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Feasibility Study for Evaluating Redistribution of Juvenile Salmon in the McNary Bypass Channel Using Behavioral Technologies: 1996

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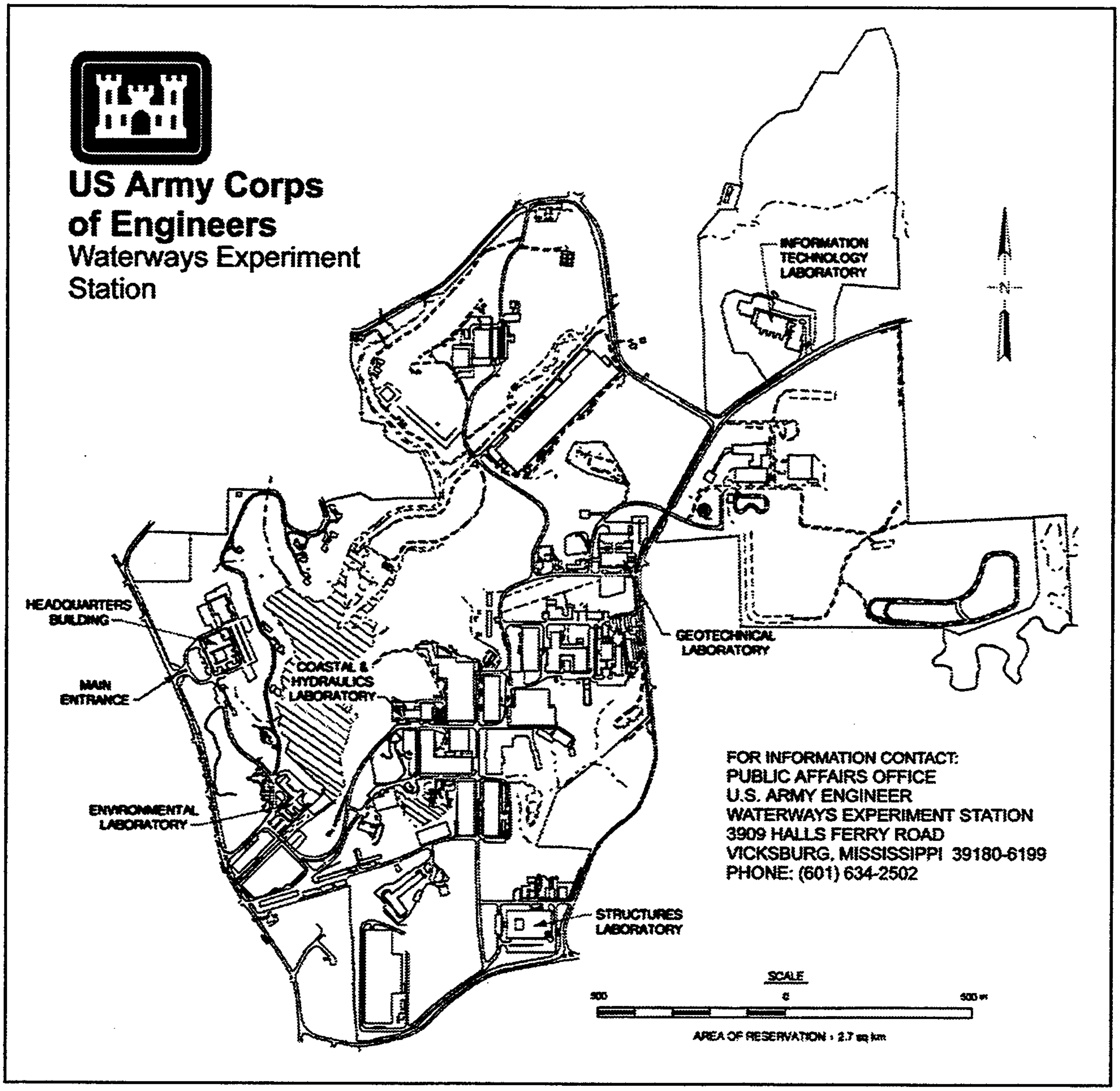
Prepared for U.S. Army Engineer District, Walla Walla



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Preface

This report was prepared by the Fisheries Engineering Team, Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES),with support from the AScI Corporation (AScI), 1365 Beverly Road, McLean, VA 22101.

The report was prepared by Messrs. Peter N. Johnson (AScI, Inc.) and Gene R. Ploskey (WQCMB), Drs. Thomas J. Carlson (WQCMB) and John M. Nestler (WQCMB), and Mr. James Evans, Instrumentation Systems Development Division, Information Technology Laboratory, WES, and was conducted under the general supervision of Dr. Mark S. Dortch, Chief, WQCMB; Dr. Richard E. Price, Chief, EPED; and Dr. John Harrison, Director, EL. Messrs. Mike Burczinski, Dyntel Corporation, and Grant Law, contract student, EL, helped generate some of the figures in the report.

Local support was provided by Mr. Brad Eby, Senior Biologist, McNary Dam, U.S. Army Engineer District, Walla Walla. Dr. Nestler and Messrs. Evans and Lonnie Smith, Instrumentation Systems Development Division, conducted the sound field characterization portion of this study.

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Summary

Outmigrant juvenile salmon in the Columbia and Snake River System encounter numerous obstacles in route to the marine environment, including hydropower projects. Quick and efficient passage around or through hydropower dams is key to the survival of young salmon. In recent years, surface collection of migrant fish has become an experimental tool for bypassing smolts at U.S. Army Corps of Engineers projects. A necessary element of surface collector technology is the requirement of handling increased volumes of water in outfall sluiceways and bypass channels. The result of increased water volume in outfall channels may be a much higher incidence of impingement and injury of young salmon along dewatering screens. Redistributing juvenile salmon migrants away from dewatering structures using behavioral technologies could resolve potential impingement problems.

Evaluation of behavioral technologies to redistribute juvenile salmon in dewatering sections of a bypass channel encompasses two study years. The first year (Fiscal Year 1996) was more preliminary in nature and focused on two objectives: (a) characterize the acoustic environment in selected areas of the McNary bypass channel; and (b) evaluate the feasibility of using infrared lights and infrared-sensitive underwater video cameras to image salmon smolt in the McNary channel.

We characterized underwater sound fields by measuring sound pressure and structural vibration over a 3-day period in September 1996. Measurements of the pressure component of underwater sound in selected areas of the McNary channel were made using a Multi Sensor Fish Surrogate (MSFS), a device that emulates the spatial pattern of fish lateral line sensors. High sound pressure levels at frequencies less than 24 Hz were observed at all sampled locations. The maximum sound pressure levels (172 dB referenced to 1 µPa) were in the frequency range 0.125 to 1 Hz. Within the 1- to 24-Hz frequency range, the distribution of infrasound observed in the channel exhibited a pattern with almost all of the highest readings occurring in the transition between the concrete lining and the discharge duct and reduced readings near the water level indicator. Additionally, sound pressure levels measured at two depths per station were observed to decrease toward the surface. Vibration levels in and around the channel were quantified using a low G range Kistler servo-accelerometer. Substantial vibration of the channel lining was observed at frequencies less than 24 Hz, especially near the water level indicator.

We assessed the utility of sampling techniques needed to evaluate the effectiveness of behavioral technologies for redistributing smolts in the dewatering sections of the McNary bypass channel. During spring and summer of 1996, we examined the feasibility of using infrared-sensitive underwater cameras to image smolt passage in the bypass channel. Results from these studies indicate that infrared lights and underwater cameras can effectively image smolts in the channel but visibility is limited to approximately 0.91 m. We tested different lighting schemes and found forelighting to be most effective for imaging smolt-sized targets. We compared time-lapse with real-time recording and determined the former to be ineffective due to the reduced number of framed images captured in the high flows of the McNary channel.

It is likely that fish passage and distribution within the dewatering portion of the McNary Dam bypass channel are strongly affected by patterns of infrasound. We recommend that a detailed acoustical/structural evaluation of the channel be conducted independent of any effort to modify the bypass to increase capacity, particularly in the area where the concrete lining transitions to the stainless steel discharge pipe. The study should include a full array of operational conditions and measurements made with accelerometers to separate hydrodynamic (local flow water particle acceleration in addition to bulk transport) from acoustical (sound pressure) effects.

Infrared lights and infrared-sensitive video cameras demonstrated promise as a means of capturing smolt passage in the McNary bypass and ultimately as a tool to evaluate effectiveness of behavioral technologies for redistributing salmon smolts in collection channels or dewatering facilities. Limitations of lighting orientation schemes and video sampling rates allow us to optimize sampling configurations for future studies in bypass systems.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers

Introduction

The U.S. Army Corps of Engineers operates and maintains hydropower dams on rivers that support valuable but dwindling anadromous fisheries in the northwestern U.S. Outmigrating juvenile salmonids in the Columbia and Snake Rivers encounter numerous obstacles in route to the marine environment, including hydropower projects. Generally, smolt passage routes through power production facilities include spillways, ice and trash sluiceways, and turbine intakes. Once committed to turbine passage, traveling or bar screens 'guide' a proportion of fish to gatewell orifices and into channels that bypass turbine galleries and eventually deposit the juvenile salmon into the tailrace. The USACE District, Walla Walla, is presently testing alternative surface collector designs to enhance smolt survivability during the outmigration. If testing yields promising results, full-scale surface collectors may be constructed at several federal dams on the main stem Columbia River.

Surface collectors at Columbia River dams will require juvenile bypass facilities and other channels to handle substantially more water. Increasing sluiceway capacity to meet target water velocities at the openings of surface collectors will potentially exceed the hydraulic velocity criteria of dewatering screens presently used to concentrate salmon smolts prior to passage. The perceived concern in violating of this criteria may result in increased impingement of smolts on dewatering screens. If smolts could be repelled from the immediate vicinity of the screen surface, then it may be possible to increase velocity of water through screens without increasing impingement. A number of different studies has shown that salmon life-stages from swim-up fry to adults will avoid infrasound (sounds < 25 Hz). The Army Corps of Engineers, Walla Walla District, wishes to explore the possibility of using infrasound to repel fish from the immediate vicinity of the dewatering screen surface so that future application of fish bypass systems using large scale dewatering (e.g., 300 cfs surface bypass collectors) can be used without compromising safe passage for juvenile migrants.

Background

The water-particle-motion component of infrasound has been shown to be an effective stimulus for eliciting avoidance responses in Atlantic salmon smolts (Knudsen et al. 1992, 1994; Taft et al. 1995), steelhead smolts (Knudsen et al., In Prep.), hatchery-reared and wild chinook salmon smolts (Mueller et al., 1998; Knudsen et al., In Prep.), and rainbow trout (Mueller et al. 1998). A sound field consists of both movement of the particles comprising the medium as well as changes in local pressure. The particle-motion component predominates near the sound source (within the near field of the sound source). Within the near field of the sound source the particle motion component of the sound field exhibits directivity, and the magnitude of particle motion diminishes in proportion to the inverse of the range^3 for the volume displacement sources used to modify fish behavior. The other component of sound fields is pressure, which predominates in the far field of a sound source, and under free field conditions diminishes as the inverse of the range. Many species of fish have hearing adaptations that permit them to hear sound in the far field where acoustic pressure predominates; however, few of those species able to hear in the far field have shown avoidance responses. The directivity and limited range of effectiveness of the water-particle-motion component of infrasound could be valuable assets for redistributing fish without deterring passage through intakes or channels. Directivity of particle-motion may be beneficial in guidance applications (i.e. movement of fish away from dewatering screens to minimize impingement events) whereas limited range of effectiveness is important in constricted environments such as bypass channels where escape routes around ensonified areas are necessary.

Innate avoidance responses by juvenile salmonids to infrasound under both laboratory and field conditions have been repeatedly demonstrated, with a low rate of habituation to repeated exposure. The observed responses result from the near field local flow component of sound fields generated by volume displacement infrasound sources operated within the 5 to 20 Hz frequency range. Knudsen et al. (1994, 1996) found the local flow acceleration threshold for avoidance response in juvenile Atlantic and Pacific salmonids to be 10^{-2} ms^{-2} at a frequency of 10 Hz.

Characterization of existing sound fields present within passage facilities is an important step towards understanding the relationship between fish behavior and fish passage. Hydropower dams and bypass systems have been shown to generate high-energy acoustic fields (Anderson 1988; Anderson et al. 1989). Nestler and Davidson (1995) suggested that fish respond to sound fields generated by turbine intake screens. We theorize that the sound fields generated by machinery at hydropower dams or the vibration of structures may be a stimulus to which fish respond and which can potentially explain poor in-turbine screen guidance or holding behavior by migrants in fish facility bypass channels.

Objectives

Evaluation of behavioral technologies to redistribute juvenile salmon in dewatering sections of the McNary bypass channel encompasses two study years. The first year (FY 96) was more investigative in nature and focused on the following objectives:

1) Characterize the acoustic environment in the McNary bypass channel.

Characterization of the existing sound fields in the McNary bypass channel is a necessary prelude to evaluation of the response of migrants passing through the channel to an infrasound field we plan to generate in the channel in FY 97. We characterized the acoustic environment of the McNary fish bypass channel in terms of the location, sound frequency, and strength of ambient sound fields. The results of sound field mapping are used to design the sound field to be generated to assure that adequate signal-to-noise ratios can be generated in various locations in the channel.

2) Evaluate the feasibility of using infrared lights and infrared-sensitive underwater video cameras to image salmon smolt in the McNary bypass channel.

The WES Fishery Engineering Team (FET) imaged fish with infrared lights and underwater video cameras to define limitations and capabilities of the gear for observation of juvenile salmonid migrants in terms of range of visibility, effective lighting schemes, and video sampling rates (real time and time-lapse). Statistically valid and effective smolt redistribution experiments cannot be designed without this information. FET used imaging rates to determine effective treatment duration and appropriate statistical power of test for FY 97 experiments.

This report describes and summarizes the efforts by which the above objectives were accomplished in FY 96. We also include a description of laboratory-scale experiments by Mueller et al. 1998, which were conducted in collaboration with this study, to document avoidance responses of small (45-65 mm) salmonid juveniles in the presence of infrasound fields. Measurements of the water particle acceleration within the local flow of the volume displacement source used in laboratory studies to observe the response of juvenile salmonids to infrasound are reported. In addition to the review of Mueller et al.'s recent infrasound experiments included in this report, we have included, as an external appendix, a video tape containing records of juvenile salmonid avoidance response reactions observed during the infrasound tests. Additional information about the contents of the videotape is included in the following section.

Infrasound Net Pen Experiments

Groups of rainbow trout and hatchery and wild chinook salmon ranging from 45 to 65 mm in length were successively acclimated to a 0.75 m wide by 2.0 m long by 1.5 m deep fine mesh net pen in a 7.32 x 3.66 m oblong tank at Battelle's Pacific Northwest National Laboratory (PNNL) in July, 1996. A volume displacement infrasound source with a piston diameter of 10 cm and a displacement amplitude of 4.5 cm (peak to peak) was used to generate an infrasound field. Groups of fish were exposed to infrasound in the frequency range of 11 to 13.5 Hz for 5 seconds. Fish responses to infrasound treatments were monitored using down- and side-looking underwater video cameras so that the behavioral response of fish in three dimensions could be observed. Camera orientations allowed for recording of vertical, lateral, and longitudinal movements of the juvenile fish as they responded to the water-particle-acceleration component of the infrasound field. Details of methods, materials, and experimental design are forthcoming in Mueller et al. 1998.

All size groups of fish exhibited innate avoidance to infrasound. Within the first second of exposure to high intensity infrasound, all test groups of fish swam away from the infrasound source, seeking refuge in most cases at the bottom of the net pen. Following cessation of the infrasound, the fish essentially instantly resumed normal behavior. Repeated exposure of 15 or more exposure cycles at time intervals of less than 2 to 3 minutes resulted in some habituation or attenuated avoidance response. However, following a brief period of rest the avoidance behavior typically returned to its initial intensity. The significant feature of the response of juvenile salmonids to infrasound is that it is innate, that is, fish do not have to be trained to respond. All fish tested, without exception, responded, and habituation is slow and recovery from habituation is rapid.

The accompanying video tape shows segments from trials where wild sub-yearling juvenile chinook salmon, hatchery reared sub-yearling juvenile chinook salmon, and hatchery rainbow trout were exposed to high intensity infrasound. The structure of the sequences is the same. Each sequence shows the distribution of test fish prior to exposure, their response during exposure, and their behavior following exposure. In all cases the infrasound source is to the left of the enclosure net.

Sound Field Characterization

A triaxial accelerometer equipped with pitch, roll, and yaw sensors was used to measure water particle acceleration in the local flow component of the infrasound near field for two water level conditions within the test tank: full and half-full. In all test cases and at all distances from the device (max of 4.2 m), the local flow acceleration exceeded the minimum required for fish avoidance response (10^{-2} ms^{-2}). However, because of the rapid attenuation of particle motion with range from the volume displacement source, there was a detectable gradient in water particle acceleration values. Background noise level in the tank (6.948E-4 ms^{-2}) was significantly lower, by two orders of magnitude, than all of the water particle acceleration measurements.

Also tested under full and half-full tank conditions was the influence of the fish containment net on the infrasound field since the netting was observed to move in response to operation of the source. Water particle acceleration observations indicated that at longer range the net appeared to increase water particle acceleration whereas at shorter range, the presence of the netting seemed to reduce water particle acceleration. The measurements were too variable to determine what effect, if any, the netting had on the infrasound field. In addition, there were confounding factors that influenced the water particle acceleration measurements. Potentially, the water particle acceleration measurement made at longer range within the net pen reflects more the shallow submergence of the infrasound device and its nearness to the tank boundaries than any effect due to the net pen. In general, boundaries such as the air-water interface or the wall of a tank are known to modulate sound fields; therefore, it is more than likely that the water particle acceleration measures obtained in the presence of the net pen represent the effects of boundaries confounded by the effects of the presence of the fish enclosure net.

Results of two other infrasound field characterization studies using the same infrasound source and triaxial accelerometer measurement device were compared with accelerations measured in the NPPL test tank. One set of sound field characterization measurements was made at the Simrad Production Facility, Seattle, WA, in a 3 m x 3 m x 3 m test tank. Another set of measurements was made under open field conditions in the Snake River at Hood Park, WA (Carlson and Campana 1996). Results of all three studies, as well as estimates of expected water particle acceleration based on local flow theory presented by Kalmijn (1988), are presented in Figure 1. The comparison reveals the observations of water particle acceleration in the two test tanks (PNNL and Simrad) were very similar to each other, below those observed under open field conditions, but higher than expected from theory. The open field observations showed water particle acceleration values considerably above those expected from theory with a decay constant of 2.6 in contrast to the theoretical decay constant of 3.0. The tank data sets showed the smallest rate of decrease in water particle acceleration with a decay constant of approximately 1.0. The trends in the test tank data indicated that while water particle acceleration in the tank was below that at the same range under free field conditions, at longer ranges it was likely that tank water particle acceleration would approach and perhaps exceed that for the free field. The slower decay under conditions in the tank is likely due to the nearness of the boundaries in the tank and resulting effects on the local flow component of the infrasound field. As expected, the pressure component of the sound field within the tank was quite variable and complex.

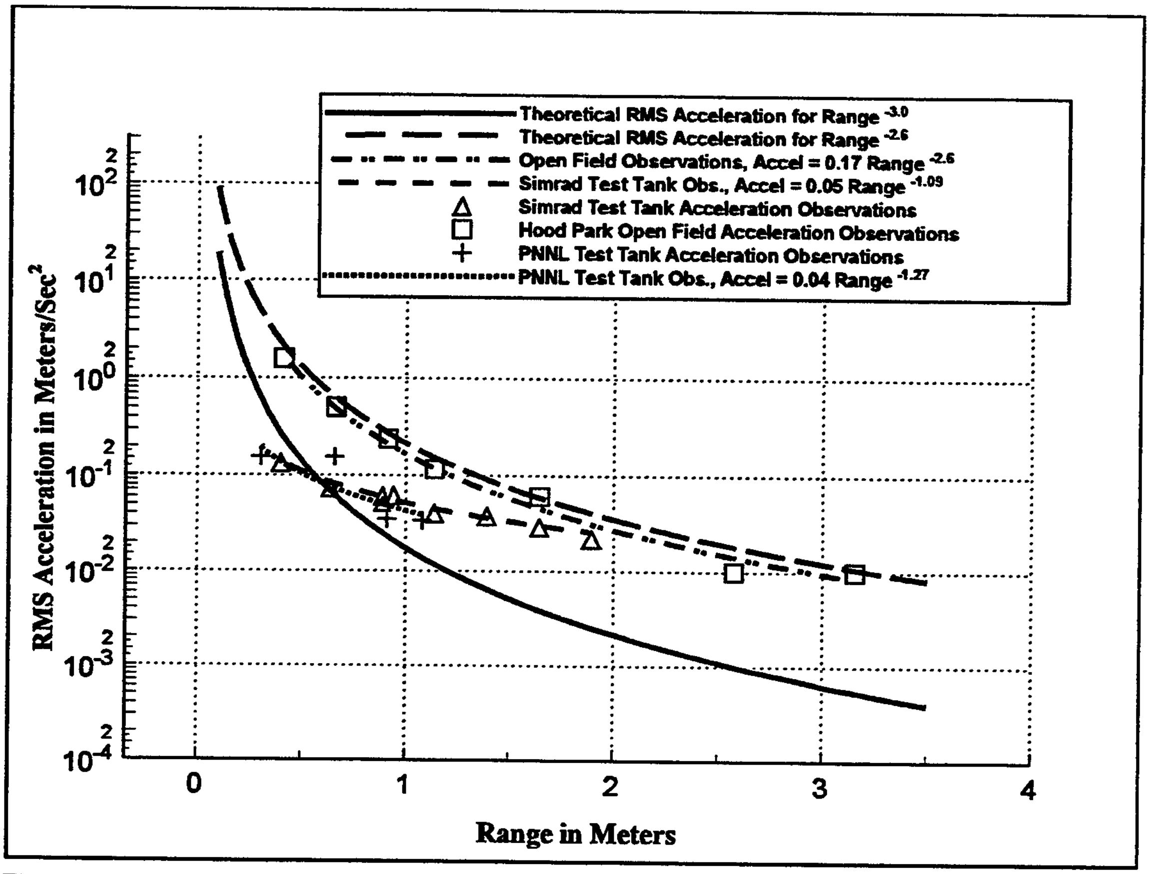

Figure 1. Comparison of tank, open field and theoretical RMS acceleration values as a function of distance from the infrasound source (from Carlson and Campana 1996)

Field measurements revealed differences in magnitude of water particle acceleration as a function of angle from the longitudinal axis of the volume displacement source. Along the maximum response axis, the range of effectiveness (the range at which water particle acceleration fell to 10^{-2} ms^{-2}) was observed to be about 3 m, whereas 30° off the maximum response axis, effective range was limited to about 220 cm. Submergence of the infrasound source at depths less than 1 m in both tank and open field applications resulted in lower values along the maximum response axis. Multipath effects related to air-water interface and other boundary reflections are thought to explain these reduced values.

Summary of Infrasound Net Pen Tests

Groups of 45 to 65 mm sized rainbow trout and hatchery and wild chinook salmon exhibited avoidance when exposed to infrasound in the frequency range of 11 to 13.5 Hz. Within the first second of exposure, all test groups of fish swam away from the infrasound source, seeking refuge in most cases at the bottom of the net pen. All fish tested, without exception, responded, and habituation was observed to be slow and recovery from habituation rapid.

Water particle acceleration values measured with a triaxial accelerometer were found to exceed the minimum required for fish avoidance response (10^{-2} ms^{-2}). Background noise level in the test tank (6.948E-4 ms^{-2}) was significantly lower than all of the water particle acceleration measurements. Field measurements revealed differences in magnitude of water particle acceleration as a function of angle from the longitudinal axis of the volume displacement source. Along the maximum response axis, the range of effectiveness (the range at which water particle acceleration fell to 10^{-2} ms^{-2}) was observed to be about 3 m, whereas 30° off the maximum response axis, effective range was limited to about 220 cm.

Acceleration values taken from other applications with the same infrasound device and triaxial accelerometer as those used in this study, as well as estimates of expected water particle acceleration based on local flow theory, were compared to measurement results obtained in this study. The comparison revealed that the results from the two test tanks were very similar to each other, below those observed under open field conditions, but higher than expected from theory.

Materials and Methods

McNary Project Site Description

McNary Dam is located on the Columbia River at river km 469 in south central Washington State (Figure 2) and serves as a multipurpose Corps of Engineers (CE) project. McNary consists of two small house units to provide internal power requirements, a 14 turbine powerhouse (3 intakes per turbine unit), a 22 gate spillway structure, and a navigation lock. There are extensive facilities to aid in the collection and transportation of both juvenile and adult migrating salmonids.

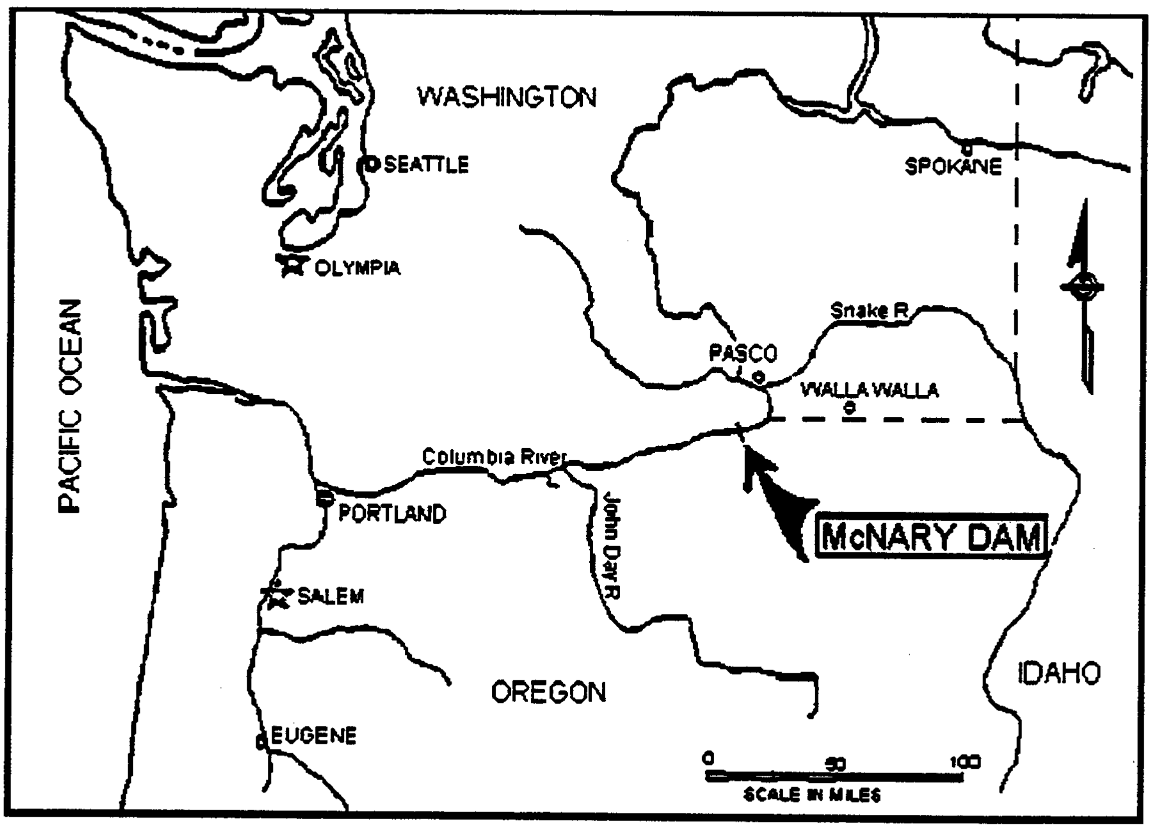

Figure 2. Map of Columbia River Basin showing location of McNary Dam.

Fish and water enter the McNary juvenile bypass channel from intake gatewell slots through one of two 0.31 m stainless steel-lined orifices per slot. The bypass is 365.7 m long, extending the length of the powerhouse. The channel slopes, with water depths varying from 1.2 to 1.98 m in the upstream north end to 3.96 m in the downstream south end, before reaching the dewatering systems. Dewatering is used to remove excess flow prior to fish transport through a 0.91 m diameter outfall pipe. Two major components comprise the dewatering system: a 21.91 m long by 2.74 m high side dewatering section located on the channel's west wall and a 14.63 m long by 3.96 m wide floor dewatering section located immediately upstream of the entrance to the outfall conduit. The floor-dewatering section inclines up, from a depth of 2.44 m at its upstream edge to 1.52 m immediately before the entrance to the outfall conduit. Bypass channel width is 2.74 m for most of its length, widening to 3.96 m just upstream of the floor dewatering area. Maximum discharge through the bypass is 19.4 cms with normal flow velocities ranging from 0.09 mps at the upstream end to 2.59 mps at the downstream end. A plan view of the bypass channel is shown in Figure 3.

McNary Channel Sound Field Characterization

Pressure measurements were made in the sluiceway with a Multi Sensor Fish Surrogate (MSFS), and vibration measurements were made in and around the sluiceway with a low G range Kistler servo-accelerometer. The MSFS was used to characterize the pressure component of underwater sound fields in the channel. The accelerometer was employed to measure structural vibration along the edge of the sluiceway above the water and also, where practicable, that of submerged structures such as the wall and floor dewatering screens. Accelerometer measurements were used to locate sources for components of the sound field observed using MSFS. Identification of potential sound sources for components of the sound field measured by MSFS was considered essential because the highly turbulent flow fields in the channel and resulting complex sound field made localization of sound sources using MSFS alone very difficult.

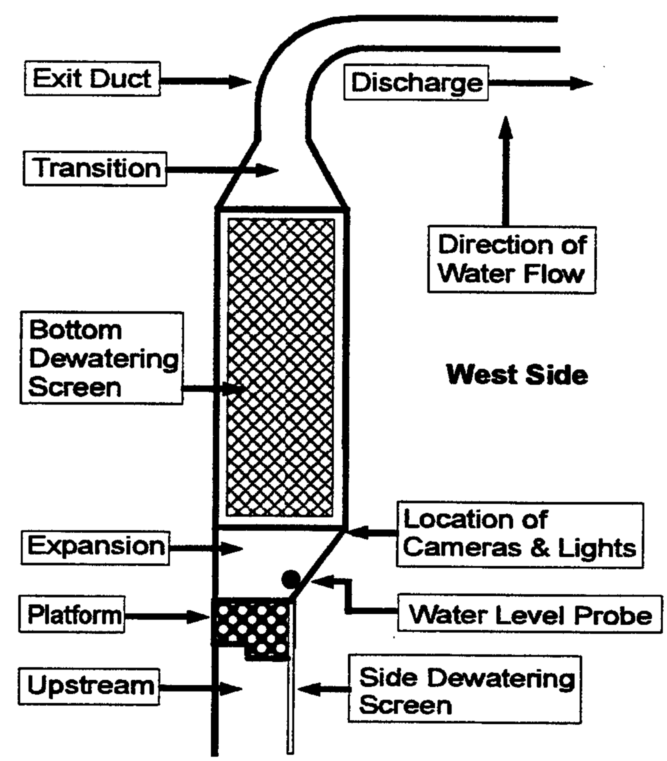

Figure 3: Location of test areas at McNary Dam

The MSFS system is comprised of several different components. A positively-buoyant hydrodynamic body about 22.9 cm long, 10.2 cm high, and 2.5 cm thick supports eight 1-cm^2 piezoelectric film sensors along each side that emulate the spatial pattern of sensors along the lateral line of fish. The bottom of the hydrodynamic body is weighted with sufficient lead strips to cause the probe system to be neutrally buoyant and also to "swim" in much the same body position of a fish when placed in flowing water. The hydrodynamic shape of the MSFS minimizes self noise. Signal processing methods can be used to compare sensor reading temporally and spatially across the MSFS to separate out pressures associated with small scale turbulent flow from propagated sound waves. However, the large flow features within the channel limited our ability to utilize this feature of the MSFS. The gain of the signal from the sensors can be adjusted remotely to prevent sensor saturation. Electric signals from each sensor are transmitted through a multi-wire cable umbilical to a dedicated 100 MHz Pentium laptop computer that can store the data on hard disk or analyze the data in near real time. The sensor system samples at a rate of 100,000 Hz total or approximately 6250 Hz for each separate sensor.

The MSFS was tethered to 2.5 cm diameter steel conduit by a light nylon cord yoke about 0.9 m long. The nylon cord not only allowed the sensor system to respond to the flow field and minimized interference from turbulence but also allowed sufficient control that the sensor system could be stationed to an accuracy of about 15 cm. The conduit was lowered at points in the channel that could be accessed from walkways or through access openings in the grating covering the bypass. The high water velocity in the channel prevented us from taking measurements more than about 1.2 m below the water's surface. Unfortunately, the automatic cleaning brushes could not be disabled for more than 30 minutes so that we could not employ a sturdier deployment system. A sturdier system could not be deployed and retrieved in less than 30 minutes.

Samples were collected over a three day period in September, 1996. Pressure data were collected at 62 locations within the channel. Of these 62 locations, 1 (0.6 m depth only) was in the downstream part of the channel containing the side dewatering screen and 30 (15 at 0.6 m and 15 at 1.2 m depths) were collected in the transition between the side and bottom dewatering screens. Eighteen (9 at 0.6 m and 9 and 1.2 m depths) data collection localities were in the part of the channel containing the bottom dewatering section, and 9 (0.6 m depth only) were in the part of the channel in which the bottom screen approached the surface immediately prior to that part of the channel that narrowed to the exit duct. Four collection points (0.3 m depth only) were where the stainless steel duct attached to the concrete liner of the channel. The positions of all sampling locations were transferred to blueprints of the bypass channel. Longitudinal position was referenced to the transition between the concrete lining of the channel and the stainless steel discharge duct (0.0 m). The most upstream station was 32.6 m upstream of the transition. Lateral positioning originated at the walkway side of the bypass (0.0 m) and ended at the forebay side of the channel (3.4 m).

The accelerometer was deployed on a weighted block that enabled the dewatering screens at the bottom of the channel to be monitored for vibration. We collected accelerometer data on the channel edges (8 samples) out of the water and on top of the stainless steel duct (3 samples) through which the channel discharges. One underwater sample was collected on the floor-dewatering screen before the sensor wire was dislodged from the accelerometer by the high water velocities.

Data Processing

Eight second long time series of pressure and vibration data were collected at each sampling location and stored on hard disk. The time series data were converted from the time domain to the frequency domain using Fast Fourier Transformation (FFT). All data (in volts) were divided by the gain (gain of 1000X was used in the data sampling). Inspection of the data indicated occasional cropping (sensor saturation) of signals in those parts of the channel having the highest sound pressure levels. Consequently, for data segments where this occurred, maximum sound pressure levels may be underestimated and sound spectra distorted. Data were collected from all 16 sensors; however, only the data from sensor number five were analyzed. Preliminary inspection indicated that the pattern in the data could be described using the following bands: 0-1Hz, 1-16 Hz, 16-24 Hz, 24-40 Hz, and 40-93 Hz. These bands incorporate the frequency range of maximum sound sensitivity by salmonids. The MSFS system was previously calibrated to a hydrophone in a vibration tank at WES using standard acoustical methods.

Video Evaluations

Evaluations of infrared lights and underwater video cameras for imaging juvenile salmonids in the McNary juvenile bypass channel were conducted during May and June, 1996. We used high resolution infrared-sensitive Sony (SSC-M350) CCD black and white cameras fitted with ultra-wide angle (105°) lenses contained in two-piece underwater housings provided by Fuhrman Diversified. Illuminators used were American Dynamic (model 1020) 30 watt, 50 degree LED light banks. Light banks consist of 22 rows of LED's and produce peak wavelengths (880 nm) that are outside the experimentally derived spectral sensitivity of salmonids (Coughlin and Hawryshyn 1994). Detailed camera and light specifications are listed in Appendix A. The cameras were powered with a Sony (YS-W230) adaptor and sampled consecutively using a Sony (YS-S100) intelligent sequential switcher. Video images were recorded with either a Sony (EV-C200) real time Hi8 deck or a Sony (EV-T820) time lapse deck and viewed on a Sony (SSM-171) black and white image monitor. Infrared light banks were powered using Tripp-Lite (model PR-15) precision DC power supplies.

We first visited the channel on March 27, 1996, to gain experience using the video cameras, design the forthcoming video evaluation tests, and measure the current velocity in the dewatering areas using a Marsh-McBirney flow meter. With a camera and light banks mounted to an aluminum pole, we attempted to gauge the effective range of visibility by deploying the camera at varying depths at selected locations: (1) in the upstream and middle portion of the side-dewatering section; (2) from the platform immediately downstream of the floor dewatering section; and (3) from the transition zone between the two dewatering areas. Qualitative observations of effective range of visibility were made based on sweeping a metal rod across the field of view at successive distances from the face of the camera. Additionally, observations regarding the presence and relative abundance of entrained air were recorded.

On May 20, 1996, we deployed three pole-mounted cameras and lights in the expansion zone of the bypass channel between the side- and floor-dewatering areas. The pole was tethered to the hand railing on the west side of the channel with the cameras aimed perpendicular to the flow and horizontal to the surface. To optimize vertical coverage of the channel, cameras were set 0.82 m apart. Metal rods with incremental distances marked with tape were fixed to the cameras so that the rods were visible in the cameras' fields of view and effective ranges of visibility could be noted. Turbidity was measured with a LaMotte (model 2008) nephelometer.

We tested three lighting schemes and two sampling rates to determine optimal sampling configurations. The near bottom camera was equipped with light banks immediately above and below it and oriented in the same direction as the camera (fore-lighting). We tested back-lighting with the mid-depth camera by mounting a pair of light banks on a separate pole at mid-depth located 1.52 m away and oriented towards the camera. The near-surface camera utilized the ambient light provided by overhead lights in the channel gallery. We sampled the near surface camera in time lapse mode (4 frames per second) and the other 2 cameras in real time mode (30 frames per second), and sequentially switched among cameras at one minute intervals. Images of fish passage were recorded from 8 p.m. to midnight on 20 May and 7:10 a.m. to 9 a.m. on 21 May by mid-depth and near-bottom cameras. Images of fish passage were recorded from 8 p.m. on 20 May to 9 a.m. on 21 May by the near-surface camera.

On June 25, 1996, we deployed pole-mounted cameras and lights (Figure 4) in the transition zone of the bypass channel between the side- and floor-dewatering areas.

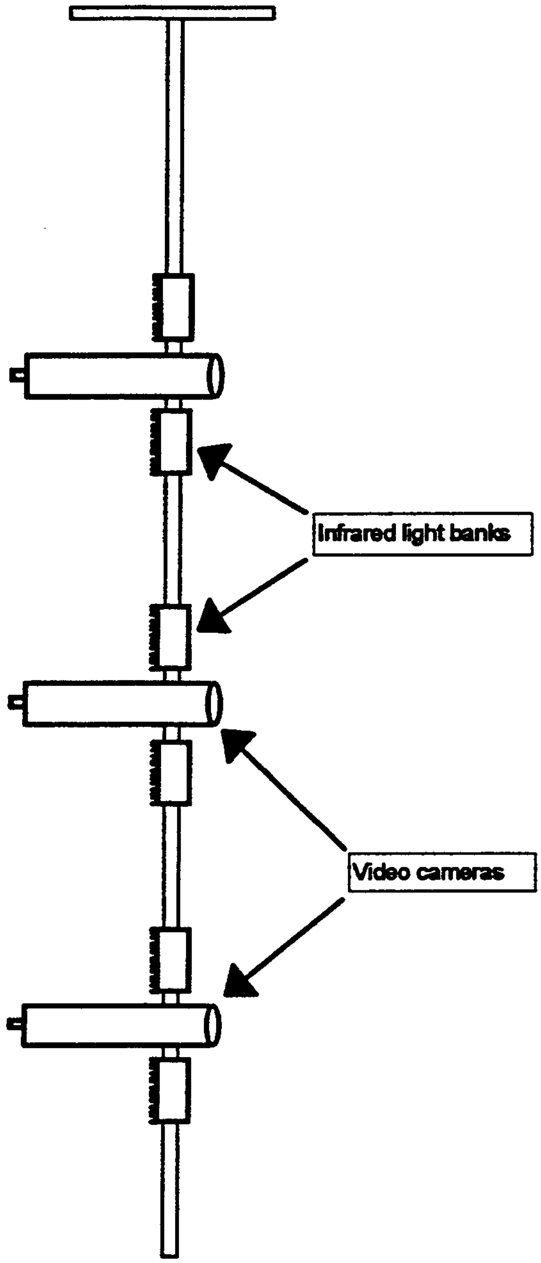

Figure 4. Pole-mounted cameras and infrared light banks used for video evaluations of McNary juvenile bypass in June, 1996. Each camera's field of view was illuminated with 2 infrared light banks.

Based on May results of ambient and back-lighting schemes and time lapse sampling rates as discussed below, we employed fore-lighting and real time sampling rates for all three cameras during the summer video evaluation efforts. Images of fish passage were recorded from 6:40 p.m. to 9:40 p.m. and 9:55 p.m. to 12:55 a.m. All cameras were sequentially switched at one minute intervals. As in the spring, turbidity was measured with a LaMotte nephelometer.

Results and Discussion

Sound Field Characterization

Frequency Range: 0.125 Hz to 1.0 Hz

All stations measured with the MSFS showed the presence of very high sound pressure levels in the 0.125 to 1 Hz range. A number of readings were obtained having pressure levels greater than 165 dB // 1 µpa (Figure 5) with a maximum reading of 172 dB // 1 µpa. No pattern in the distribution of readings was noted. Results from the accelerometer confirmed the presence of a substantial vibration of the channel lining at this frequency. Given the pervasive nature of the sound, the high sound pressure levels obtained, and other observations made at the site, we conclude that the 0.5 Hz signal is probably not entirely due to a propagated sound wave but also has a major hydrodynamic local flow and or bulk flow component. We observed flows surging through the small adjustable side gates at the most downstream end of the sluiceway and suspect that flows within the channel are hydraulically unstable. Unlike most situations in which the vibration of the hydraulic structure provides the source of underwater sound, the turbulence may be exciting the structure to vibrate.

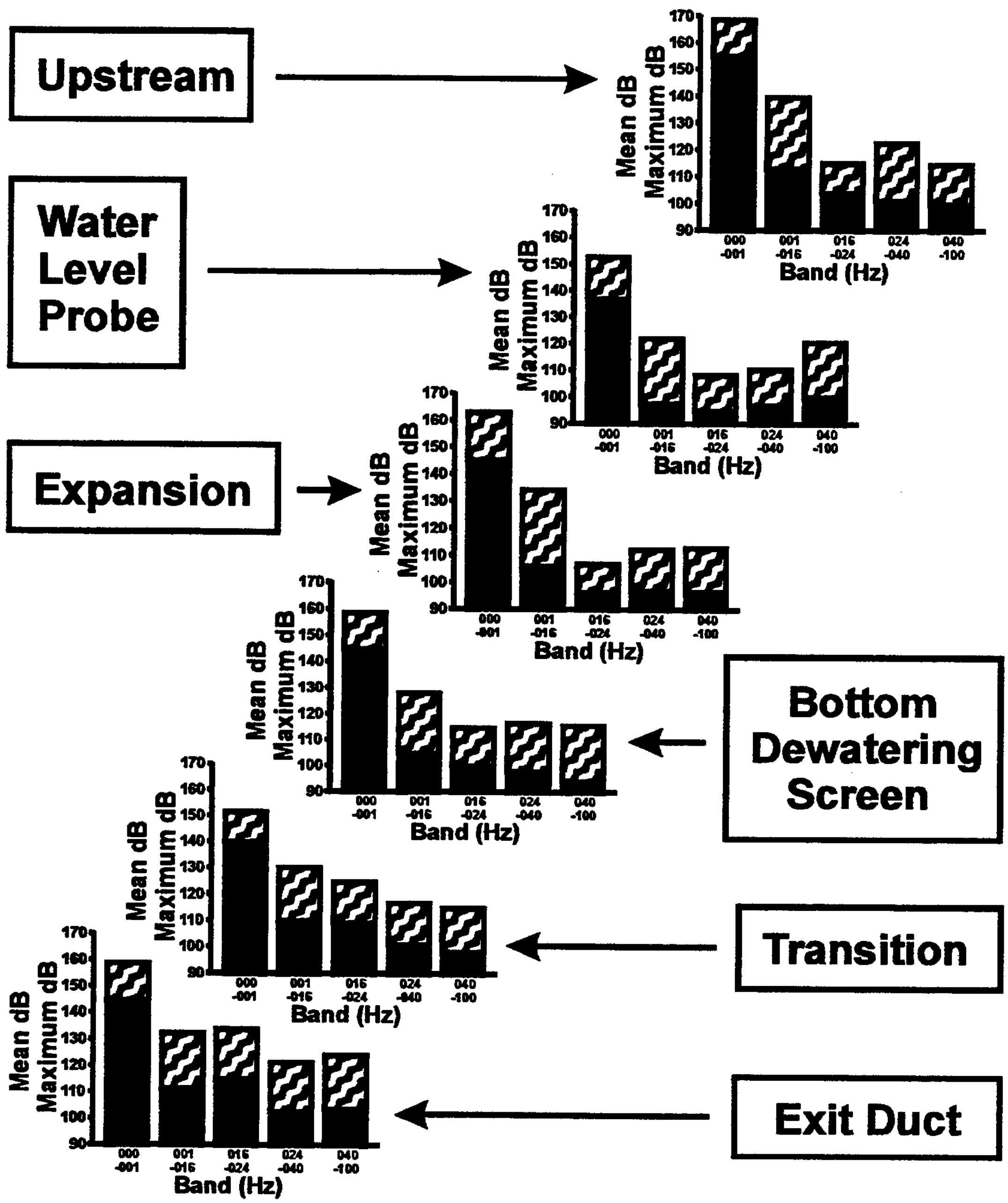

Figure 5. Longitudinal distribution of mean and maximum sound pressure (dB // 1 µpascal) in selected bands at .6 M depth in the dewatering section of the McNary Juvenile Bypass System from the exit duct to the downstream end of the side dewatering screen.

Frequency Range: 1 Hz - 24 Hz

Infrasound levels within the sluiceway were also high, with a maximum reading of 147 dB//1 µpa. Unlike the frequencies below 1 Hz, we know of no possible coarse-scale hydrodynamic patterns that would account for these high sound pressure levels. Distribution of infrasound within the channel exhibited a definite pattern with almost all of the highest readings occurring in the transition between the concrete lining and the discharge duct and relatively reduced readings in the vicinity of the pipe that supports the water level detector (Figure 5). Readings made with the accelerometer detected the presence of significant infrasound structural vibration in this region of the channel. In addition, it was possible to feel substantial vibration on two valve stems in this area and qualitatively, it was possible to detect increased sound levels in this area with the unaided ear. We suspect that this transition area is a significant source of infrasound within the bypass channel. Although we were unable to measure below a depth of 1.2 m, it may be possible that infrasound levels increase towards the screen surface. Vertical differences in infrasound levels were also detected. Sound pressure levels made at the 1.2 m depth were consistently higher than 0.6 m depth sound pressure levels in those parts of the channel deep enough for both the 0.6 and 1.2 m depth measurements (Figure 6). The dewatering part of the sluiceway can be characterized as containing reduced infrasound levels near the surface, similar to the pattern determined for infrasound levels in smolt transport barges (Carlson et al. In review). However, the channel has an infrasound peak at the discharge duct.

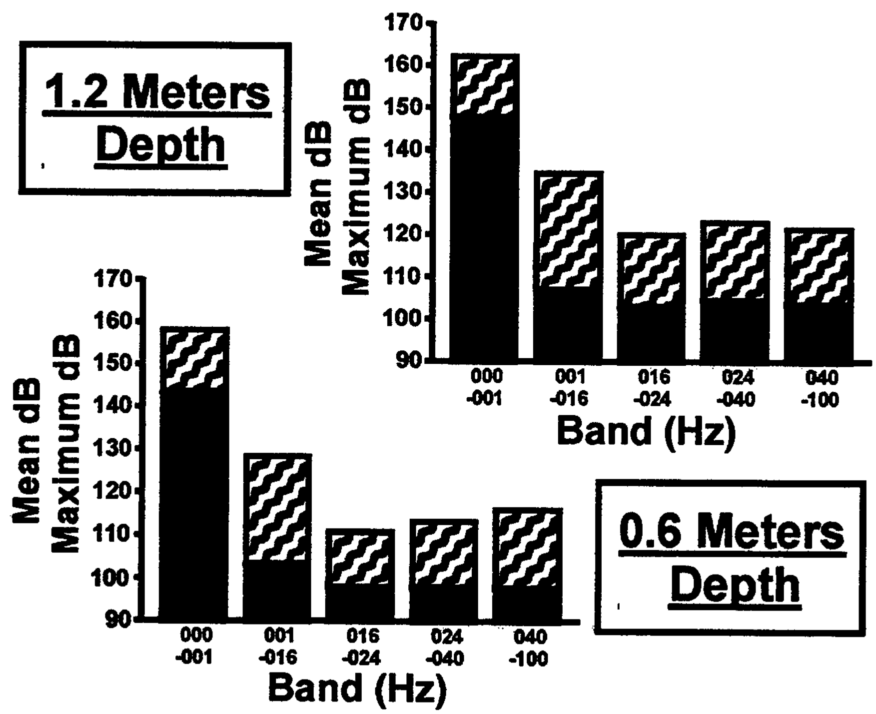

Figure 6. Vertical pattern at mean and maximum sound pressure level (dB // 1 μpascal) in selected bands in the bottom dewatering screen, "expansion," and "water level probe" sections of the McNary Juvenile Bypass Channel

This pattern in infrasound also seems to explain observations of fish behavior and distribution within the bypass channel. We have been told by project personnel that fish are known to hold for considerable time periods. Fish may be reluctant to pass through the infrasound peak at the discharge end. In addition, fish seem to concentrate near the pipe that supports the depth recorder in an area of the channel that exhibits consistently lower infrasound pressure levels. Fish may also concentrate near the depth recorder for hydraulic reasons.

Observation of the response of juvenile salmonids to intense infrasound in controlled experiments (Mueller et al. 1998) would suggest that the holding pattern of juvenile migrants could be explained by response to the infrasound field at the entrance to the outfall conduit. The innate avoidance response by migrants to regions where particle motion at infrasound frequencies is high could explain both the holding pattern and locations for holding within the juvenile bypass. In addition, the observed habituation cycle of juvenile fish exposed to high intensity infrasound could partially explain the passage of migrants through the bypass following a period of exposure to infrasound.

Summary of Sound Field Characterization

High sound pressure levels at frequencies less than 24 Hz were observed at all sampled locations. The maximum sound pressure levels (172 dB // 1 µpa) were in the frequency range 0.125 to 1 Hz. Within the 1 to 24 Hz frequency range, the distribution of infrasound observed in the channel exhibited a pattern with almost all of the highest readings occurring in the transition between the concrete lining and the discharge duct and reduced readings near the water level indicator. Additionally, sound pressure levels measured at two depths per station were observed to decrease toward the surface. Substantial vibration of the channel lining was observed at frequencies less than 24 Hz, especially near the water level indicator.

Video Evaluations

Qualitative observations of effective range of visibility conducted in March, 1996, indicated that 0.76 to 0.91 m was the maximum range the cameras could detect juvenile migrants in the bypass channel under the water turbidity conditions existing at the time of the observations. Deployment of the pole-mounted lights and camera at the upstream end of the side-dewatering area at a depth of 1.83 m resulted in the field-of-view filled with a large volume of entrained air bubbles. High densities of air bubbles reduced ability to detect migrants in addition to the limitations imposed by high turbidity. Redeployment 9.14 m downstream at a depth of 1.52 m yielded fewer air bubbles, indicating that increasing distance from the orifices decreases the confounding effects of entrained air on imaging capability at this depth. Deployment from the upstream edge of the transition zone platform showed a decrease in volume of entrained air with increasing depths, an expected effect given the buoyant nature of air bubbles. Very few air bubbles were observed in the widened portion of the channel immediately upstream of the floor-dewatering area.

Current velocity measurements taken near the channel's west wall just below the water's surface in the side-dewatering area were between 1.28 and 1.34 mps. Velocities near the water's surface in the floor-dewatering area ranged from 0.91 to 1.04 mps.

Results of May, 1996, video sampling based on recorded images of juvenile salmonids and non-smolts (adult salmonids, lamprey and suckers) and varying lighting schemes and sampling rates are shown in Table 1. Numbers of fish imaged with the near-surface camera using ambient lighting and time lapse sampling rate were quite low for all hours sampled. Juvenile salmonid counts were highest with the fore-lit camera whereas non-smolt counts were highest with the back-lit camera (potential explanation for this is discussed below). Average visibility for the near-bottom camera was observed to be approximately 0.76 m. Assessment of effective visibility range for remaining cameras was problematic due to insufficient light (near-surface) and light orientation (mid-depth). Backlighting did not allow for estimation of the range of detected fish from the camera. Turbidity was measured as 14.3 nephelometric turbidity units (NTU's). Smolt imaging rate (total number of smolt / total time sampled) for the fore-lit camera was 24 smolt per hour, and non-smolt imaging rate for the same camera was 4.5 per hour.

Table 1. Evaluation results of May, 1996, video sampling in McNary bypass channel. Fish counts are arrayed by date/hour and camera position; lighting schemes and sample rates are listed by camera. Hours reported include only those samples by all cameras.

		Near surface camera Light scheme; ambient Sampling rate: 4 frames/sec			Mid depth camera Light scheme: back Sampling rate: 30 frames/sec			Near bottom camera Light scheme: fore Sampling rate: 30 frames/sec		
Date	Hour	smolt count	non-smolt count	% hour sampled	smolt count	non-smolt count	% hour sampled	smolt count	non-smolt count	% hour sampled
20-May	20	0	1	27	0	0	13.5	2	0	13.5
20-May	21	0	1	100	1	4	50	19	4	50
20-May	22	1	1	100	2	7	50	22	4	50
20-May	23	0	0	100	1	5	38.5	2	2	38.5
21-May	7	1	1	100	2	8	42.5	5	1	42.5
21-May	8	0	0	100	2	5	50	9	0	50

Results of June, 1996, video sampling based on recorded images of smolt and non-smolt with equal sampling effort among all cameras are shown in Table 2. Highest smolt counts were seen with the mid-depth camera whereas highest non-smolt counts were obtained with the near-surface camera. However, due to equipment problems, these counts do not accurately reflect vertical distributions of in-channel passage. Both the near-surface and near-bottom cameras showed signs of water leaking into the underwater housings causing condensation to form on the inside of the lens port. This problem was greatest with the near-bottom camera. Since the leakage compromised the equality of sampling effort among cameras, imaging rates were calculated only for the mid-depth camera (14 smolt and 8.5 non-smolt per hour). Average visibility for this camera was observed to be approximately 0.76 m. Turbidity was measured as 7.8 NTU's.

Table 2. Evaluation results of June, 1996 video sampling in McNary bypass channel. Fish counts are arrayed by date/hour and camera position; lighting schemes and sample rates are listed by camera.

		Near surface camera Light scheme; fore Sampling rate: 30 frames/sec			Mid depth camera Light scheme: fore Sampling rate: 30 frames/sec			Near bottom camera Light scheme: fore Sampling rate: 30 frames/sec		
Date	Hour	smolt count	non-smolt count	% hour sampled	smolt count	non-smolt count	% hour sampled	smolt count	non-smolt count	% hour sampled
25-Jun	18	0	4	10	3	2	10	2	0	10
25-Jun	19	2	7	33.3	6	2	33.3	0	0	33.3
25-Jun	20	4	7	33.3	3	7	33.3	0	0	33.3
25-Jun	21	2	4	25	6	2	25	0	0	25
25-Jun	22	1	2	33.3	3	1	33.3	0	1	33.3
25-Jun	23	1	5	33.3	4	2	33.3	0	0	33.3
26-Jun	0	3	1	31.7	3	1	31.7	1	0	31.7

Initial efforts in March determined the areas within the bypass channel that were problematic for video imaging due to large volumes of entrained air. Qualitative results indicate that video imaging satisfactory for experimental purposes would not be possible in the upstream portion of the side-dewatering section because of the high density of bubbles resulting from the proximity of this area to the most downstream fish bypass inlet orifice. Closing the farthest downstream orifice would likely decrease the density of bubbles near the upstream end of the side-dewatering section and would make this area more conducive for underwater video imaging. Entrained air was observed to decrease with increasing depths in the channel just upstream of the transition zone platform suggesting that deeper camera deployments would yield higher quality video data. There were few air bubbles in the widened portion of the channel immediately upstream of the floor dewatering area relative to the upstream deployments demonstrating that this is a good channel location for video evaluations.

Results from the video samples collected in the widened portion of the channel just upstream of the floor dewatering section in May and June indicate the following: (1) ambient lighting provided by overhead lights in the channel gallery is not sufficient to adequately illuminate the near-surface camera's field of view given the horizontal camera orientation; (2) time-lapse sampling rate of four frames per second is too slow to effectively detect smolt passage events given observed flow velocities; (3) fore-lighting is more effective for illumination and detection of smolt-sized fish than back-lighting; (4) camera range of visibility using fore-lighting is no greater than 0.76 m given measured turbidity levels; and (5) based on smolt imaging rates we are able to determine the required sample size and power of the tests required to reject a false null hypothesis (detection of true differences between on/off treatments of infrasound and strobe lights).

The failure of ambient light to adequately illuminate smolts is related more to lighting/camera orientations than light penetration. As evidenced by reviewing the surface camera's recorded video tape, ambient light had penetrated the field of view (camera was 0.82 m below water surface) but the resulting illuminated images were difficult to distinguish as fish or non-fish. Because the light source was from above, only the top half of any passing object was illuminated, leaving the bottom half dark and without contrast relative to the dark background. It was impossible to defensibly identify recorded images of passing objects as fish since the camera was oriented horizontally.

Time lapse sampling rates are beneficial as both a man-power savings (fewer tapes changed) and storage media savings (fewer tapes consumed). However, these benefits were more than offset by the lack of sufficient information collected per imaging event (i.e. the number of successive frames in which a passing fish was detected). Given the current velocity measured in the location of the video evaluations (0.91 to 1.04 mps), smolts are passing through the channel at rates that exceed sampling capabilities of our time-lapse recording deck (i.e. fish could pass through the monitored volume in the time between frames or only be detected on one or two successive frames). Video data collected in real-time (30 frames per second) resulted in the acquisition of ten or fewer video frames per event. Often times, smolt characterization of passing objects entails examination of a series of frames before making a decision to count the object as a smolt. Subtle swimming motion such as a caudal fin flap is sometimes the only clue available to the observer for characterizing fish from non-fish. Subtle motion cannot be recorded using a time-lapse sampling rate of four frames per second because only every eighth frame is sampled, thus preventing the capture of continuous movement.

Light source orientation has important implications for illumination of passage events and determination of camera detectibility range. Comparing video imaging results among back-lit and fore-lit cameras reveals that the former lighting scheme captured a much lower smolt to non-smolt ratio (nearly 1 to 4) than the latter lighting scheme (> 5 to 1). Non-smolt fish were comprised of mostly adult salmonids and lamprey, large targets with much greater surface area relative to smolts. A large target will be detected within a greater range than a small target given back-lighting conditions because the area of contrast between the illuminated background and a large target is much greater than that produced by smolts. Back-lighting was located 1.52 m from the camera, yielding an effective detectibility range for large targets of 1.52 m and for small targets somewhat less than that distance. This may explain the predominance of larger detected targets using background lighting. Fore-lighting offers more of a target-size independent range of detectibility since any objects beyond the range of illumination, regardless of size, are not detected.

Knowledge of effective camera visibility range is critical for design and implementation of valid experimental tests using video as the sampling tool. For underwater applications, visibility range is primarily a function of turbidity. Turbidity levels of 14.3 and 7.8 NTU's in spring and summer, respectively, resulted in a visibility range no more than 0.76 m from the face of the fore-lit cameras. These relatively high turbidity levels reflect the abnormally high water year of 1996, as more normal water years yield a visibility range in the McNary bypass channel on the order of 1.52 m (S. Rainey, NMFS, personal communication). Although a range of 0.76 m may be conservative given a normal water year, this realization forced a redesign and simplification of the behavioral technology evaluation experiments scheduled for FY 97.

Hourly smolt imaging rates based on fore-lit cameras allowed for determination of the required sample size needed to detect a given true difference in the means of on/off treatments. Convergence tables (i.e. Table 3) were constructed based on measured coefficients of variation, desired difference in the means, desired probability level, known t values for alpha and 1-P, and a first guess of required sample size in order to calculate required sample size necessary for detection of differences in the means. Power curves based on various sample sizes were used to determine the level of power a test would have given the desired detectable difference in means (Figure 7). For example, the power curve for nighttime sampling shows that a sample size of N=8 or less would be inadequate if 50% difference in the mean is the desired level of detection at a 90% probability level. Inadequate sample size increases the probability of accepting a false null hypothesis.

Summary of Video Evaluations

We assessed the utility of sampling techniques needed to evaluate the effectiveness of behavioral technologies for redistributing smolts in the dewatering sections of the McNary bypass channel. During spring and summer of 1996 we examined the feasibility of using infrared sensitive underwater cameras to image smolt passage in the bypass channel. Results from these studies indicate that infrared lights and underwater cameras can effectively image smolts in the channel but visibility is limited to approximately 0.91 m. We tested different lighting schemes and found fore-lighting to

Table 3. Convergence table for calculating required sample sizes for summer nighttime video sampling in the McNary bypass channel.

Estimated Required Sample Size	Measured CV, %	Smallest True Difference %	t-value for (alpha, v)	Probability that will be significant if it is as small as the smallest true difference	t-value for (1-P, v)	Required Sample Size
2	30.1	50	12.71	0.9	6.31	262
262	30.1	50	1.97	0.9	1.65	9
9	30.1	50	2.31	0.9	1.86	13
12	30.1	50	2.20	0.9	1.80	12
12	30.1	50	2.23	0.9	1.81	12
12	30.1	50	2.23	0.9	1.81	12
12	30.1	50	2.23	0.9	1.81	12
12	30.1	50	2.23	0.9	1.81	12
12	30.1	50	2.23	0.9	1.81	12
12	30.1	50	2.23	0.9	1.81	12
12	30.1	50	2.23	0.9	1.81	12
12	30.1	50	2.23	0.9	1.81	12
12	30.1	50	2.23	0.9	1.81	12
12	30.1	50	2.23	0.9	1.81	12

be most effective for imaging smolt sized targets. We comparing time-lapse with real-time recording and determined the former to be ineffective due to the reduced number of framed images captured in the high flows of the McNary channel.

Conclusions and Recommendations

It is likely that fish passage and distribution within the dewatering portion of the McNary Dam bypass channel are presently strongly affected by patterns of infrasound. These patterns may account for the holding of fish within the channel, but more importantly, prolonged stays within the channel may increase physiologic stress and increase the probability of predation or of screen impingement within the bypass. We recommend that a detailed acoustical/structural evaluation of the channel be conducted independent of any effort to modify the bypass to increase capacity, particularly in the area where the concrete lining transitions to the stainless steel discharge duct. The more detailed study should include a full array of operational conditions and measurements made with accelerometers to separate hydrodynamic (local flow water particle acceleration in addition to bulk transport) from acoustical (sound pressure) effects. The more detailed study should be performed at a time when the cleaning brushes can be disabled long enough to use a sturdier sensor deployment system that will allow readings to be made close to the screen surface.

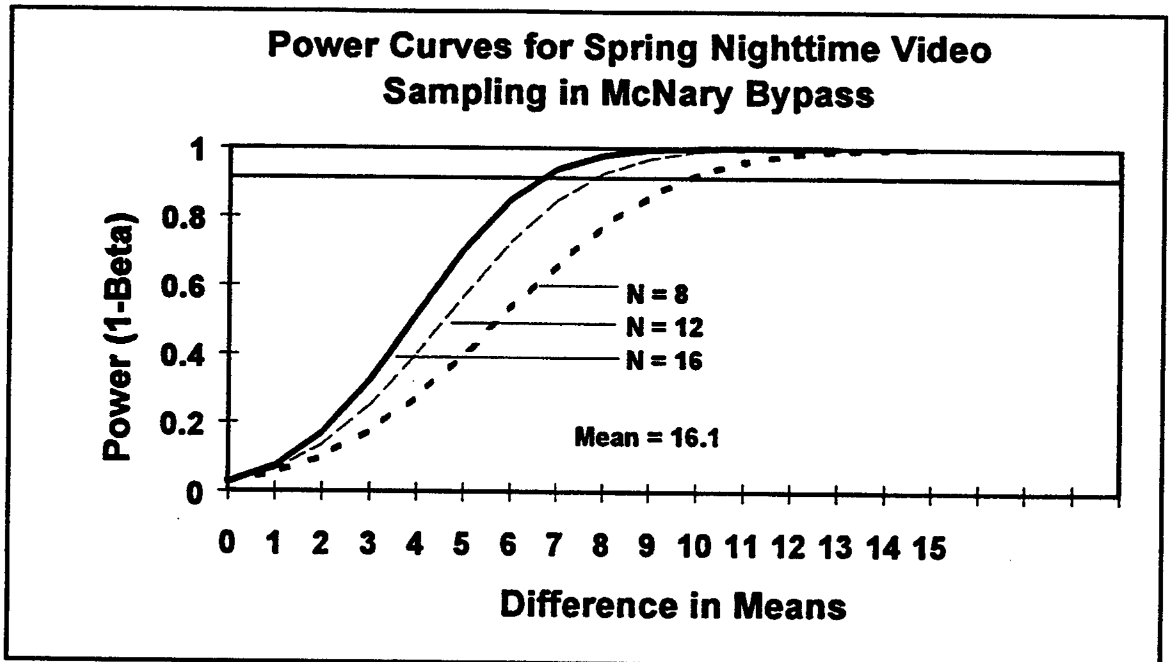

Figure 7. Power of the test curves for varying sample sizes using video sampling in McNary bypass channel. Sample size represents paired hours of on-off treatments. Curves are used to determine required sample size given desired level of mean difference detection. Sample size of n=12 will allow for 90% power to reject the null hypothesis of no difference given a 50% difference in the means.

Given the distribution of infrasound patterns within the channel, we see two possible alternative methods for increasing screen capacity. First, it is quite possible that the screens at McNary Dam are presently a source of infrasound within the channel. It is well known that most hydraulic structures vibrate when water at high velocity passes through or around them. By better understanding and controlling these vibrations, it may be possible to manage infrasound levels within the bypass by designing the structures (dynamic structures) to create acoustic conditions that would expedite the movement of fishes through the dewatering portion of the channel. This could be accomplished by eliminating zones of high infrasound within the central portion of the bypass away from dewatering screens and at the entrance to the bypass exit and by creating regions of high infrasound to limit fish access to the near region of dewatering screens and regions within the bypass that migrants might use to hold. Second, it may be possible to use infrasound sources to repel fish from the surface of dewatering screens. However, even the use of infrasound sources should be done in the context of managing the total acoustic environment within the sluiceway. Even if infrasound sources could be used to repel fishes from the screens, the presence of the infrasound peak near the outfall may increase residence time within the bypass and thereby, increase stress as well as the probability of impingement (assuming that the longer fish stay in the channel, the more likely they are to be impinged) and partially eliminate benefits in fish passage efficiency obtained from using a surface collector.

Important considerations for infrasound applications encompass many issues. In order to achieve optimal effectiveness of infrasound fields for purposes of behavioral modification, careful examination of boundaries that may confound desired effects needs to be addressed. Deployment of volume displacement devices, in both field and laboratory scale experiments, should be to depths greater than 1 m to avoid reflections from the air-water interface. The development of infrasound sources that are integrated into bypass facilities that have low operations and maintenance needs is required if infrasound is to be used as an elementary part of fish bypass facilities.

Infrared lights and infrared-sensitive video cameras demonstrated promise as a means of capturing smolt passage in the McNary bypass channel and ultimately as a tool to evaluate effectiveness of behavioral technology for redistributing salmon smolts in collection channels or dewatering facilities. Limitations of lighting orientation schemes recognized in this pilot study allow us to optimize lighting configurations for future video sampling studies in bypass systems. Comparison of video sampling rates revealed the importance of continual motion video data for fish characterization. Results of video tests were used to determine appropriate sample sizes to ensure valid and powerful statistical analysis for smolt redistribution experiments scheduled for FY97.

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Appendix A.

Specifications for video cameras and infrared lights

Sony SSC-M350 CCD black and white video camera

a. Sensitivity: 0.3 lux
b. Resolution: 250,000 pixel
c. Pickup device: inter-line transfer type CCD
d. Shutter speed: 1/60 s - 1/10000 s variable setting
e. Sensing area: 6.3 x 4.7 mm
f. Lens: 3.6 mm (105 deg) auto iris
g. Power: for 12 V DC supply - 12 V DC +/- 10%
   for YS-W230 camera adaptor: 24 V DC +/- 5 V
h. Size: 64 x 57 x 155 mm
i. Weight: 660 g
j. Size of housing: 95 x 280 mm cylinder
k. Cost: camera $1182.00; lens $201.00; housing $605.00

American Dynamic 1020 series LED infrared illuminator

a. Wattage at nominal voltage: 30 W
b. Infrared wave length: 880 nm
c. Beam dispersion: 50 deg

d. Approx. range in air: 20 m

e. Operating voltage: 13.5 V DC

f, Current: 2.5 A

g. Protection rating: NEMA6

h. Size: 128 x 182 x 650 mm

i. Weight: 350 g

j. Cost: $430.00

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13. ABSTRACT *(Maximum 200 words)*

Evaluation of behavioral technologies to redistribute juvenile salmon in dewatering sections of a bypass channel encompassed two study years. The first year (Fiscal Year 1996) was preliminary and focused on two objectives: (a) characterizing the acoustic environment in selected areas of the McNary bypass channel; and (b) evaluating the feasibility of using video cameras to image salmon smolt in the McNary channel.

We characterized underwater sound fields by measuring sound pressure and structural vibration in September 1996. High sound pressure levels at frequencies less than 24 Hz were observed at all sampled locations. The maximum sound pressure levels (1702 dB referenced to 1 μPa) were in the frequency range 0.125 to 1 Hz. Within the 1- to 24-Hz frequency range, the distribution of infrasound observed in the channel exhibited a pattern with most of the highest readings occurring in the transition between the concrete lining and the discharge duct and reduced readings near the water level indicator. Additionally, sound pressure levels measured at two depths per station were observed to decrease toward the surface. Substantial vibration of the channel lining was observed at frequencies less than 24 Hz.

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During spring and summer of 1996, we examined the feasibility of using infrared-sensitive underwater cameras to image smolt passage in the bypass channel. Results indicate that infrared lights and underwater cameras can effectively image smolts in the channel but visibility is limited to approximately 0.91 m. We tested different lighting schemes and found forelighting to be most effective for imaging smolt-sized targets. We compared time-lapse with real-time recording and determined the former to be ineffective due to the reduced number of framed images captured in the high flows of the McNary channel.

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Behavioral technologies
Bypass channels
Columbia River
Fish passage
Hydropower dams
Infrared lights
Infrared-sensitive video cameras
Juvenile salmonids
McNary Dam
Snake River
Surface collection technologies