMZ) may extend at least 150 meters (about 500 feet) from pile driving with the large hammer without sound attenuation.

For the driving of Pile 1D, using the large hammer with no sound attenuation, results from the caged fish experiments also show that at about 500 meters (about 1,650 feet), 10 percent of the fish sustained injuries, and no fish sustained serious injuries (See Table 4-6). Based on the acoustic measurements recorded on November 9, 2000, the sound pressure level at 500 meters (1,650 feet) was approximately 183 dB. Although the highest sound pressure level was recorded during driving of Pile 1D with the large

hammer on November 9, 2000, the hammer was not used at maximum energy on that day. If the hammer were used at maximum energy (about 1,750 kJ), the estimated 180-183 dB contour would be between approximately 665 meters and 950 meters (assuming no excess attenuation).

Based on these findings, the DMZ at the PIDP site for the unattenuated large hammer is estimated to extend out at least about 150 meters (about 500 feet) and up to about 1,000 meters (about 3,280 feet) for small fish. The size of the IMZ and DMZ will vary with the species, size, physiological condition of the fish and environmental conditions. Fish without swim bladders will probably not be as adversely affected as those with swim bladders. The IMZ and DMZ are presented as estimates only. There is an inadequate amount of experimental data on pile driving impacts to draw more than general conclusions.

The furthest distance to where no behavioral response can reasonably be expected to occur is not known and cannot be reasonably estimated based on existing PIDP data. This project did not study the startle response of fish at great distance from pile driving. Shin (1995) found that fish behaved differently when the noise in the water was 36 dB re 1 μPa above ambient. The ambient underwater noise SPL level near the barge was 121 dB re μPa (Rodkin personal communication 2001). SPLs in excess of 160 dB re 1μPa at frequencies between 60 Hz and 160Hz can elicit a startle response in clupeids (Sonalysts 1997).

5.3 Air Bubble Curtain and Fabric Barrier System

Based on observations of fish floating to the surface and the foraging behavior of birds, the air bubble curtain and the fabric barrier system were effective in decreasing fish mortalities to varying degrees. Both sound attenuation systems reduced the incidence of fish floating to the surface and gull foraging behavior during pile driving with the small hammer. The gull foraging observations and caged fish experiments indicate that the fabric barrier system with aerating mechanism was also effective in reducing fish mortalities and injuries during pile driving with the large hammer. There is limited observation and experimental data on the effectiveness of the air bubble curtain during pile driving with the large hammer. The results of this study indicate that the use of an air bubble curtain or fabric barrier system with an aerating mechanism will reduce, but may not eliminate, fish mortalities.

Use of the two sound attenuation systems on the PIDP provided information about the benefits and disadvantages of each. The air bubble curtain is effective and adaptable to a seafloor with either a sloping or flat bottom. As seen at the installation of Pile 2, the air bubble curtain has a disadvantage in that fast currents in deep water may divert the air bubbles at an angle thereby reducing the effectiveness of the curtain. However, even with strong currents during the PIDP, the bubbles always surrounded Pile 2. Assembly of the bubble ring must typically be done off-site where sufficient land area is available for construction. For repeated use during the proposed East Span Project, this system could be redesigned to better withstand the pressures of being repeatedly raised to the surface. When compared to the fabric barrier system with aerating mechanism, there would be a larger economy of scale if it were designed for multiple reuse. The air bubble curtain is advantageous in that it does not need to be attached to the pile template itself, and marine construction equipment can easily maneuver around and over the site

without any hindrance from the air bubble curtain. Marine construction equipment does not appear to affect the operation of the bubble curtain. For reuse, the air bubble system's lack of bulk reduces the deployment logistics of relocating it to other pile locations. Once deployed, this system requires minimal inspection. With easier deployment, maneuverability, and minimal inspection, the chances for time consuming delays would likely be decreased. For the PIDP, the bid cost was $120,000 for one installation at Pile 2.

The fabric barrier system with aerating mechanism, used at Pile 3, would be most effective in an area where a flat bottom exists. Differences in bottom contour would result in a gap between the bottom of the curtain and the seafloor where sound would not be attenuated. For the proposed East Span Project, this system might be redesigned to be smaller for a single pile or much larger for a whole pier system. When compared with the air bubble curtain, there would be a smaller economy of scale if this system were designed for multiple reuse. Designing this system for reuse may include moving the template off-site, fitting different length curtains to it, and returning the refitted template back out to the project site. This could reduce the possibility of a gap between the bottom of the curtain and the sloping seafloor bottom. Costs would increase if the system needed to be redesigned for varying bottom elevations. Strain on the system from currents is less of a problem with this device than with the air bubble curtain alone, as the weight of the curtain typically keeps the system nearly vertical. For the PIDP, the fabric barrier system was attached to the pile template by the proprietor of the system. In future applications, this can be expected to be performed off-site. The bulkiness of this arrangement makes movement to the project site and movement between piles to be driven very difficult. The first attempt to deploy this system at the PIDP had to be postponed because in windy weather the curtain and template effectively acted as a sail. The height of this system and having it welded to the template also does not allow for easy maneuverability for the marine equipment. For example, a derrick barge cannot maneuver over it, and equipment on the barge must reach over the barrier to the pile being driven. Once deployed, this system requires inspection of the condition of the zippers in the fabric and the bottom alignment. Any damage to the fabric barrier system would likely require removing the template and barrier from the water to conduct repairs. This would cause time-consuming delays to the pile driving operations. For the PIDP, the bid plus change order cost was $580,000 for one installation at Pile 3. This included an additional bubble ring between the curtain and the pile, which was not in the project specifications, but likely aided in sound attenuation.

5.4 Anticipated Impacts from Pile Driving Operations

The PIDP was conducted in a time outside the peak outmigration period of juvenile salmon. No salmon or steelhead were recovered during the PIDP. Juvenile outmigrants are approximately the same size as the anchovies collected. Physiologically they are very similar and have the same kind of swim bladder. Therefore, it is likely that juvenile salmon and steelhead would have been injured or killed had they been present. Experimental studies with fish have shown that larger fish are able to withstand shock waves generated by explosives better than small fish (Yelverton 1975). Similar response to pile driving would be anticipated.

A relatively continuous mortality of federally managed (EFH) species of fish with swim bladders can be anticipated during the use of the small and large hammer without

attenuation. Acoustic attenuation with an air bubble curtain or fabric barrier system using an aerating mechanism would reduce but may not eliminate all mortalities. Losses of federally managed species are not expected to have a population level impact since the main biomass of the federally managed species is in the Pacific Ocean outside San Francisco Bay.

Mitigation for the East Span Project will be implemented to minimize impacts to herring (Caltrans 2001). Construction activities that occur during the peak herring spawning season, generally January to March, would be monitored by a qualified biologist to watch for the presence of spawning herring. If the biologist (or CDFG) observes spawning in the area, in-water construction activities such as pile driving and dredging would be suspended within 200 meters (660 feet) of observed spawn. In-water construction activities would not resume at that location for a period of up to 14 days (as determined by a qualified biologist), allowing herring eggs to hatch and larvae to disperse.

There would be some loss of surfperch expected during pile driving without attenuation but the rate of mortality is not expected to amount to a population level impact.

6.0 DEFINITIONS AND ACRONYMS

DEFINITIONS

Decibel (dB) – A dB or decibel is a logarithmic unit of measure for describing differences in loudness or sound pressure relative to reference loudness. The reference pressure for water is 1 micro Pascal or 0.0002 newtons/m^{-2}.

Delayed Mortality Zone (DMZ) – The radius around a pile being driven where the peak sound pressure level and impulse are not great enough to result in immediate death but result in mortality several hours to several days later.

Environmentally Significant Unit (ESU) – a population that 1) is substantially reproductively isolated from the conspecific populations and 2) represents an important component of the evolutionary legacy of the species (Busby et al. 1996).

Hertz (Hz) – Hertz, frequency or cycles per second.

Impulse – Impulse is the time integral of the peak pressure. It recognizes that a short pulse may do less damage than a longer duration pulse of the same pressure. Sound pressure is equivalent to kilowatts while impulse is equivalent to kilowatt-hours. It is typically described in units of psi-msec. The conversion of psi-msec to dB-msec uses a conversion rate of $6.9 * 10^9$ µPa per psi.

Immediate Mortality Zone (IMZ) – Radius around a pile being driven where the peak sound pressure level and impulse are great enough to kill a fish resulting in the fish floating up to the surface or sinking to the bottom.

Kilojoule (kJ) – The basic unit of force moving a body a unit distance in the metric system is 1 newton-meter or 1 joule. One joule is 0.7376 ft-lbs. A thousand joules or one kilojoule is represented as kJ.

Linear Peak Level (LPL) – Linear peak level of sound pressure is the largest absolute value of the instantaneous sound pressure (Illingworth & Rodkin 2001).

Near-field – Hydrodynamic flow or molecular displacement close to the sound source where the pressure falls off according to the square of the distance ($1/r^2$).

Otolith – Small irregularly shaped bones found in the head of fish that contribute to hearing.

Pascal (Pa) – A Pascal is a unit of pressure equal to one Newton per square meter.

Propagation loss – The decrease in sound pressure level due to the spherical spreading of the sound wave. In the farfield the rate of decrease in the sound pressure level is proportional to the distance or 1/r. In an unbounded, homogeneous medium, propagation loss will be on the order of 6 dB for every doubling of the distance.

Predation – the act of preying on another animal.

PSI – Pounds per square inch.

Micro Pascal (µPa) – Most underwater acoustic sound pressure measurements are stated in terms of a pressure relative to one micro Pascal.

Root-Mean-Square (RMS) – An average wave height commonly used in repetitive or relatively continuous measurements such as in speech or highway noise. It is not applicable to transient signals such as explosions. It is used in calculating longer duration sound pulses such as a pile driving pulse of sound

RMS Sound Pressure – Root square of the energy divided by the duration. It is the mean square pressure level of the pulse of sound from a strike of the hammer on the pile. It is described as the average pulse pressure and accepted as the reaction threshold for whales to seismic signals. RMS sound pressure is expressed in dB re 1 micro Pascal.

RMS Impulse – Root square of the energy divided by a 1/32 second RMS time constant (Illingworth & Rodkin 2001). The use of this standard time constant results in a conservative measure of the RMS sound pressure. RMS impulse is expressed in dB re 1 micro Pascal.

Secchi disk - A Secchi disk is a 20 cm flat plastic disk with black and white pie shaped sections that is lowered into the water to indicate the transparency of the water. A high reading indicates the water is clear. A low reading indicates the water is turbid.

Sound Pressure Level (SPL) – Sound pressure levels are expressed as a ratio between a measured level and a reference level of power per unit area. SPL = 20 log $\left\{ P_1 / 1\mu P_a \right\}$

Swim bladder – Gas filled sac in the body cavity of most species of fish.

Transducer – A device to convert underwater sound into electrical voltage.

Transect – A line or strip along which samples are taken.

ACRONYMS

CDFG – California Department of Fish and Game.

Caltrans – California Department of Transportation.

EFH – Essential Fish Habitat.

ESA – Endangered Species Act.

ESU – Evolutionarily Significant Units.

IHA – Incidental Harassment Authorization.

NMFS – National Marine Fisheries Service.

NRDC – Natural Resources Defense Council.

MSFCMA – Magnuson-Stevens Fishery Conservation and Management Act.

USFWS – U.S. Fish and Wildlife Service.

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ABSTRACT

The limited information available on entrainment and turbine mortality of non-salmonid species of fish has made it difficult to assess fisheries impacts at many hydro projects. As a result of the Federal Energy Regulatory Commission relicensing process, many studies addressing these issues were initiated over the past several years. These studies have generated a substantial amount of new information; however, much of this data was not readily accessible. Summarizing this new information was the major objective of the report. Reviewing recent studies of fish entrainment and turbine mortality also provided an opportunity to examine and evaluate the various methods employed in these types of studies. Separate sections of the report are devoted to describing and evaluating these methods.

Most of the entrainment studies reviewed were conducted in the states of Michigan and Wisconsin, but the overall trends observed were consistent with observations made in studies conducted in other regions. Small fish (<200 mm) generally comprised over 90% of the fish entrained. Entrainment was usually highest in the late spring and summer, and was consistently low in the winter and early spring. Diurnal patterns were variable from site to site, by season and between species. Fish passage rates typically averaged between 1 and 10 fish per hour for each turbine unit sampled.

The turbine mortality data reviewed did not indicate any large differences in mortality between the various types of species evaluated. Researchers that were successful in minimizing net-related mortality were able to demonstrate that the mortality of naturally-entrained resident fish was sometimes as low as 1-2% and averaged approximately 6% at both Francis and Kaplan turbines. The mortality rate of artificially introduced fish was usually higher (10-30%), partially due to their typically larger size and in part due to the additional stress of transport, marking and introduction techniques. The mortality rates of juvenile clupeid species appears to be much lower than had been indicated in earlier studies using the same species. Recent studies of juvenile American shad and blueback herring using the balloon tag technique indicate an average turbine mortality of approximately 3.6% for Kaplan turbines and 16% for Francis turbines. One of these studies demonstrated that mortality was a full order of magnitude lower than had been estimated in an earlier study conducted at the same turbine unit.

The limited information available for other types of turbine runners indicate that bulb turbines may offer slightly lower mortality rates than Kaplan turbines, and that Ossberger Cross-Flow turbines are likely to cause high rates of mortality to larger fish due to the narrow spacing of the runner vanes. Information on the one operating STRAFLO turbine evaluated suggests that the mortality of adult American shad was

approximately 20%, while the mortality rate of juvenile clupeids at this site is still the subject of considerable debate. The single study conducted at a tube turbine showed mortality rates ranging from 9-25% for the species evaluated.

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APPENDIX B BIBLIOGRAPHY OF PREVIOUS TURBINE MORTALITY REVIEWS

EXECUTIVE SUMMARY

Entrainment and turbine mortality are two of the most significant issues currently faced by applicants and resource agencies during the licensing and relicensing of hydroelectric facilities. Until recently, little information was available on the rates at which fish (particularly non-migratory "resident" species) are entrained, and the mortality caused during turbine passage was understood relatively well only for juvenile salmonids. Many of the hydro projects undergoing relicensing at this time must address these issues for resident species of fish and/or migratory clupeid species (shad, alewives and herring).

The limited information available on entrainment and turbine mortality has made it difficult to assess fisheries impacts at many hydro projects. As a result of the FERC relicensing process, many studies addressing these issues were initiated in the past several years. These studies have generated a substantial amount of new information; however, much of this data is not readily accessible. Summarizing this new information was the major objective of this report.

Reviewing the many recent studies of fish entrainment and turbine mortality also provided an opportunity to examine and evaluate the various methods employed in these types of studies. Separate sections of the report were devoted to describing and evaluating these methods.

Three primary methods for evaluating fish entrainment were identified: netting, hydroacoustics and telemetry techniques. Tailrace netting was the method most commonly employed and was frequently combined with studies of turbine mortality. Most studies used a net which sampled the entire discharge from one or more operating units. In several studies, nets were deployed at other locations (at the power canal entrance or turbine intake), while in other studies only part of the outflow from a turbine was sampled. When tailrace conditions are conducive to sampling and the turbine output is not excessive, a full-flow tailrace net is preferred to ensure that a representative sample is collected. Netting enables the size and species composition of entrained fish to be evaluated; however, many studies suffer from low catch efficiencies for smaller-sized fish. In order to retain fish smaller than 100 mm in length, it was found that the net mesh should be no larger than 0.5 inches (square measure).

Entrainment studies using hydroacoustic techniques have usually employed periodic netting to assess species composition and to verify fish counts. Although some studies have shown relatively good correspondence between net and hydroacoustic counts, other studies have had less success. Most studies have used the hydroacoustic data to compare entrainment rates between units and to assess the rate of

entrainment in the intervals between net sampling periods. Radio telemetry techniques have been most effectively used to follow the movements of migratory species in order to evaluate exposure to turbine passage, the effectiveness of fish bypasses and delays in passing dams, and for siting of fish passage facilities.

The primary methods used to evaluate turbine mortality include tailrace netting, balloon tagging and radio telemetry techniques. Tailrace nets offer the advantage of allowing mortality to be evaluated for naturally-entrained fish, eliminating the stresses associated with transport, handling and introduction when using introduced fish. However, many studies employing tailrace nets were affected by net-related mortality, which often compromised the accuracy of turbine mortality estimates. By evaluating the characteristics of the nets used in these studies, it was found that high rates of net mortality could usually be ascribed to injuries caused in the cod end of the net (when no live car live car was used to provide a low-velocity refuge for collected fish), the use of knotted net material, or the use of a net with a short taper (less than 3:1 length-to-width ratio).

The balloon tag method involves attachment of a self-inflating tag to the fish, introducing them into the turbine intake, and recovering the fish when the inflated balloon buoys the fish to the surface of the tailrace. This method has been shown to be effective for evaluating turbine mortality rates, particularly for species which are typically stressed or injured when recovered in a collection net. The method usually achieves a relatively high rate of fish recovery, which can produce credible estimates of turbine mortality with relatively small sample sizes. The primary disadvantage of the method is the large amount of labor involved in fish recovery, which could be prohibitive in studies at a given site where multiple species and size classes of fish and/or multiple turbine operating conditions must be evaluated. Radio tags are sometimes used in conjunction with balloon tags to improve fish recapture rates.

Radio tags have been used in several studies to assess turbine mortality based on observations of fish movement following turbine passage. Tag regurgitation (if orally-inserted) and loss of signals from fish have limited the accuracy of some studies. Another limitation of this method is that information on turbine injuries and delayed mortality cannot typically be collected.

Most of the entrainment studies reviewed were conducted in the states of Michigan and Wisconsin, but the overall trends observed were consistent with observations made in studies conducted in other regions. Small fish (<200 mm) generally comprised over 90% of the fish entrained. Entrainment was usually highest in the late spring and summer and was consistently low in the winter and early spring. Diurnal

patterns were variable from site to site, by season and between species. Fish passage rates typically averaged between 1 and 10 fish per hour for each turbine unit sampled.

The turbine mortality data reviewed did not indicate any large differences in mortality between the various types of species evaluated. Researchers that were successful in minimizing net-related mortality were able to demonstrate that the mortality of naturally-entrained resident fish was sometimes as low as 1-2% and averaged approximately 6% at both Francis and Kaplan turbines. The mortality rate of artificially introduced fish was usually higher (10-30%), partially due to their typically larger size and in part due to the additional stress of transport, marking and introduction techniques. The mortality rates of juvenile clupeid species appears to be much lower than had been indicated in earlier studies using the same species. Recent studies of juvenile American shad and blueback herring using the balloon tag technique indicate an average turbine mortality of approximately 3.6% for Kaplan turbines and 16% for Francis turbines.

The limited information available for other types of turbine runners indicate that bulb turbines may offer slightly lower mortality rates than Kaplan turbines, and that Ossberger Cross-Flow turbines are likely to cause high rates of mortality to larger fish due to the narrow spacing of the runner vanes. Information on the one operating STRAFLO turbine evaluated suggests that the mortality of adult American shad was approximately 20%, while the mortality rate of juvenile clupeids at this site is still the subject of considerable debate. The single study conducted at a tube turbine showed mortality rates ranging from 9-25% for the species evaluated.

Section 4

SUMMARY OF RECENT ENTRAINMENT AND TURBINE MORTALITY STUDIES

This section summarizes information on fish entrainment and turbine mortality gathered from recent studies. Most of the information is from studies conducted during relicensing of projects located in the U.S., although some studies of turbine mortality conducted in Canada were also reviewed. Section 4.1 and 4.2 provide a general summary of the information gathered on fish entrainment and turbine mortality. These subsections are intended to provide the reader with information regarding the overall trends in entrainment and mortality and the factors which affect these statistics. Section 4.3 is composed of individual summaries of the studies reviewed. Since many of the studies are from reports with limited availability, the summaries were designed to provide sufficient detail for the reader to understand the methods, scope, and principal findings of each study. In some cases, additional information beyond that reported in the source report was obtained, or results were tabulated in a different format to facilitate comparison of the results between sites.

In reviewing the information that was received, it became apparent that most recent research was focused in two areas: 1) entrainment and turbine mortality of resident fish species, and 2) turbine mortality of migratory clupeid species. Until recently, there was insufficient information to assess the potential impacts of hydro operations on these types of species, which are the primary fish of concern at many of the projects undergoing relicensing. Summarizing the newly available information on these topics is thus the major focus of this section. Also included is new information developed on the mortality of salmonid species, including several studies involving newer types of turbines and others which provided direct comparisons with non-salmonid species. Since the relatively large data base on turbine mortality of anadromous salmonids has been summarized in a number of recent papers, an exhaustive review of this topic was not attempted.

In order to conform with U.S. engineering standards, plant characteristics such as discharge capacity and runner diameter are given in English units (following the metric equivalent if source information has been converted from metric units). Since metric units are more convenient and more widely used in presenting fish length data, metric values are given for this statistic (following the english equivalent, if converted).

Table 4-1 (pg 2 of 5)

SUMMARY DATA FROM ENTRAINMENT STUDIES REVIEWED

Site* Location, Reference	Plant Description	Monitoring Method	Predominant Species		Estimated Entrainment
French Landing Huron River Michigan Bohr and Sandquist 1991	Head 32' 1 vertical Francis unit Flow 800 cfs/unit Trashrack spacing 2 1/2" Intake submergence <20' Reservoir size 1,270 acres	Full-flow tailrace net	Black crappie Bluegill Pumpkinseed Gizzard shad	75.9% 17.7% 1.6% 1.2%	Peak catch was during September. Annual entrainment estimated at 1,593,342 fish (181.9 fish/hr). Estimate adjusted for net efficiency but not fish intrusion
High Falls Deep River North Carolina Tomljanovich 1989	Head 17' 3 vertical Francis units Flow 665 kW (flow not given) Trashrack spacing 2 3/8" Intake submergence < 20' Reservoir size not given	Partial recovery tailrace net sampling 40-68% of powerhouse outflow	Threadfin shad Redhorse YOY Snail bullhead Bluegill Redbreast sunfish	33.1% 20.0% 7.5% 5.7% 5.4%	Tailrace catch averaged 0.32 fish/hr in January and 5.8 fish/hr in August. Most of the summer catch was composed of threadfin shad and YOY redhorse bullheads, minnows and sunfish
Kleber Black River Michigan Johnston & Hunsicker 1991	Head 48' 2 vertical Kaplan units Flow 400 cfs (total) Trashrack spacing 3" Intake submergence <20' Reservoir size 270 acres	Full-flow tailrace net and hydroacoustic monitoring at one unit	Yellow perch Bluegill Black bass White sucker Pumpkinseed Brown bullhead	32.5% 29.4% 24.9% 5.2% 3.3% 1.7%	The mean annual entrainment rate for one unit was estimated at 173 fish/day (7.2 fish/hr) via hydroacoustics. Net catch at the same unit averaged 412.0 fish/day (17.4 fish/hr), but was influenced by high alewife or tailrace fish. Entrainment rates were high in April 1990, peaked in September with a lesser peak in October. Early April 1991 had the lowest catch rate. The size distribution of captured fish was 46% <100 mm 50% 100-200 mm 3% 200-300 mm 1% 300-600 mm
Marshall French Broad River North Carolina LP & L 1988	Head 31.4' 2 inclined Kaplan units Flow 2,500 cfs (total) Trashrack spacing 2 1/2" Intake submergence <20' Reservoir size not given	Partial recovery tailrace net	Channel catfish Northern hogsucker Flathead catfish Black bullhead Redbreast sunfish Silver redhorse	30.8% 20.2% 11.1% 10.2% 9.2% 3.0%	Median passage rates for one unit (average passage not reported) January - March 0.00 fish/hr April - June 4.74 fish/hr July - September 2.55 fish/hr October - December 0.37 fish/hr Annual 1.27 fish/hr
Melville Shenandoah River West Virginia LP&L 1991	Head 24' Unit #1 Francis Flow 580 cfs Unit #2 Propeller Flow 695 cfs Unit #3 Kaplan Flow 650 cfs Trashrack spacing Intake submergence <20' Reservoir size not given	Full-flow tailrace netting at Unit #1	Redbreast sunfish Spotfin redhorse Bluegill Channel catfish	26.4% 20.1% 16.0% 14.6%	Total 1990 entrainment at all units was estimated at 19,173 fish (2.19 fish/hr). Low entrainment in winter (less than 1 fish/hr for December - March). Peak entrainment in April (8.5 fish/hr) and June (6.8 fish/hr)

*(listed alphabetically by project name)

Table 4-1 (pg 3 of 5)

SUMMARY DATA FROM ENTRAINMENT STUDIES REVIEWED

Site* Location, Reference	Plant Description	Monitoring Method	Predominant Species		Estimated Entrainment
Morrow Kalamazoo River Michigan Bohr and Loeser 1987	Head 12' 4 run-drive propeller units Flow 235 cfs/unit Trashrack spacing 2 1/2" Intake submergence <20' Reservoir size 1,000 acres	Full-flow tailrace net at one unit	Bluegill Common shiner Black crappie Rosyface shiner Pumpkinseed Northern pike	29.1% 19.6% 18.4% 7.8% 6.2% 2.0%	Total entrainment for all four units combined was estimated at 45,987 fish (9.63 fish/hr) for the period of 5 April through 20 October. Entrainment was highest in June through August
Mt. Elbert Pumped Storage Twin Lakes Colorado Mussko, 1987	Head 440' 2 reversible 100 MW turbines Flow not given Trashrack spacing not given Intake submergence bottom withdrawal Reservoir size 280 acres (upper) 1,821 acres (lower)	Partial recovery tailrace net Partial intake net	Opossum shrimp	NA	Generation cycle: Mean shrimp density ranged from 0.05 to 1.21 shrimp/m3 of discharge. 50,000 to 714,000 entrained in an eight hour cycle with 98% of the shrimp entrained in the first sample hour Pump back cycle: Mean shrimp density ranged from 2.38 to 17.19 shrimp/m3 of discharge. 6 million to 44 million entrained in an eight hour cycle
			Various fish species	NA	Generation cycle: 1.52 fish/million m3 fish entrained >15 cm (based on capture of 2 trout and 1 sucker). 3.14 fish/million m3 fish entrained <15 cm (based on capture of 1 trout) Pump back cycle: Mean entrainment rate for fish over 15 cm was 14.32 fish/million m3 of water 4.59 rainbow trout/million m3 (4 captured) 4.59 long nose sucker/million m3 (4 captured) 3.44 lake trout/million m3 (3 captured) 2.29 white sucker/million m3 (2 captured) 104.71 kokanee salmon/million m3 (10 captured) During the pump back cycle sample period June-October 1985, at the above entrainment rates, 20,282 kokanee, 1112 rainbow trout, 589 long nose suckers, 666 lake trout and 223 white suckers would be entrained
N. Fork Mokelumne River California Hubowski et al. 1987	Plant description not given. Study assessed the number of trout entrained at three diversions on first and second order streams	Inclined plane trap sampling of 100% of diverted flow	Rainbow trout Brown trout	92.0% 8.0%	Total trout diverted averaged less than one fish/day. YOY fish comprised 51% of the rainbow trout and 98% of the brown trout that were diverted
Park Mill Menominee River Wisconsin Hartz 1988	Head 16' 2 horizontal Francis units 3 vertical Francis units 1 unknown unit (new) Flow 2,540 cfs (total) Trashrack spacing 3" Intake submergence <20' Reservoir size 510 acres	Hydroacoustic monitoring of intake bay. Partial netting at canal entrance	Rock bass Smallmouth bass Black crappie	45.0% 24.0% 6.0%	May 38.8 fish/hr June 22.7 fish/hr July 40.5 fish/hr August 184 fish/hr September 166.0 fish/hr October 23.3 fish/hr These are hydroacoustic estimates for the entire plant. Net data indicates entrainment of 1 to 7 fish/hr

*(listed alphabetically by project name)

Table 4-2

SIZE DISTRIBUTION OF ENTRAINED FISH

Project and Location	Size Distribution of Entrained Fish	Trashrack Spacing
Kleber Michigan	46% < 100 mm 96% < 200 mm	3 inches
Prickett Michigan	84% < 4" (102 mm) 99% < 8" (203 mm)	not given
Tower Michigan	50% < 100 mm 82% < 200 mm	1 inch
Centralia Wisconsin	95% < 100 mm	3.5 inches
Pine Wisconsin	49% < 100 mm 94% < 200 mm	none upstream of netting site
Wisc. River Division Wisconsin	96% < 100 mm	2 3/16 inches
Thornapple Wisconsin	68% < 4" (102 mm) 85% < 8" (203 mm)	1 11/16 inches
*Escanaba Dam #1 Michigan	59% < 5" (127 mm) 93% < 7.5"(191 mm)	1 3/4 inches
*Escanaba Dam #3 Michigan	75% < 5" (127 mm) 96% < 7.5"(191 mm)	1 3/4 inches

* At Escanaba Dam #1 and Dam #3, lengths were recorded for sunfish, perch, minnows and black crappie.

were 100 mm or less in length and could have easily passed through the trashracks protecting the turbine intake (the top portion of the trashrack at the powerhouse has 1 inch bar spacing, but most of the submerged trashrack area has 2 3/8" spacing).

4.1.2 Species Composition

The predominant species reported from entrainment data from each site is summarized in Table 4-3. For projects located in Michigan and Wisconsin, the catch was most frequently dominated by bluegill, black crappie and minnow or catfish species. Other species which formed over 10% of the catch at one or more sites included rock bass, yellow perch, walleye and smallmouth bass. The one project in New York showed a similar composition (dominated by walleye, minnows and rock bass) for the relatively few fish caught at this site. Dominant fish caught in the two projects in North Carolina and two in West Virginia included some of the same species (bluegill, rock bass, smallmouth bass, channel catfish, other catfish species), but also included threadfin shad, redhorses, hogsuckers and redbreast sunfish. The two projects located on the Ohio River were unique in the catch being dominated by gizzard shad, with drum being the second most abundant fish caught at both sites (although comprising less than 10% of the catch at Vanceburg).

Comparisons of the species composition from entrainment samples to the population of the upstream reservoir is usually difficult due to the biases associated with most reservoir population sampling techniques. Usually, a number of different sampling techniques are or must be employed to develop a reasonably accurate estimate of the reservoir population. Olson et al. (1988) used a variety of techniques to assess the species composition in the Ohio River upstream of the Vanceburg Hydroelectric Project. Their study indicated that species classified as game fish comprised 12% of the population upstream of the project, but only 0.3% of the fish captured in entrainment samples. No studies were identified which used the release of marked fish into the reservoir population to assess susceptibility to entrainment.

4.1.3 Seasonality

Hourly catch (or detection) rates for sites which provided seasonal data on entrainment rates are summarized in Tables 4-4 and 4-5. Values presented for Park Mill are hydroacoustic estimates of total passage for the entire plant. Most of the other sites listed represent catch or detection rates for a single unit [the flow capacity of the unit(s) sampled and the entire plant flow are indicated at the bottom of the

Table 4-5

ESTIMATED MONTHLY ENTRAINMENT (FISH/HOUR) OF RESIDENT AND SEMI-PELAGIC SPECIES (DRUM AND GIZZARD SHAD) AT MAINSTEM PROJECTS ON THE OHIO RIVER

	Vanceberg			Racine [1]		
Month	Gizzard shad	Drum	Other	Gizzard shad	Drum	Other
January						
February						
March	83	16	3	250	20	73
April				262	392	31
May	13	10	5	508	154	41
June				800	25	54
July				1845	8	84
August						
September	5985	263	20			
October						
November						
December						
Sampling method	Turbine gallery net			Partial recovery tailrace net		
Net efficiency	100% [2]			100% [2]		
Capacity of Units sampled (cfs)	11866			16000		
Plant Capacity (cfs)	35598			32000		

1 Based upon Table 6-36 in WAPORA (1987).

2 Estimate adjusted by author for catch efficiency.

tables]. In order to provide an indication of the proportion of turbine-passed fish that were sampled, net efficiency estimates are also given.

With the exception of Park Mill and the two Ohio River projects, catch or detection rates were generally less than 10 fish/hr for most or all of the year at the units sampled. The relatively high counts shown for Park Mill are based on hydroacoustic counts that were not verified by tailrace netting (limited netting at the power canal entrance indicated passage of only 1-7 fish/hr). High fish counts observed at the two Ohio River projects (Table 4-5), were associated with large movements of gizzard shad in the fall.

Peaks in the reported entrainment rates generally occurred between April and July. Projects which provided data over the winter months showed consistently low rates of entrainment from late fall into early spring, generally extending from October through March.

4.2 TURBINE MORTALITY

Until recently, nearly all studies of turbine mortality have examined the passage of juvenile salmonids through Francis and Kaplan turbines. The factors affecting mortality of juvenile salmonids are relatively well understood and have been summarized in a number of previous reviews (listed in Appendix B). The information summarized in this review contains a substantial amount of new data on mortality of other species and size classes of fish and for newer types of turbines. Although the new information does not appear to be sufficient to determine predictive relationships of mortality rates for individual species and turbine types, trends can be compared to the existing data base on salmonids. The following section gives a brief summary of existing information on factors that influence the mortality of salmonids passing through Francis, Kaplan and bulb turbines, an analysis of information for non-salmonid species for these types of turbines, and a summary of the relatively limited information that is available for STRAFLO, tube and Ossberger Cross-Flow turbines. Examples of each type of turbine are shown in Figures 4-1 through 4-6. Detailed summaries of individual studies are presented in Section 4.3.

4.2.1 Previous Reviews of Mortality of Salmonids at Francis, Kaplan and Bulb Turbines

Previous reviews indicate that the mortality of juvenile salmonids passing through Francis turbines is quite variable, and is frequently greater than the mortality observed at Kaplan turbines. Eicher (1987) indicates that the reason for higher mortality in Francis turbines may be related to their locations at sites with

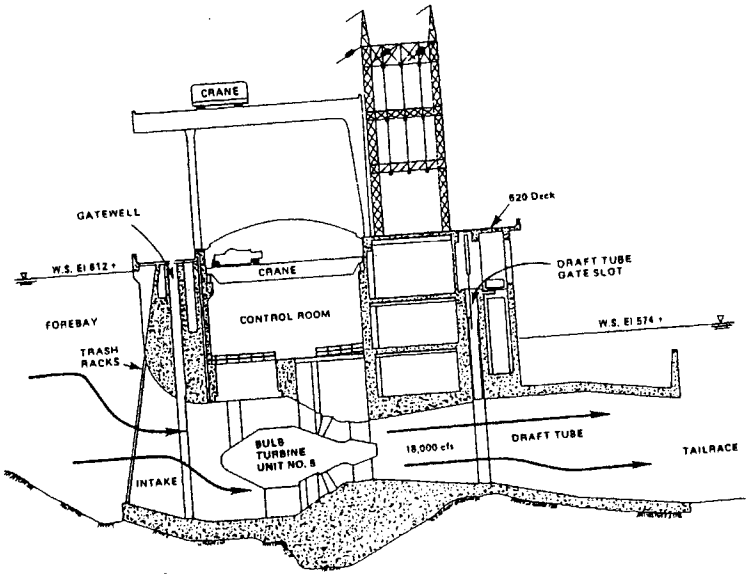
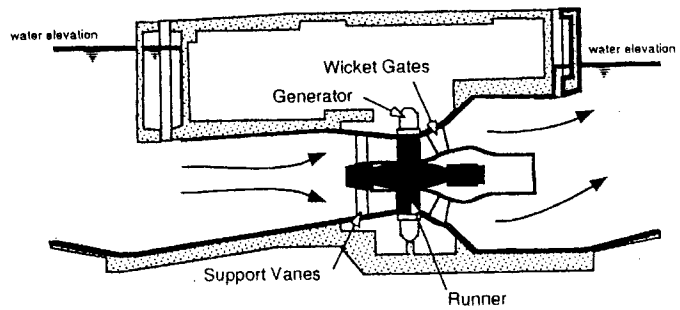


Figure 4-3. Section view of a bulb turbine.
Source: Olson & Kaczynski 1980



STRAFLO TURBINE

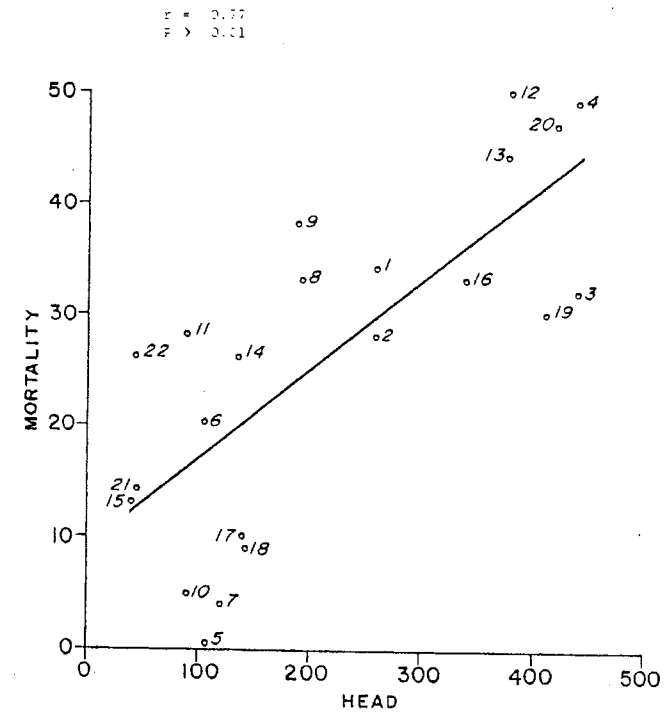
Figure 4-4. Section View of a STRAFLO Turbine.

higher heads and with higher elevation of the runner in relation to tailwater as compared to Kaplan turbines. Examining the data from 22 studies of fish mortality at Francis turbines, Eicher demonstrated that mortality was positively correlated with both head (Figure 4-7) and peripheral runner velocity (Figure 4-8).

Several studies have shown that maximum survival of salmonids passing through Francis turbines occurs when the unit is operating near peak efficiency, and that smaller fish tend to suffer lower mortality (Figure 4-9). Increased mortality outside of the peak efficiency range appears to be related primarily to the effects of cavitation or subatmospheric pressures occurring short of cavitation (Eicher 1987). Operation of Francis units at low gate settings can also increase mortality due to narrow clearances between the wicket gates. In addition, low clearances between the trailing edge of the wicket gates and the runner blades may occur when the wicket gates are in the full-open position. The size of clearances may be of particular importance in passage of larger fish and at higher runner speeds (Eicher 1987). Collins and Ruggles (1982) evaluated clearances and runner openings of Francis turbines installed in Canada, and predicted that mortalities would be about 10% for juvenile salmonids at most installations when operated at peak efficiency, but might be over 50% at units with smaller clearances (primarily small units at high head installations).

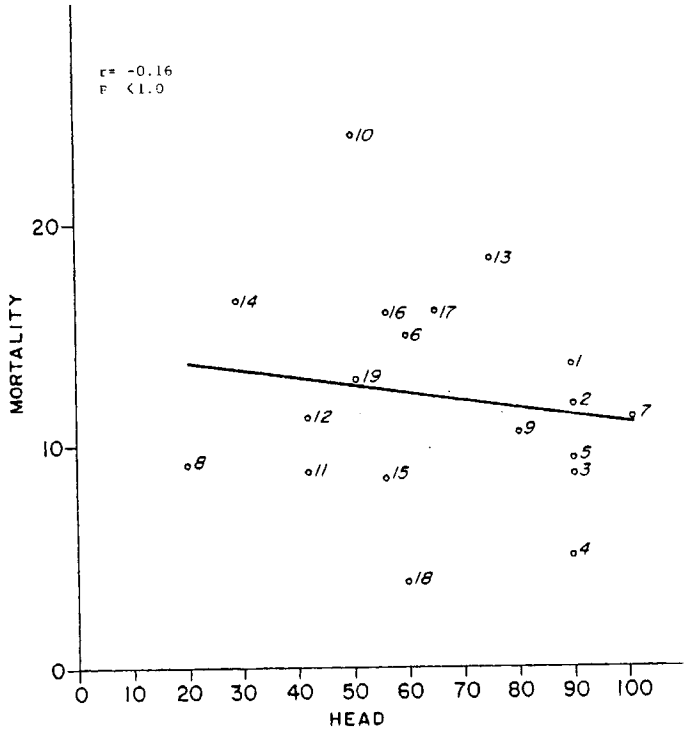
The mortality of juvenile salmonids passing through Kaplan turbines is usually lower than that found for Francis turbines. In contrast to Francis turbines, Eicher (1987) found no relationship between mortality and operating head (Figure 4-10) or peripheral runner velocity in his review of 19 studies conducted at Kaplan turbines. As with Francis turbines, survival tends to be highest when the turbine is operated near peak operating efficiency (Figure 4-11). Survival and efficiency curves both tend to be flatter for Kaplan turbines than for Francis units (Bell 1981). Olson and Kaczynski (1980) state that the 11% mortality rate estimated by Schoeneman (1961) is the most widely accepted mortality estimate for juvenile salmonids passing through typical Kaplan turbines on the Columbia River.

The limited information available on bulb turbines indicates that mortality is somewhat lower than that reported for Kaplan turbines. Mortality estimates for juvenile salmonids passing through bulb turbines range from 2% (Knight & Kuzmeskus 1982) to 3-7% (Olson and Kaczynski 1980).



1. Baker steelhead
2. Baker coho
3. Cushman 1960
4. Cushman 1962
5. Elwha 1954
6. Elwha 1985
7. Faraday
8. Glines 1954
9. Glines 1983
10. Leaburg 1954
11. Leaburg 1980
12. Lequille 1980
13. Lequille 1982
14. North Fork
15. Publishers
16. Puntledge
17. Ruskin
18. Seton Creek
19. Shasta January
20. Shasta November
21. Sullivan chinook
22. Sullivan steelhead

Figure 4-7. Relationship of head to mortality for Francis turbines. Source: Eicher 1987



1. Big Cliff 1957
2. Big Cliff 1964
3. Big Cliff 1966
4. Big Cliff 1967 CH
5. Big Cliff 1967 ST
6. Bonneville 1940
7. Foster
8. Gold Hill
9. McNary
10. Model UBC
11. Sullivan chinook
12. Sullivan steelhead
13. Tobique
14. Tusket
15. Walterville 1954
16. Walterville 1983
17. Wells
18. Bonneville 1954
19. Holyoke

Figure 4-10. Relationship of head to mortality for Kaplan turbines.
Source: Eicher 1987

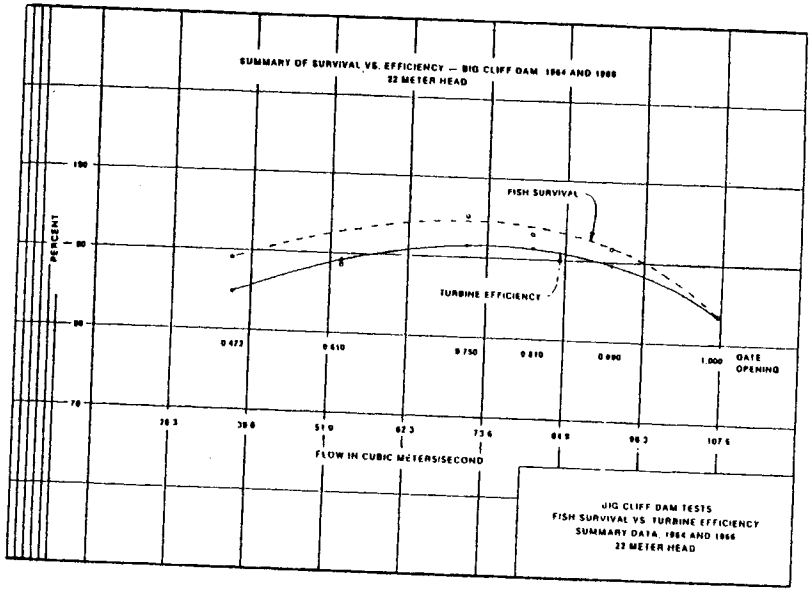


Figure 4-11. Fish survival versus turbine efficiency at a Kaplan turbine.
Source: Oligher and Donaldson 1966

Table 4-6 (pg 2 of 7)

SUMMARY DATA FROM TURBINE STUDIES REVIEWED

Site* Location Reference	Description of Turbine(s) Tested	Study Method	Species Tested	Fish Size	Turbine Operation	Estimated Mortality	Comments
Craggy Dam French Broad River North Carolina (RMC, 1990c)	Type Kaplan Head approx 22' Flow 600 cfs MW 0.7MW Dia 68.9" 4 blades RPM 229	Self-ediating balloon tags	Bluegill Channel catfish - -	Juv 3.0-4.7" (76-119 mm) Ad 4.8-8.7" (122-221 mm) Juv 4.7-8.7" (119-221 mm) Ad 8.8-13.0" (224-330 mm) Juv 4.7-8.7" (119-221 mm) Ad 8.8-13.0" (224-330 mm)	13° blade angle - 15° blade angle - 26° blade angle -	6% (intermediate) 14% 10% 21% 7% -	Latent mortality (72 hr) comparable for test (33%) and controls (33%) No latent mortality (72-hr) observed Latent mortality (72-hr) was 1%
Cincinnati Mohawk River New York (RMC, 1992a)	Type Kaplan Head 27' Flow 300-1,600 cfs MW 3 Dia 9' RPM 144	Self-ediating balloon tags	Blueback herring	Juvenile 60-90 mm	Near full capacity	4% (intermediate) 0% (24 hr) 0% (48 hr)	Recovered let 3% of test fish and 87.8% of control fish live. Mortality at 48 hrs was comparable for test fish (14.7%) and control fish (19.4%)
Dam #4 Potomac River WV/MD EPM 1986	Type Quadruplex horizontal Francis Head 17.3' Flow 541 cfs MW 0.5 Dia not given RPM 168	Net recovery of entrained fish	Mixed resident species	Variable	Variable	13.8% (intermediate) 4.6% turbine-related injury	
Escanaba River Hydro Dam 3 Escanaba River Michigan LaFave 1992	Type vertical Francis Head 24' Flow run-of-river Max capacity of 325 cfs MW 1.95 Dia 57" 14 blades RPM 150	Net recovery of entrained fish	Mixed resident species	Variable	Variable	10.4% (intermediate) 5.1% turbine-related injury	The 10.4% mortality rate included an influx of young-of-year juvenile black crappie in one sample period with a mortality rate of 65%, probably due to net injuries. If these fish are not included in the calculation, mortality is 6.4%
Escanaba River Hydro Dam 2 Escanaba River Michigan LaFave 1992	Type vertical Francis Head 29' Flow run-of-river Max capacity of 625 cfs MW 2.5 Dia not given 15 blades RPM 120	Net recovery of entrained fish	Mixed resident species	Variable	Variable	6.1% (intermediate) 4.9% turbine-related injury	
Essex Merrimack River Massachusetts (Knight & Kurmeskus 1982)	Type bulb Head 29' Flow 4,500 cfs MW 7.8 Dia 12' RPM 129.6	Radio telemetry	Atlantic salmon	Smolt 225-330 mm	6-7.8 MW	2.0% (within 2 hrs)	

*(listed alphabetically by project name)

Table 4-6 (pg 3 of 7)

SUMMARY DATA FROM TURBINE STUDIES REVIEWED

Site* Location Reference	Description of Turbine(s) Tested	Study Method	Species Tested	Fish Size	Turbine Operation	Estimated Mortality	Comments
Finch Pruyn Hudson River New York (RMC, 1990a)	Type horizontal Francis Unit #4 quad runner Unit #5 double runner Head 48' Flow 920 cfs/unit MW 12.7 (total for 5 units) Dia 41" RPM 225	Self-ediating balloon tags	Smallmouth bass - - Smallmouth bass - -	< 7.5" (191 mm) 7.5-9.0" (191-229 mm) 9.3-12.0" (236-305 mm) < 7.5" (191 mm) 7.5-9.0" (191-229 mm) 9.3-12.0" (236-305 mm)	Unit #4 60" - wicket gate - Unit #5 60" - wicket gate -	5.0% (intermediate) 9.0% 7.0% 6.0% (intermediate) 9.0% 29.0%	Latent mortality (48-hr) averaged 35%, but was highly variable due to poor initial conditions of some groups Latent mortality (48-hr) averaged 5%, 2% once adjusted for control mortality
Five Channels Au Sable River Michigan (LMS, 1991)	Type Quadruplex horizontal Francis Head 36' Flow not given MW not given Dia 55" 16 blades RPM 150	Net recovery of entrained fish	Bluegill Golden/Common shiner Northern pike Rainbow trout Spotted shiner Walleye White sucker Yellow perch All species combined	72-189 mm 113-244 mm 62-153 mm 111-207 mm 209-415 mm 69-137 mm 275-360 mm 69-132 mm 78-139 mm 231-384 mm 81-241 mm 225-442 mm 78-187 mm 131-283 mm	81.10% wicket gate 1,034-1,167 cfs - - - - - - - - - -	*6.4% (48-hr) *10.8% 18.2% 14.5% 8.7% 4.2% 22.2% *63.6% 28.8% 23.3% 11.4% 28.6% *27.9% *22.9% 20.8%	*Indicates mortality estimate affected by fungus or debris
Fourth Lake Sissiboo River Nova Scotia (Huggles et al. 1990)	Type horizontal tube "S turbine" Head 76' Flow 529 cfs MW 3.1 Dia 5.5' 6 blades 360 rpm	Net recovery of entrained and introduced fish	Brook trout Alewife Yellow perch Atlantic salmon	105-114 mm 84-98 mm 78-105 mm 164-172 mm	80% - wicket gate - - -	13.18% (intermediate) 9.14% 14.25% 16.0%	Values represent the authors best estimate based on several years of data on entrained and introduced fish
French Landing Huron River Michigan (Burr & Sundquist 1991)	Type vertical Francis Head 32' Flow 800 cfs MW 1.8 Dia 106" RPM 120	Net recovery of entrained fish	Mixed resident species 76% Black crappie 18% Bluegill 6% other species	not given	Variable	Total with external injury < 1%	Latent mortality least complicated by high control mortality
Goodyear Lake N Branch Susquehanna River New York (Glass et al. 1982 and Gebo & Walk, 1983)	Type Ossberger crossflow (2 units) Head 32' Flow 298 cfs, 402 cfs MW 0.65, 0.95 Dia 3.7, 4.1' RPM 135, 104	Net recovery of introduced fish	Rainbow trout Steelhead trout Atlantic salmon Striped bass American shad	85 mm 10 280 mm 67-70 mm 136 mm 84-90 mm	Variable data combined from both units - - - 850 kW unit operated at 300-540 kW	8.0% (48 hrs) 72.0% 11.2% (immediate) 38.5% 50.0%	Mortality of all three salmonid species was similar and varied little between turbines or over the range of operation levels tested Net injury resulted in high losses of test and control groups following recovery and probably contributed to immediate mortality

*(listed alphabetically by project name)

Table 4-6 (pg 6 of 7)

SUMMARY DATA FROM TURBINE STUDIES REVIEWED

Site* Location Reference	Description of Turbine(s) Tested	Study Method	Species Tested	Fish Size	Turbine Operation	Estimated Mortality	Comments
Pickett Sturgeon River Michigan (RMC 1990a)	Type Francis Head 54' Flow 326 cfs MW 1.1 Dia. 53 3/8" RPM 257	Net recovery of entrained fish	Mixed resident species 45% Bluegill 40% Black crappie 15% other	84% < 100 mm 16% 101-200 mm 1% > 200 mm	Variable	2.2% (intermediate)	Based on visible injuries. Not mortality high on all groups
		Net recovery of introduced fish	Bluegill	1-3" (25-76 mm) 3-5" (76-127 mm) > 5" (127 mm)	42% wicket gate - -	3.3% (immediate) 7.5% 14.3%	Latent mortality tests conducted by high control mortality for all introduced fish
			White sucker	5-8" (127-200 mm) > 10" (254 mm)	- -	26.3% 64.3%	
			Golden Shiner	2-4" (51-102 mm)	-	6.1%	
Hadley Ohio River, Ohio/West Virginia (WAPORA 1987)	Type horizontal bulb Head 22' Flow 8,000 cfs MW 24 Dia 25.3' 3 blades RPM 82.1	Net recovery of entrained fish with a partial recovery net (3.7% efficiency)	Drum	not given	Variable	6.0%	Mortality rates were adjusted for entrainment and net injury (allowing duplication of the cited reference). The rates presented here are the total values agreed on with the fisheries agencies
			Gizzard shad	not given	-	6.5%	
			Game species	Variable	-	6.0%	
		Net recovery of introduced fish with a partial recovery net (3.7% efficiency)	Drum	10.6" (269 mm)	-	Visible turbine injury 35.4% Severe turbine injury 1.6%	Latent mortality corrected by high control mortality
			Gizzard shad	6.2" (158 mm)	-	Visible turbine injury 6.5% Severe turbine injury 4.3%	
Rock Island Columbia River Washington (Olson & Kaczynski 1980)	Type horizontal bulb Head 40' Flow 18,000 cfs MW 40 Dia not given RPM not given	Recovery of entrained fish at downstream dams (17.9%-18.2% of fish recovered)	Coho smolts	111-116 mm	91.5% efficiency	7.0% (from recovery of downstream dams)	Mortality of fish passing through the bulb turbines at Rock Island dam appears to be lower than the 11-13.5% mortality rate noted for vertical Kaplan units at other Columbia River projects
			Steelhead smolts	166 mm	93.5% efficiency	3.1%	
Hydro Muskegon River Michigan (RMS 1991)	Type vertical Francis Head 39.2' Flow not given MW not given Dia 60" 15 blades RPM 150	Net recovery of introduced fish	Bluegill	50-155 mm 108-180 mm	67-100% wicket gate 308-1216 cfs	4.0% (48 hr) 14.8%	
			Golden/Common shiner	70-112 mm	-	46.3%	
			Largemouth Bass	101-173 mm	-	2.5%	
			Northern pike	74-139 mm	-	20.0%	
			Rainbow trout	248-420 mm	-	16.0%	
			Spotted shiner	57-158 mm	-	10.1%	
			Walleye	278-401 mm	-	38.8%	
			White sucker	58-174 mm	-	20.5%	
			Yellow perch	155-200 mm	-	13.8%	
			All species combined	50-315 mm	-	14.8%	
				102-413 mm	-	14.0%	
				50-169 mm	-	8.2%	
				121-310 mm	-	11.9%	
					-	16.1%	
Tomahawk Wisconsin River Wisconsin (Paines & Moore 1991)	Type Sampson (Unit #3) Vertical propeller (Unit #5) Head 18.22' Flow 460 cfs (Unit #4) 626 cfs (Unit #5) MW not given Dia 35" (Sampson) 14 blades 82" (propeller) 4 blades RPM	Net recovery of entrained fish	Mixed resident species	Variable: 67% young of year (catfish and gizzard)	Unit #4 (variable) Unit #5 (variable)	1.3% visible turbine injury (48 hr) 2.1% visible turbine injury (48 hr)	Most delayed mortality was probably associated with non-induced injury. Delayed mortality of net controls averaged 41.7% at Unit #4 and 18.8% at Unit #5. Some of the control mortality was caused by poor holding conditions
		Net recovery of introduced fish	Mixed fish/fishery fish		Unit #4 (variable) Unit #5 (variable)	32.6% visible turbine injury (48 hr) 3.0% visible turbine injury (48 hr) 39.4% 8.5% visible turbine injury (48 hr) 51.4%	

*(listed alphabetically by project name)

Table 4-6 (pg 7 of 7)

SUMMARY DATA FROM TURBINE STUDIES REVIEWED

Site* Location Reference	Description of Turbine(s) Tested	Study Method	Species Tested	Fish Size	Turbine Operation	Estimated Mortality	Comments
Safe Harbor Susquehanna River Pennsylvania (RMC 1991a)	Type vertical "mixed flow" propeller Head 55' Flow 5,200 cfs MW 37.5MW Dia 240"-7 blades RPM 76.6	Self-validating bulkhead logs	American shad	Juvenile 55-140 mm	Mixed-flow unit at peak efficiency (uninvented)	2.0% (immediate) 0.0% (24-hr) 0.0% (48-hr)	The mixed-flow propeller unit is injurious when an aeration system and it operated in a vented mode during periods of low dissolved oxygen. The turbine is not normally operated in the vented mode when most shad outmigrate
					Mixed-flow unit at peak efficiency (vented)	4.0% (immediate) 0.0% (24-hr) 17.0% (48-hr)	
	Type vertical Kaplan Head 55' Flow 8,300 cfs MW 32MW Dia 220"-5 blades RPM 109.1	Self-validating bulkhead logs			Kaplan unit at peak efficiency (uninvented)	2.0% (immediate) 0.0% (24-hr) 0.0% (48-hr)	
Thornapple Flambeau River Wisconsin (Everhart 1994)	Type fixed blade propeller Head 15' Flow 700 cfs MW 0.7 Dia 110" RPM 120	Net recovery of entrained fish	Mixed resident species	Variable	Variable	Kaplan 4.7% (intermediate)	Based on questionable response. Report should be available at a later date
Tower Black River Michigan (Johnson & Nelson 1991)	Type vertical Francis Head 20' Flow 180 cfs MW 0.28 Dia not given, 6 blades RPM 225	Net recovery of introduced fish	Mixed resident species	117-352 mm	68-100% wicket gate	28.0% (immediate) 9.0% (72 hr) 37.0% (total) Cause of turbine injury was 12% for fish 100-199 mm, 33% for fish 200-299 mm, 52% for fish 300-600 mm	High control mortality makes estimate of delayed mortality uncertain
Valley Ohio River Ohio/Kentucky (Odin et al 1986)	Type horizontal bulb Head 30' Flow 11,866 cfs MW 23 Dia 20' RPM not given	Radio telemetry	Sunfish	Range 210-300 mm avg. 252 mm	Variable	14.0% (intermediate)	Evaluation of Dig regurgitation indicates that mortality was probably lower
Wisconsin River Division Wisconsin River Wisconsin (Hertz 1951)	Type horizontal Francis Head 18' Flow approx. 430 cfs MW 800 HP hydromechanical Dia 53 1/2" RPM 240	Net recovery of entrained fish	Mixed resident species	56.0% < 100 mm	Variable	Total dead 64% Total with turbine injury 8%	Mortality estimation corrupted by high net injury. Fish introduced directly into the recovery net had an immediate mortality of 40% for fish < 70 mm and 25% for fish 70-100 mm

Racine

Valley

Table 4-7 (pg 3of 6)

DATABASE ON TURBINE INJURY AND MORTALITY BY SPECIES GROUP AND TURBINE TYPE

SPECIES/TURBINE DATA GROUP		TURBINE CHARACTERISTICS						TEST RESULTS					
									FISH SIZE			MORTALITY (%)	
SITE	REFERENCE	TURBINE TYPE	HEAD (FEET)	TURBINE DIAMETER (INCHES)	RPM	PERIPHERAL VELOCITY (FPS)	TURBINE OPERATION	SPECIES	MIN	MAX	MEDIAN	LOW HIGH	BEST
MORTALITY - CENTRARCHIDS													
FRANCIS TURBINES													
Prickett	RMC 1991b	Francis	54	ng	ng	39.3	42%	Bluegill	25	76	51		2.0
Rogers	LMS 1991	Francis	39.2	60	150	40.2	82-100%	Bluegill	46	155	101		4.0
Finch, Pruyn	RMC 1990a	Francis	48	41	225	40.2	60%, #4	Smallmouth bas	101	191	146		5.0
Finch, Pruyn	RMC 1990a	Francis	48	41	225	40.2	60%, #5	Smallmouth bas	101	191	146		6.0
Finch, Pruyn	RMC 1991b	Francis	48	41	225	40.2	60%, #4	Smallmouth bas	236	305	271		7.0
Prickett	LMS 1991	Francis	48	41	ng		42%	Bluegill	76	127	102		7.5
Hardy	RMC 1990a	Francis	54	ng	163.6	50.8	ng	Bluegill	120	186	153		8.5
Finch, Pruyn	RMC 1990a	Francis	100.2	83.75	225	40.2	60%, #4	Smallmouth bas	191	229	210		9.0
Finch, Pruyn	LMS 1991	Francis	48	41	225	40.2	60%, #5	Smallmouth bas	191	229	210		9.0
Alcona	LMS 1991	Francis	48	41	90	39.3	60-75%	Smallmouth bas	58	154	106		9.8
Hardy	RMC 1991b	Francis	43	100	163.6	59.8	ng	Bluegill	79	149	114		10.5
Prickett	LMS 1991	Francis	100.2	83.75	ng		42%	Bluegill	127		127		14.3
Rogers	LMS 1991	Francis	54	ng	150	39.3	82-100%	Bluegill	108	180	144		14.8
Alcona	LMS 1991	Francis	39.2	60	90	39.3	60-75%	Bluegill	95	206	151		15.9
Hardy	LMS 1991	Francis	43	100	150	39.3	82-100%	Bluegill	74	139	107		22.6
Finch, Pruyn	RMC 1990a	Francis	39.2	60	163.6	59.8	ng	Largemouth bas	80	162	121		20.8
		Francis	100.2	83.75	225	40.2	60%, #5	Largemouth bas	236	305	271		29.0
		Francis	48	41				Smallmouth bas					11.7
MORTALITY - PERCIDS													
FRANCIS TURBINES													
Hardy	LMS 1991	Francis	100.2	83.75	163.6	59.8	ng	Yellow perch	122	293	208		4.5
Rogers	LMS 1991	Francis	39.2	60	150	39.3	82-100%	Yellow perch	98	169	134		8.2
Rogers	LMS 1991	Francis	39.2	60	150	39.3	82-100%	Yellow perch	131	310	221		11.9
Rogers	LMS 1991	Francis	39.2	60	150	39.3	82-100%	Walleye	155	600	378		12.8
Hardy	LMS 1991	Francis	100.2	83.75	163.6	59.8	ng	Yellow perch	85	173	129		16.9
Hardy	LMS 1991	Francis	100.2	83.75	163.6	59.8	ng	Walleye	148	638	393		22.7
Five Channels	LMS 1991	Francis	36	55	150	36.0	81-90%	Walleye	231	384	308		23.3
Five Channels	LMS 1991	Francis	36	55	150	36.0	81-90%	Walleye	78	139	109		28.8
Alcona	LMS 1991	Francis	43	100	90	39.3	60-75	Yellow perch	75	241	158		44.9
Alcona	LMS 1991	Francis	43	100	90	39.3	60-75	Walleye	132	361	247		61.3
													33.6

Table 4-7 (pg 4of 6)

DATABASE ON TURBINE INJURY AND MORTALITY BY SPECIES GROUP AND TURBINE TYPE

SPECIES/TURBINE DATA GROUP		TURBINE CHARACTERISTICS						TEST RESULTS					
									FISH SIZE			MORTALITY (%)	
SITE	REFERENCE	TURBINE TYPE	HEAD (FEET)	TURBINE DIAMETER (INCHES)	RPM	PERIPHERAL VELOCITY (FPS)	TURBINE OPERATION	SPECIES	MIN	MAX	MEDIAN	LOW HIGH	BEST
MORTALITY - ESOCIDS													
FRANCIS TURBINES													
Five Channels	LMS 1991	Francis	36	55	150	36.0	81-90%	Northern pike	299	415	357		8.7
Alcona	LMS 1991	Francis	43	100	90	39.3	60-75%	Grass pickerel	177	293	235		13.3
Rogers	LMS 1991	Francis	39.2	60	150	39.3	82-100%	Northern pike	248	420	334		16.6
Hardy	LMS 1991	Francis	100.2	83.75	163.6	59.8	ng	Northern pike	321	437	379		24.0
Alcona	LMS 1991	Francis	43	100	90	39.3	60-75%	Northern pike	295	456	376		48.8
													22.3
MORTALITY - CATASTOMIDS													
FRANCIS TURBINES													
Alcona	LMS 1991	Francis	43	100	90	39.3	60-75%	White sucker	111	278	195		5.6
Alcona	LMS 1991	Francis	43	100	90	39.3	60-75%	White sucker	161	395	278		9.6
Five Channels	LMS 1991	Francis	36	55	150	36.0	81-90%	White sucker	81	241	161		11.4
Rogers	LMS 1991	Francis	39.2	60	150	39.3	82-100%	White sucker	162	413	288		14.0
Rogers	LMS 1991	Francis	39.2	60	150	39.3	82-100%	White sucker	82	219	151		19.8
Hardy	LMS 1991	Francis	100.2	83.75	163.6	59.8	ng	White sucker	96	237	167		23.1
Five Channels	LMS 1991	Francis	36	55	150	36.0	81-90%	White sucker	225	442	334		28.6
Prickett	RMC 1991b	Francis	54	ng	ng		42%	White sucker	127	203	165		29.2
Hardy	LMS 1991	Francis	100.2	83.75	163.6	59.8	ng	White sucker	137	375	256		35.5
Prickett	RMC 1991b	Francis	54	ng	ng		42%	White sucker	254		254		64.3
													24.0
MORTALITY - CYPRINIDS													
FRANCIS TURBINES													
Prickett	RMC 1991b	Francis	54	ng	ng		42%	Golden Shiner	51	102	77		6.1
Rogers	LMS 1991	Francis	39.2	60	150	39.3	82-100%	Gold&com. shin	103	173	138		7.5
Hardy	LMS 1991	Francis	100.2	83.75	163.6	59.8	ng	Gold&com. shin	113	204	159		11.3
Hardy	LMS 1991	Francis	100.2	83.75	163.6	59.8	ng	Gold&com. shin	74	165	120		14.5
Five Channels	LMS 1991	Francis	36	55	150	36.0	81-90%	Gold&com. shin	111	207	159		14.5
Alcona	LMS 1991	Francis	43	100	90	39.3	60-75%	Gold&com. shin	101	188	145		15.3
Five Channels	LMS 1991	Francis	36	55	150	36.0	81-90%	Gold&com. shin	62	153	108		18.2
Alcona	LMS 1991	Francis	43	100	90	39.3	60-75%	Gold&com. shin	65	129	97		19.1
Rogers	LMS 1991	Francis	39.2	60	150	39.3	82-100%	Spottail shiner	58	174	116		26.5
Alcona	LMS 1991	Francis	43	100	90	39.3	60-75%	Spottail shiner	81	128	105		40.5
Rogers	LMS 1991	Francis	39.2	60	150	39.3	82-100%	Gold&com. shin	70	114	92		46.3
													20.0

considerable overlap between the size groups used in different studies. The results of this analysis are presented below.

4.2.2.1 Comparisons Among Species

The average mortality rates determined for various groups of species passing through Francis, Kaplan and Bulb turbines are presented in Table 4-8. Although only a limited number of studies using salmonids were included in the data base, the average mortality calculated for salmonids passing through Francis and Kaplan turbines falls within the middle of the range shown in previous reviews (see Figures 4-7 and 4-9).

Overall, the mortality rates reported for non-salmonid species are consistent with the existing data base on salmonids, indicating that mortality is usually highest at Francis turbines and lowest at bulb turbines. One of the most important findings was the overall comparability of mortality rates for clupeid and salmonid species. One early study (Taylor and Kynard 1985) had indicated that juvenile clupeids suffered an immediate mortality rate of 62-82% in passing through a Kaplan turbine. More recent studies at this and other sites have demonstrated much lower rates of immediate mortality, averaging 3.6% at Kaplan turbines and 16.0% at Francis turbines (Table 4-8).

Due to problems of high control mortality, the delayed mortality of juvenile clupeids was successfully evaluated in only three of these studies. Total mortality (including immediate mortality) was estimated at 2% for juvenile American shad 48 hrs after passing through a Kaplan turbine at the Safe Harbor Project (RMC 1991a). At the Holtwood Project, the total mortality of juvenile American shad was estimated at 31.7% and 22.0% 24 hours after passing through two Francis turbines (RMC 1992c). Total mortality at 48 hrs was estimated at 40% at the first turbine, while high control mortality (47%) invalidated tests at the second turbine. The mortality estimates at Holtwood correspond closely with the proportion of fish observed with visible injuries at the two turbines (38% and 37%, respectively). Mortality of juvenile blueback herring was estimated at 4% (immediate) with no additional mortality 48 hrs after passage through a Kaplan turbine at the Crescent Hydroelectric Project (RMC 1992a).

Mortality rates indicated for other species groups are also quite uniform, particularly for the data on Francis units. One factor which may account for the relatively consistent results shown for Francis units is that most of the observations come from a single study (LMS 1991), which provided information for ten species at four different sites using a standardized methodology. It is of particular interest that species

Table 4-8

AVERAGE MORTALITY RATES BY SPECIES GROUP AND TURBINE TYPE

Species Group	Francis Turbines			Kaplan Turbines			Bulb Turbines		
	Sites[1]	N[2]	Avg.	Sites[1]	N[2]	Avg.	Sites[1]	N[2]	Avg.
Salmonids	4	8	18.2%	2	2	7.6%	2	3	4.0%
Clupeid juveniles	3	3	16.0%	4	6	3.6%	0	0	na
Clupeid adults	1	1	28.6%	2	2	19.1%	0	0	na
Resident (entrained)	4	4	5.8%	2	2	6.3%	0	0	na
Resident (introduced)	1	1	37.0%	2	2	30.2%	0	0	na
Centrarchids	6	17	11.7%	2	3	8.5%	0	0	na
Percids	4	10	23.6%	0	0	na	1	1	14.6%
Esocids	4	5	22.3%	0	0	na	0	0	na
Catostomids	5	10	24.0%	0	0	na	0	0	na
Cyprinids	5	11	20.0%	0	0	na	0	0	na
Ictalurids	0	0	na	1	4	11.3%	0	0	na
AVERAGE	--	--	20.7%	--	--	12.4%	--	--	9.3%

[1] Number of individual turbines tested (more than one unit at some sites).

[2] Number of observations including tests conducted with different size groups or at different operating conditions.

Several studies have been conducted to assess mortality of fish passing through the STRAFLO turbine at the tidal Annapolis Generating Station located on the Bay of Fundy in Nova Scotia. Studies on the passage of adult American shad conducted in 1985 using sonic tags indicated a single pass mortality of 46.3% (Hogans and Melvin 1985, cited from Baker and Daborn 1990). The test program was refined and repeated in 1986, resulting in an estimated mortality of 21.3% (Hogans 1986, cited from Baker and Daborn 1990). The mortality of juvenile clupeids passing through the Annapolis turbine was estimated at 46.3% based on examination of injuries on entrained fish in 1985 and 1986 (Stokesbury and Dadswell 1991). This estimate is corrected for a control (net) injury rate of 18.6%, determined from 43 fish that were held in the net for 30-60 minutes. It appears that entrained fish may have suffered more extensive net injury, since the net was fished for up to five hours at a time (in 1985 all fish were recovered in 5-hour sets, and in 1986 fish were recovered in 0.5, 1, 2 and 5-hour sets). Alternative mortality estimates for juvenile clupeids at Annapolis ranging from 1-2.5% were developed by Ruggles and Palmeter (1989) based on models on the likelihood of blade contact and from the relationship of mortality to peripheral runner speed (see below). Mortality of juvenile clupeids at this site is still the subject of considerable discussion.

The mortality of several species of fish passing through a tube turbine was examined at the Fourth Lake project on the Sissiboo River in Nova Scotia (Ruggles and Palmeter 1989, Ruggles et al. 1990, Ruggles 1992). Turbine mortality estimates were shown to be strongly affected by the level of stress imposed by experimental protocol, even after correction for control mortality. Evaluating several years of data, the author's best estimates for mortality were approximately 9-14% for juvenile alewife (avg. 84-98 mm), 13-18% for brook trout (avg. 105-114 mm), 16% for Atlantic salmon smolts (avg. 164-172 mm) and 14-25% for yellow perch (avg. 78-105 mm). Mortality rates for alewife were compared to those observed in studies of the STRAFLO turbine at Annapolis (reported above) and estimates derived from models on the likelihood of blade contact and the relationship of mortality to peripheral runner speed observed in other studies (Ruggles and Palmeter 1989). The models produced mortality estimates of 12.5-14% for Fourth Lake and 1.2-2.5% for Annapolis. The lower mortality rate predicted by the model for the Annapolis turbine was related to its larger size and lower peripheral runner speed compared to Fourth Lake (see turbine data presented in Table 4-6).

Available information on the mortality of fish passing through Ossberger Cross-Flow turbines is limited to a single study (Gloss et al. 1982; Gloss and Wahl 1983) conducted at Goodyear Lake on the North Branch of the Susquehanna River in New York. Mortality of Atlantic salmon, rainbow trout and steelhead was similar between species and at different turbine operation levels, but was highly size-

dependent. For salmonid species, 48-hour mortality ranged from 15% for 85 mm fish to 72% for 280 mm fish. High mortality of larger fish passing through these turbines seems inevitable due to narrow spacing between the runner blades (30 and 40 mm in the two units tested). Immediate mortality of striped bass ranged from 11.2% for 67-70 mm fish to 38.5% for 136 mm fish. Immediate mortality of juvenile American shad (84-90 mm) averaged 50%. The cumulative stress of turbine passage and injury caused during recovery may have resulted in over-estimation of turbine mortality for both striped bass and American shad.

4.2.2.4 Mortality at Spillways and Fish Bypasses

Several recent studies provide information on the relative survival of fish passing over spillways and through fish bypasses. Studies are being conducted at Bonneville Dam on the Columbia River to assess the relative survival of subyearling chinook salmon smolts passing via the turbines, the spillway and the fish bypass system (Ledgerwood et al. 1990, Ferguson 1991). The results indicate that the survival of spill groups (tested in 1989 only) exceeded that of fish released into the frontroll (surface eddy downstream of the draft tube) of the turbine discharge, apparently due to lower susceptibility to predation. The recapture rates of fish released in 1988-89 into the turbine and bypass system averaged 2-3% and 10%, respectively, less than that of frontroll release groups. Losses from predation at the exit to the bypass system appear to have been of greater magnitude than losses that occurred during passage over the spillway or through the Kaplan turbines. Long-term survival will be determined from adult returns.

The mortality of Atlantic salmon smolts passing through an ice-log sluiceway used as a fish bypass at Bellows Falls on the Connecticut River in Vermont was evaluated using balloon tags (RMC 1991c). The sluice is made of concrete and slopes approximately 30 feet over its 500-foot length, terminating in a vertical drop of approximately 30 feet into the tailrace. Immediate mortality was 0-4% depending on whether unrecovered fish were counted as mortalities. No delayed mortality was observed after 48 hrs.

Preliminary results on passage of juvenile blueback herring over a spillway at the Crescent Hydroelectric Project on the Mohawk River in New York were reported by RMC (1992a). The vertical drop at the spillway was approximately 12 feet and the spill flow was approximately 40 cfs. Results indicated no immediate mortality, and mortality of 11.7% at 48 hours after passage.

Section 7
Document 13

Hydro Québec

ÉVALUATION DE LA MORTALITÉ DES POISSONS PASSANT PAR LA CENTRALE HYDROÉLECTRIQUE DE LA CHUTE-BELL (2000)

RAPPORT FINAL

Hydro Québec Centre de documentation
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Hydro Québec

ABSTRACT

Author(s) and title (for reference) :

THERRIEN, Jean et Claude LEMIEUX. 2000. *Évaluation de la mortalité des poissons passant par la centrale hydroélectrique de la Chute-Bell (2000).* Prepared by Genivar Consulting Group for the Direction Expertise et Support technique de production, Unité hydraulique et Environnement, Hydro-Québec 58 p. and appendices.

English title : Evaluation of fish mortality after passage through the Chute-Bell Hydroelectric Generating Station (2000).

Abstract :

Fish mortality after passage through a turbine at the Chute-Bell Hydroelectric Generating Station on the Rouge River was estimated between May 26 and June 1, and on June 15, 2000. The Kaplan double-setting turbine generates 4.95 MW at a nominal flow of 40 m^3/s and it is preceded by 6 stay vanes and 16 wicket gates. The fish species investigated are smallmouth bass (*Micropterus dolomieui*), considered a sturdy species, and rainbow trout (*Oncorhynchus mykiss*), a more fragile species. The rainbow trout came from a fish hatchery and the smallmouth bass from a natural pond.

The specimens were distributed in 100 mm length classes, five for rainbow trout (100 to 600 mm) and three for smallmouth bass (100 to 400 mm). The fish were released in the water intake at three different flows: approximately 27, 34 and 39 m^3/s. The release device comprised a water tank on which a rigid poly-ethylene pipe was fixed, extended by a semi-rigid rubber tubing, 15 cm in diameter. A net, filtering almost 99 % of the flow, was set at the turbine exit to catch the fish passing through. Groups of control fish were also released at the turbine exit to estimate mortality caused by handling and by the collecting net. After their capture, the fish were kept in tanks for 96 hours to estimate delayed mortality.

The recapture rate was 100 % for the control groups and varied from 87.6 % to 95 % for the groups released in the turbine. The instantanoeus mortality rate of rainbow trout after turbine passage varied from 35.4 % at 27 m^3/s to 41.5 % at 38 m^3/s. The delayed mortality rate (after 96 hours) increased significantly ($p<0.05$) with the discharge, from 35.6 % at 27 m^3/s to 57.8 % at 38 m^3/s. Conversely, the instantanoeus and delayed (96 hours) mortality rates of smallmouth bass decreased with an increase in flow. The instantaneous mortality rate varied from 17.9 % 28 m^3/s to 0 % at 39 m^3/s. The delayed mortality rate (96 hours) ranged from 20.8 % at 28 m^3/s to 12.8 % at 39 m^3/s. The mortality rate increases significantly ($p<0,05$) with fish size for both species. At similar length classes, mortality is higher for rainbow trout than for smallmouth bass. This difference may be caused by their different sturdiness or by the origin of the rainbow trout (fish hatchery). In general, the latter are less resistant than wild populations.

The mortality rates by length class were compared with those of a theoretical model based on data collected at 50 hydroelectric generating stations on the Garonne River (France). The values obtained for smallmouth bass correspond to those predicted by the model, while for rainbow trout they are way above.

Key words : mortality, Generating Station, Kaplan turbine, rainbow trout, smallmouth bass, Chute-Bell Generating Station

Distribution list: Ministère de l'Environnement du Québec, Société de la faune et des parcs du Québec, Fisheries and Oceans Canada, Canadian Electrical Association

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