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Guidelines for Performing Hydraulic Field Evaluations at Fish Screening Facilities

U.S. Department of the Interior
Bureau of Reclamation
Denver, Colorado

April 2009

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Disclaimer

Abbreviations and Acronyms

1D	one dimensional
2D	two dimensional
3D	three dimensional
ADC	acoustic digital current
ADCP	acoustic Doppler current profiler
ADFM	acoustic Doppler flowmeter
ADV	acoustic Doppler velocimeter
CDFG	California Department of Fish and Game
EM	electromagnetic
ft	ft
ft/s	feet per second
ft^3/s	cubic feet per second
GCID	Glenn-Colusa Irrigation District
GPS	global positioning system
Hz	hertz
MHz	megahertz
NMFS	National Marine Fisheries Service
Reclamation	Bureau of Reclamation

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Introduction

The Bureau of Reclamation (Reclamation) must comply with Federal and State fisheries criteria at water diversion structures and their components. Reclamation currently conducts field measurement evaluations with specialized instrumentation at diversion facilities used for irrigation, power generation, and water supply. Various structures such as fish screens, fish bypasses, screened pump intakes, and louver systems must comply with Federal and State fisheries criteria in order to maintain uninterrupted operations.

Since diversion structures have site-specific geometry, components, and operational goals, and fisheries criteria vary by species, life stage, season, and region, it is not possible to recommend one standard method for conducting hydraulic evaluations at all field sites. The intent of these guidelines is to offer general field methodologies and instrumentation that can be applied to field evaluations. Keeping in mind that each site requires unique consideration, these guidelines will be a resource for field personnel in planning an efficient testing program with appropriate instrumentation.

Reclamation published *Fish Protection at Water Diversions* (Bureau of Reclamation, 2006) to provide design guidance for fish protection at small dams and water diversion structures. This technical publication will be used internally by Reclamation and as a technology transfer to other agencies and the public. As a supplement to *Fish Protection at Water Diversions*, these guidelines provide information on conducting hydraulic field evaluations at water diversion structures.

These guidelines address field evaluations at diversion structures with fish screens, including an overview of various types of positive barrier and behavioral fish screens that are commonly installed at diversion structures. The regulatory agencies that typically develop screening criteria are identified. Information is provided on how to obtain current criteria for the region where hydraulic evaluations are being conducted.

Important parameters needed for hydraulic evaluations will be summarized. The guidelines identify typical measurement locations that are considered critical to fish passage and survival by fisheries agencies and acceptable, practical methods that can be used to evaluate these critical locations. The guidelines also identify specific areas where the best methodology is unclear. Several field instruments are discussed and compared. Postconstruction evaluations for baffle adjustment and performance validation, as well as long-term monitoring programs, are discussed. The guidelines conclude with case studies of several hydraulic fish screen evaluations. These case studies describe some of the challenges that a researcher may encounter during field evaluations.

Overview of Hydraulic Evaluations at Fish Screening Facilities

Fish protection structures may be installed at water diversions to prevent or reduce fish entrainment into the diversion. The objective of water resources agencies and organizations installing fish protection structures is to abide by State and Federal laws to preserve endangered species while continuing to meet current water deliveries and allowing for future water development. Hydraulic evaluations are needed to ensure that the hydraulic performance of the structure optimizes fish exclusion efficiencies and satisfies all applicable State and Federal fisheries criteria.

The primary component of a fish protection structure is a positive barrier fish screen or behavioral barrier. Reclamation's *Fish Protection at Water Diversions* manual contains a comprehensive discussion of fish protection alternatives, including detailed descriptions, advantages and disadvantages, and examples of installation locations (Bureau of Reclamation, 2006).

Positive barrier screens create a physical boundary to fish passage. Off-river barrier screens contain a fish bypass component to return fish safely back to the river. Positive barrier screens are highly effective at reducing fish entrainment, but hydraulic conditions must be monitored to prevent fish injury or mortality from impingement on the screens or delay in migratory passage. Since positive barrier screens are highly susceptible to debris fouling and sediment deposition, cleaning mechanisms and sediment control devices are typically included in the design. These types of devices can affect hydraulic field evaluations by hindering access to the screens or altering flow patterns near the screens.

Positive barrier screens include flat plate screens (figures 1 and 2), traveling screens (figure 3), bottom screens such as inclined and horizontal flat plate screens (figure 4), Coanda screens (figure 5), drum screens (figure 6), submerged cylindrical screens (figure 7), cone screens (figure 8), and closed conduit (Eicher and modular inclined screen [MIS]) screens.

Behavioral barriers produce a stimulus that elicits a fish response to avoid entrainment. As a structural guidance device, vertical louvers (figure 9) are intended to achieve fish exclusion by generating disturbances in the flow field that fish respond to and avoid. Fish maintain a distance off the louver face, while the sweeping flow is intended to guide fish along the louver line and into the bypasses. Alternative behavioral technologies include light and acoustic devices, electric fields, air bubble curtains, hanging chains, and water jet curtains. Although fish exclusion efficiencies can be much lower than positive barrier screens, behavior barriers are generally less expensive to install and easier to maintain. They may be a viable option at sites where 100-percent exclusion is not required or where installation of a positive barrier is difficult or inappropriate due to site-specific issues.

Figure 1. Government Highline Canal in-canal V-screen near Grand Junction, Colorado. This construction photo shows the wedge-wire flat plate screen panels (right), vertical baffles (left), and fish bypass intake (center).

Figure 2. Flat plate screens installed at Wilkins Slough Pumping Plant on the Sacramento River (Reclamation District No. 108). On-river fish screens are common for large diversions.

Figure 3. Multiple traveling screens at Roza Fish Screens Facility near Yakima, Washington.

Figure 4. Inclined screens at Savage Rapids Diversion near Grants Pass, Oregon.

Figure 5. Coanda screen at Lake John near Walden, Colorado.

Figure 6. Rotating drum screens at Roza Fish Screens Facility near Yakima, Washington.

Figure 7. Retractable submerged cylindrical screen on Sacramento River near Grimes, California.

Figure 8. Cone screen installed by Intake Screens, Inc. Cone screens are typically used in shallow estuaries or tidally influenced areas (photo courtesy of Intake Screens, Inc.)

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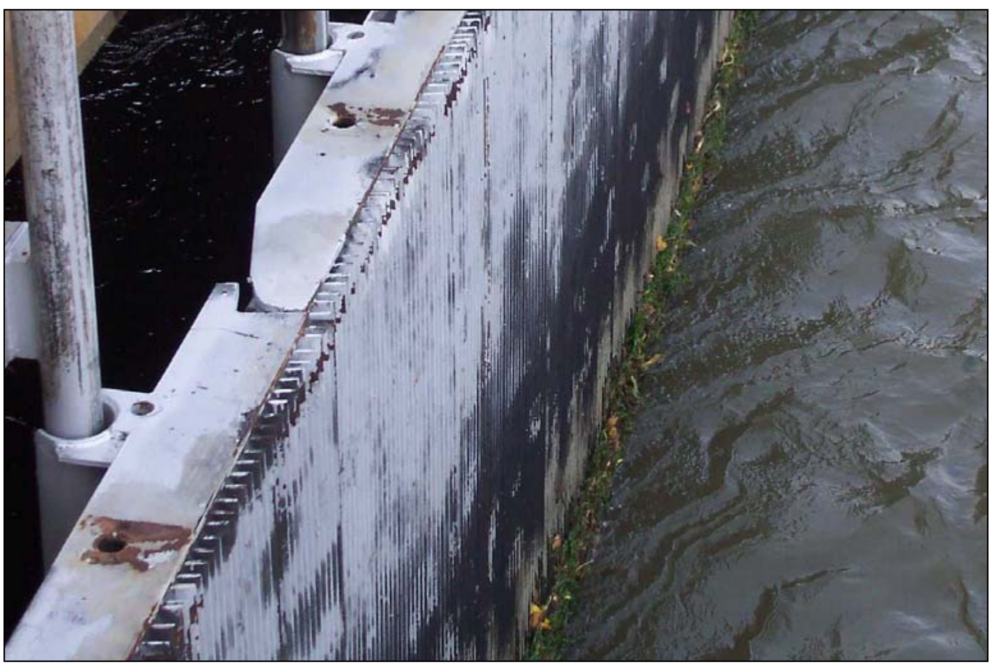

Figure 9 . Louver line at Tracy Fish Collection Facility near Tracy, California.

In addition to a fish barrier, several other components may be present at a water diversion, including debris booms, trashracks, fish bypass systems, cleaning mechanisms, sediment control devices, and pumping or dewatering facilities. Hydraulic field evaluations may be required at any or all of the fish protection components at a diversion facility.

At fish protection structures, postconstruction field evaluations may be required to validate design performance or to adjust flow baffles or weirs to obtain effective performance. Hydraulic evaluations may be requested to identify optimal operational conditions during critical fish protection periods. Long-term monitoring tests are used to ensure proper performance and to address cleaning or maintenance concerns.

Field evaluations are generally conducted by qualified personnel from the agency or organization that owns the diversion structure. If specialized expertise or local employment is desired, evaluations may be performed by private consulting companies, irrigation districts, or other State or Federal agencies.

Fish Protection Criteria

Positive Barrier Screens

Federal and State agencies develop, update, and enforce fish screening criteria to protect fishery resources at water diversions. *Fish Protection at Water Diversions* gives a synopsis of fish protection legislation and lists the Federal and State agencies that have authority over, or a vested interest in, fishery resources in the United States (Bureau of Reclamation, 2006).

Federal governance of fish screening criteria is dictated by the Endangered Species Act, Federal Power Act, and Fish and Wildlife Coordination Act. The National Marine Fisheries Service (NMFS) prepares fish protection criteria for anadromous fish (species that migrate up rivers from the sea to spawn in fresh water) listed under the Endangered Species Act. The U.S. Fish and Wildlife Service applies fish protection requirements for endangered nonanadromous species on a project-specific basis. State fish and game agencies enforce and, in some cases, design local criteria governing the protection of endangered and nonendangered species. If State or local agencies have more stringent screening criteria, the more conservative criteria are generally followed. See Attachment A of *Fish Protection at Water Diversions* for examples of Federal and State fish screening criteria.

When a field evaluation is requested, the researcher must identify the fish screening criteria that apply to the water diversion. Pump intake screening criteria may be described separately from general fish screening criteria. There is not one universal set of fisheries criteria. Fisheries criteria vary by species, life stage, region, and season. Water resource managers and resource agency staff with working knowledge of the fish protection structure are often the best resource for obtaining this information. If there is a discrepancy over which criteria to use or whether updated criteria are available, the field researcher can obtain updated criteria from the regional resource agency that maintains screening criteria for fish species that are affected by the water diversion. It is possible that certain elements of the criteria may be waived due to site constraints or for screens constructed prior to enactment of criteria.

Since there is a broad range of screening criteria, the specific details of criteria will not be discussed. However, several important parameters and critical measurement locations are common to most hydraulic field evaluations. Important definitions related to hydraulic field evaluations include:

Channel velocity: Velocity of the flow approaching the fish screen or louver, consisting of the approach and sweeping velocity components (depicted as Vc in figure 10).

Approach velocity: Velocity vector component perpendicular to, and in front of, the screen face (depicted as Va in figure 10).

Sweeping velocity: Velocity vector component parallel and adjacent to the screen face (depicted as Vs in figure 10). For pump intake screens, the sweeping velocity is measured with the pump turned off (National Marine Fisheries Service, 1996).

Baffle system: Perforated plate, flow control louvers or vanes, stoplogs, or other flow restriction or resistance element installed behind fish screens (or inside the screen for cylindrical screens). When adjusted properly, the baffles generate localized head loss to produce a more uniform velocity distribution near the screen face.

Bypass flow: Flow rate necessary to effectively attract fish into the bypass entrance and through the bypass system.

Bypass ratio: Ratio of the water velocity entering the bypass to the water velocity in the main channel

Effective screen area: Total submerged screen area, excluding structural members. For rotating drum screens, it is the projected area onto a vertical plane.

Fish bypass system: Component of a downstream passage facility that transports fish from the diverted water back into the original body of water, usually consisting of a bypass entrance, a bypass conduit, and a bypass outfall.

Impingement: Prolonged physical contact of fish with a structure due to its inability to swim against the approach velocity.

Pump intake screen: Screening device attached directly to a pressurized diversion intake pipe. Typically, active pump intake screens are equipped with a cleaning mechanism, while passive pump intake screens do not have a cleaning mechanism.

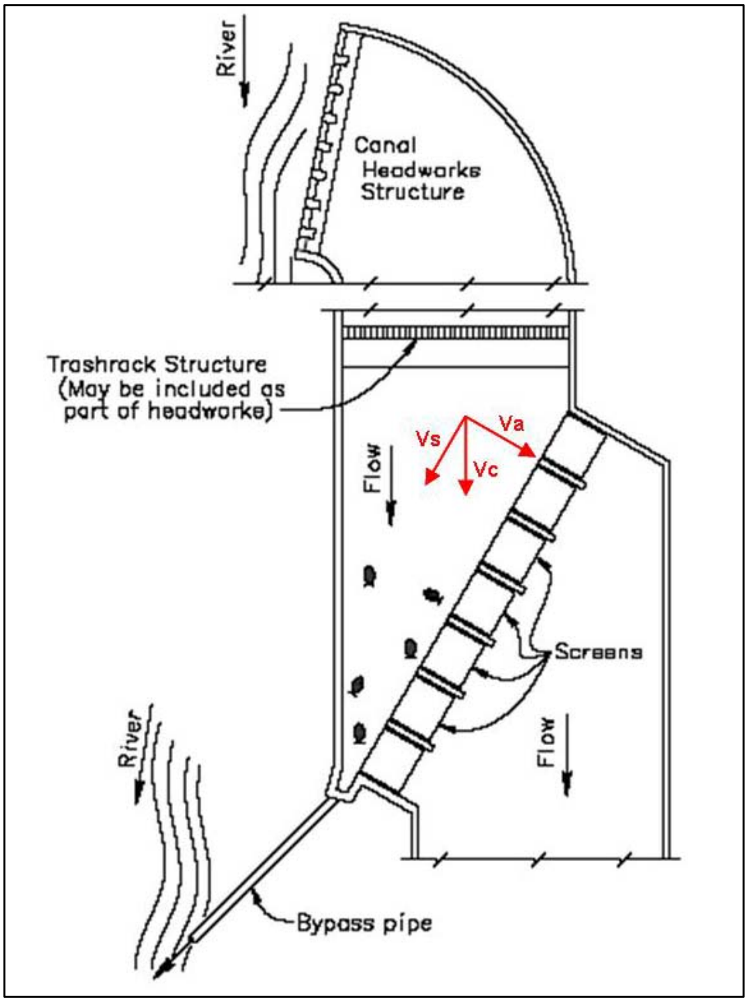

Figure 10. Plan view of an in-canal fish screening structure. The channel velocity (Vc) approaches the screen face. The approach velocity component (Va) is perpendicular to the screen face, and the sweeping velocity component (Vs) is parallel to the screen face.

During a hydraulic field evaluation of a fish screening facility, velocity measurements are typically made near the screen face, at the bypass entrance, and inside the bypass channel or conduit. Water depths in the forebay, at the upstream face of the screen, and in the bypass may need to be measured.

The following critical measurement locations and generalized criteria are commonly identified for hydraulic field evaluations:

Fish Screen Velocity Magnitudes

- Approach velocity must be less than a specified allowable value at a location, typically 3 inches perpendicular to, and in front of, the screen face (deviations from the 3-inch requirement may be necessary when the total screen surface is not readily available, as for cylindrical-shaped screens).

- Sweeping velocity must be greater than approach velocity. An optimal sweeping velocity or sweep-to-approach velocity ratio may be specified.

- Sweeping velocity shall not decrease in the downstream direction along the length of the screen face or in the bypass channel.

Fish Screen Velocity Uniformity

- A uniform velocity distribution should be maintained over the screen surface to minimize approach velocities. (Note: Adjustable porosity control or baffles on the downstream side of screens and/or flow training walls may be installed to improve uniformity.)

- Approach and sweep velocities should be measured at a specified distance from the screen face (typically 3 inches). Multiple sampling points are collected over the screen face, with each point representing the flow conditions over a particular percentage of the open screen area.

- Criteria may or may not define "uniformity." Specific criteria may state that uniform approach conditions are achieved when no individual approach velocity measurement exceeds the allowable criteria value by a specified percentage. If uniformity is undefined, fishery resource agency staff may have general guidance for acceptable distributions at the site.

Screen Submergence

- A minimum effective screen area must be submerged so that the allowable approach velocity can be achieved. For rotating drum screens, the design submergence will be defined as a percentage of the drum diameter. For cylindrical pump intake screens, the depth of submergence will be defined as a specified screen radius below the minimum water surface.

Fish Bypass System Velocities

- Criteria may specify that the minimum bypass entrance flow velocity be greater than the maximum velocity upstream of the bypass entrance by a specified percentage.
- A maximum increase rate per foot of travel (acceleration) may be required between the screens and the bypass system.
- A design velocity range for the bypass conduit may be specified.
- A maximum impact velocity from the bypass outfall may be specified.

Flow Continuity

- Flow continuity is a comparison of the calculated water diversion rate using the approach velocities and the submerged screen area from the field evaluation to the measured water diversion rate from facility flow measurement instrumentation.
- If the calculated discharge values are significantly different from the measured values, the approach velocities may not be fully describing the flow conditions along the entire screen or may not have accounted for hot and/or cold spots. If continuity is not conserved, it is possible that the instrument mounting technique may have interfered with velocity collection or the experimental setup was in error.

Behavioral Barriers

Behavioral barriers are generally not accepted by regulatory agencies since exclusion rates tend to be lower than conventional positive barrier screens. Fish species and life stage, along with site-specific hydraulic and environmental conditions, often cause the effectiveness of behavioral barriers to vary. Specific criteria for behavioral barriers are not published; however, some guidance on the experimental process for researching experimental fish guidance devices can be found in NMFS literature (National Marine Fisheries Service, 1994). When behavioral barriers are employed at a site, regulatory agencies will likely require site-specific field studies to show that fish exclusion performance is acceptable.

Postconstruction or periodic efficiency evaluations at louver systems involve many of the same critical measurement locations as fish screening systems. Effectiveness of louver systems depends on maintaining uniform sweeping flow across the louver face and guiding fish efficiently into the bypasses. Passage delays throughout the system should be minimized. Fish should not be exposed to the louver line for more than 60 seconds without access to a bypass to minimize loss through the louvers. Fish should be accelerated into the fish bypass. The bypass ratio, defined as the velocity in the bypass divided by the channel velocity in front of the bypass, should always be greater than 1.0 to effectively transport fish into and through the bypass.

The effectiveness of acoustic and light barriers, electric fields, air bubble curtains, and other behavioral exclusion methods are analyzed primarily using fish release and capture tests. These tests quantify barrier efficiency under a wide range of environmental conditions such as day and night, tidal cycles, and flow rates. Hydraulic evaluations typically include measuring velocities and mapping flow fields near to the barrier because hydraulic conditions can greatly contribute to the overall effectiveness of these barriers.

Instrumentation

Hydraulic field data are collected with a combination of portable instrumentation and permanent facility equipment. Several types of portable instruments can be used to measure velocities and flow rates at fish screening facilities. Instrument capabilities, performance specifications, costs, and availability may dictate which type of equipment is chosen. Selection of instrumentation may be dependent on site-specific factors such as site location and geometry, water quality, support structure interference (cleaning arms, dividing piers), and difficulties related to mounting and retrieving the instruments.

To assist in selecting the most appropriate field instrumentation for a hydraulic study, a description of various available technologies is provided, along with some advantages and disadvantages of using the instrument for the specified application. There are many high-quality instruments available in each instrumentation category. Specific proprietary products and materials are only mentioned to provide examples of the instruments but this should not in any way be construed as an endorsement by Reclamation. The appropriate instrumentation and mounting technique must be determined by the practitioner.

Instruments for Near-Field Screen Measurements

Acoustic Doppler Velocimeter

Acoustic Doppler velocimeters (ADV) utilize the Doppler principle to measure three-dimensional (3D) velocity vectors in a small remote sampling volume. The ADV emits sound pulses (pings) at a specific frequency. At a fixed distance from the probe, the signal reflects off of particles present in the water, providing a precise instantaneous reading at a “point” (i.e., sample volume of about 0.01 cubic inches). The frequency shift of the returning sound wave increases or decreases, depending on whether the water is moving toward or away from the receivers. The difference between the emitted and received frequency is used to calculate the water velocity.

Typically, ADV probes are configured as “down-looking” or “side-looking,” describing the location of the sample volume with respect to the probe axis, and can collect two-dimensional (2D) or 3D velocity data. ADVs are effective for measuring near-screen velocities because they can measure close to boundaries. ADVs can fit into areas with minimal lateral clearance, but they cannot fit into areas with minimal vertical clearance, such as underneath the curvature of a drum screen, due to the configuration of the signal conditioning module. Particles in the water act as scatterers to provide adequate return signal strength and signal-to-noise ratio. If the ADV does not have a strong signal in clean water applications, the water may need to be seeded with scattering material if possible. ADVs are not able to collect data in water with heavy air entrainment because bubbles attenuate the acoustic energy.

It is good practice to check the factory calibration of an ADV before each use. However, an ADV does not require periodic calibration unless the physical characteristics of the probe are changed (e.g., a receiver arm is bent). If an ADV probe is damaged during transport or use, factory repair and recalibration are required.

An example of a commercially available acoustic Doppler velocimeter is the SonTek/YSI ADV (figure 11). The 10-megahertz (MHz) ADV can acquire data at sampling rates up to 25 hertz (Hz), allowing for the measurement of turbulence. With no zero offset, the ADV performs at low flows and is bidirectional. The 6-MHz Nortek Vector velocimeter can collect data at a rate as high as 64 Hz (figure 12).

Figure 11. SonTek/YSI 10-MHz ADV probe and splash proof signal processing housing photo (courtesy of SonTek/YSI).

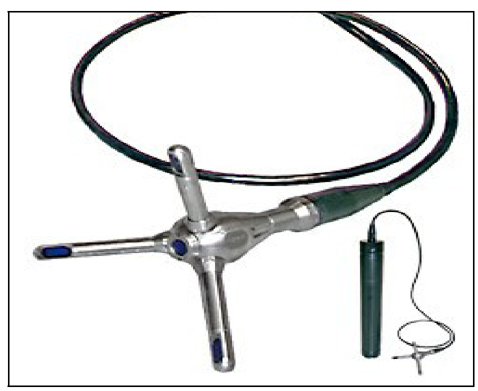

Figure 12. Nortek Vector velocimeter 6-MHz probe and submersible signal processing housing (photo courtesy of Nortek).

Electromagnetic Velocimeter

Electromagnetic (EM) instruments use Faraday's Law to measure the velocity of a conductive fluid. Water is a conductor due to the presence of trace amounts of ions from dissolved minerals. Faraday's Law states that a conductor passing through a magnetic field produces a voltage that is directly proportional to the relative velocity of the conductor. EM velocimeters provide a magnetic field, and electrode sensors on the probe surface measure the voltage induced by flow moving through the magnetic field.

For screen measurements, a 2D spherical or a one-dimensional (1D) bulb-shaped probe are normally used. When oriented properly, a two-dimensional probe simultaneously measures localized approach and sweeping velocities at a sample rate of up to 1 Hz. Since bulb or spherical shaped probes have electrodes on the side(s) of the sensor, the sampling volume is spherical in shape with a diameter of approximately 5 inches. The average fluid velocity is measured over the sample volume. If only 1D probes are available, a pair of probes must be mounted together to measure both approach and sweeping velocities.

Figure 13. Marsh-McBirney Flo-Mate 2000 portable electromagnetic sensor, cable, and splash proof electronics housing (photo courtesy of Marsh-McBirney, Inc).

EM velocimeters can fit into small measurement areas, which may be useful for large diameter drum screen and cylindrical screen evaluations. The calibration of EM meters must be checked before each use. Because ferrous metal screen materials interact with the magnetic field, velocity measurements must be taken at a minimum distance of 3 inches from the screen. One specific model of a 1D EM meter is the Marsh-McBirney Flo-Mate 2000 (figure 13).

Instruments for Fish Bypass System Measurements

In addition to point velocity measurements near the fish screen, hydraulic screen evaluations also may include measurement of water velocities entering the fish bypass and flow rates through the bypass pipe. If onsite water measurement weirs or permanent flowmeters are installed, they can be used to measure bypass rates. Otherwise, portable instrumentation must be used. Some examples of portable instruments are discussed below.

Acoustic Doppler Velocimeter

An ADV (discussed above) can be used to measure point velocities in or near the fish bypass system. These measurements may be required to determine if the flow is accelerating along the screen and into the bypass. The rate at which flow is accelerating can be measured with successive readings.

If a discharge measurement is required and permanent flowmeters are not available, the flow rate can be estimated using stream gauging techniques with an ADV or propeller meter (Bureau of Reclamation, 2001). For water depths greater than 2 ft, point velocities should be measured at 0.2 and 0.8 of the water depth from the surface in the streamwise direction, and the average of these values should be used to calculate the flow rate. For water depths less than 2 ft, a point velocity measurement at 0.6 of the water depth from the surface in the streamwise direction can be used to calculate the flow rate.

Other Velocity Meters

The OTT company has recently developed an acoustic digital current (ADC) meter, which includes depth measurement with a pressure sensor and temperature measurement. This acoustic instrument uses the cross correlation method to calculate water velocity. The sampling volume is located about 4 inches from the probe face (figure 14).

Figure 14. OTT acoustic digital current meter (photo courtesy of OTT).

Propeller meters are another option for measuring 1D point velocities in or near the fish bypass system. Care must be taken to ensure that the calibration is accurate and that the meter is oriented properly.

Acoustic Doppler Flowmeter

For discharge measurements, acoustic Doppler flowmeters (ADFM)[1] are typically mounted on the bottom of a channel or pipe for an "upward looking" measurement. Water velocity is measured by the Doppler principle via two, angled acoustic beams. Water depth is gauged by an uplooking acoustic depth sensor. The discharge is computed over the flow measurement area using the vertically integrated velocity. If the bypass channel is narrow and the water is deep, the acoustic signals may encounter boundary interference and cannot be used. Three examples of acoustic Doppler profiling flowmeters include the Teledyne ISCO 1.23-MHz ADFM Pro20 (figure 15),

[1] The acoustic Doppler flowmeter may also be referred to as an acoustic Doppler current profiler (ADCP).

the SonTek/YSI 3-MHz Argonaut-SW (figure 16), and the Teledyne/RDI 2.4-MHz V-acoustic Doppler current profiler (ADCP) (figure 17).

Figure 15. Teledyne ISCO 1.23-MHz ADFM Pro20 (photo courtesy of Teledyne ISCO, Inc).

Figure 16. SonTek/YSI 3-MHz Argonaut-SW (photo courtesy of SonTek/YSI).

Ultrasonic Noncontact Flowmeter

To measure the flow rate of a full-flowing closed conduit, noncontact ultrasonic meters can be clamped to a pipe. The flow measurement is based on the principle that sound waves in the fluid travel faster in the downstream direction than traveling in the upstream direction. The difference in transit times of the ultrasonic signals is a measure of the average fluid velocity. There are many manufacturers of ultrasonic, noncontact flowmeters. The Controlotron portable clamp-on flowmeter (shown in figure 18) is one example.

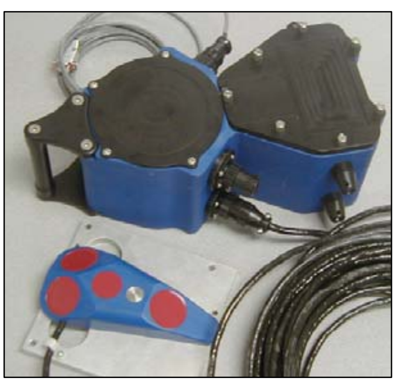

Figure 17. Teledyne/RDI V-ADCP 2.4-MHz acoustic Doppler flowmeter (photo courtesy of Teledyne/RDI, Inc).

Figure 18. Controlotron portable clamp-on flowmeter Model 1010WP (photo courtesy of Controlotron).

Support Instrumentation

Acoustic Doppler Current Profilers

Acoustic current profilers (ACP) also utilize the Doppler frequency shift principle to measure two- or three-dimensional velocity profiles in a user-specified number of depth cells. The acoustic frequency of the transceivers determines the range of the instrument and the depth size for the profile.

ACP instruments measure velocity over a large sampling volume (defined by the transceiver configuration) as opposed to point or localized velocity measured using an ADV or EM velocimeter. Although an ACP is not suited to measure near-screen velocities, it can be successfully used as a support instrument to examine approach conditions at various cross sections near the screening facility (Vermeyen and DeMoyer, 2002). Cross sections can also be taken along the length of the screens, in front or back, to identify hot spots on the screens. Examination of backscatter intensity data can provide qualitative information about suspended sediment concentrations and areas of local scour.

Instruments such as the OTT QLiner measure velocity profile data in a single plane (either vertical or horizontal, depending on the instrument orientation), requiring input of channel cross section geometry for a discharge measurement (figure 19). Instruments such as the SonTek/YSI RiverCat calculate discharge by making alternating measurements of channel cross sectional area using bottom tracking techniques and velocity profiles to define the mean vertical velocity (figure 20). Teledyne/RDI offers a similar system called the Workhorse Rio Grande ADCP. Linkquest, Inc., has also developed a line of ACPs (figure 21).

Figure 19. OTT QLiner acoustic Doppler profiler (photo courtesy of OTT).

ACPs are capable of measuring depth for each acoustic beam. As a result, ACPs can be used as multi-beam depth sounders along with integrated global positioning system (GPS) data for local bathymetric surveys (figure 22). Bathymetric data are useful for documenting changes in the approach channel geometry due to aggradation, degradation, or dredging.

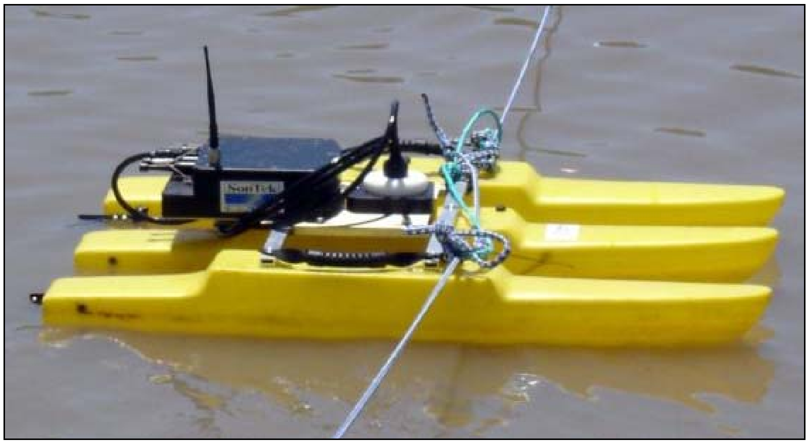

Figure 20. SonTek/YSI RiverCat acoustic Doppler profiling system (photo courtesy of SonTek/YSI).

Figure 21. Linkquest's line of ACPs (photo courtesy of Linkquest, Inc.)

Figure 22. A typical setup using a Teledyne/RDI Workhorse Rio Grande ADCP with Trimble GPS to collect bathymetric survey data.

Mounting System for Instruments

Mounting instruments in and around structures is always a site-specific challenge. Devising a workable mounting system for the instrument can take a great deal of time and effort, but it is a worthwhile investment in order to improve the efficiency and accuracy of data collection.

For fish screen measurements, portable instrumentation must be mounted close to the screen face to obtain velocity data. Probe orientation is critical when measuring directional flow. If the 2D or 3D probe is even slightly misaligned, the measured approach velocity may incorporate part of the sweeping flow, producing significant inaccuracies in the data. Some data processing software include a way to account for probe misalignment if a systematic problem is identified after data have been collected. Reclamation has developed a Windows-based viewing and postprocessing utility for ADV files called WinADV (Wahl, 2009). WinADV provides an integrated environment for reviewing and processing data collected using SonTek and Nortek acoustic Doppler velocimeters.

Velocimeters should be clamped onto a sturdy support structure that minimizes instrument movement and vibration. The most accurate way to position the instrument is to reference it directly off of the screen for each measurement. If a long cantilevered mount is necessary, the mount must be rigid so it does not deflect or vibrate in fast moving water. If movement is a concern, a stronger support should be used or the mount should incorporate intermediate supports wherever possible.

The mount should not block or disrupt the flow field around the instrument. The mounting system must have a way to determine the lateral and vertical position of the instrument. It is most efficient if the instrument can be moved between measurement locations quickly and accurately. In most cases, accurate point velocity measurements cannot be made off of a boat because boat movement is incorporated into the measured velocity. If a floating platform must be used to access the site, it should be securely anchored to minimize motion.

Velocity and discharge measurements in fish bypass channels may require affixing an instrument to the bottom, or near the bottom, of the bypass channel. If the bypass cannot be fully dewatered, the instrument should be carefully secured to the channel bottom or sidewalls in the wet. The location and orientation of the instrument must be known to get accurate results. A heavy weight or plate can sometimes be used to fix the position of the instrument. If interference from sidewalls or other structures cannot be avoided, a point velocity meter may be required.

Acoustic Doppler profilers or current meters are often mounted off of boats, bridges, or rope lines to collect supporting hydraulic data. The deployment mechanism depends on the channel geometry, water depth and velocity, transect location, and other site-specific factors. Orientation of current meters is an important consideration because the transducer must be aligned parallel to the channel centerline or perpendicular to a tagline. Compasses are often integrated into acoustic Doppler instruments to allow data collection in earth coordinates. If so, a compass calibration is required to compensate for local magnetic fields.

Types of Hydraulic Screen Evaluations

Postconstruction Field Evaluations

The purpose of postconstruction hydraulic evaluations is to validate design performance, refine hydraulic conditions, and document facility effectiveness. Hydraulic tests may include velocity measurements along the screen face, at the bypass entrance and exit, and in the bypass channel or conduit to determine if fish will be guided effectively through the system.

Before conducting a postconstruction evaluation, it is important to determine what flow conditions should be evaluated. Depending on the facility, the appropriate time period may be at low water depth, normal or peak operations, or a critical time period such as during smolt passage. Hydraulic conditions and operational settings such as diversion and bypass flow rates, water depths, screen submergence, and the weir and baffle settings should be recorded during field evaluations.

For facilities with flow control baffles downstream of the screens, hydraulic testing is necessary to properly adjust the baffles to achieve near-uniform approach velocities. A trial-and-error process is required to adjust multiple sets of flow control louvers, vertical vanes, perforated plates, or flashboards behind each screen. Several comparable rounds of velocity data will likely need to be collected. Setting baffles for in-canal screening systems tends to be more straightforward than adjusting baffles for in-river applications where variable hydraulic conditions and dynamic flow patterns add complexity to the system. Hydraulic evaluations may also be requested to identify optimal operational conditions during critical fish protection periods or to adjust bypass weirs for effective performance.

Long-Term Field Monitoring Programs

Long-term monitoring tests are used to ensure proper facility performance and to identify screen cleaning or maintenance concerns. Periodic hydraulic evaluations may be requested to measure approach and sweeping velocities across the screen face to verify screen and baffle performance. Diversion rates can be calculated from measured approach velocity values and compared with measured diversion rates.

Structural changes, such as installation of new baffles or cleaning devices, and operational changes, due to altered flow rates or criteria requirements, may require special hydraulic evaluations. Hydraulic evaluations may also help to identify underwater screen damage, debris accumulation, sedimentation, or problems with permanent instrumentation.

Field Evaluation Case Studies

Glenn-Colusa Irrigation District (GCID) Diversion

Facility type: In-river flat plate screens

Challenges: Instrument mounting due to high sweeping velocities, defining velocity uniformity for a large facility, data repeatability with dynamic flow conditions

The GCID pump station is located in north-central California, about 100 miles north of Sacramento. The diversion facility is located on an oxbow of the Sacramento River (figure 23). Up to 3,000 cubic feet per second (ft^3/s) of Sacramento River water is pumped into GCID's canal after passing through the fish screens. A portion of the water bypasses the screen and flows back into the river at the downstream end of the oxbow.

To protect fish from entrainment in the main irrigation canal, long flat plate screens with three fish bypasses were installed at the pump station in 2000 in partnership with Reclamation. The U.S. Army Corps of Engineers constructed a gradient restoration facility on the main stem of the Sacramento River to stabilize the river channel, promote upstream and downstream fish passage, and maintain adequate water surface elevations and flow rates for safe fish passage and effective screening. More information on GCID's Fish Screen Project can be found on their Web site (GCID, 2009).

Since construction, many hydraulic evaluations have been conducted by CH2M HILL, GCID, NMFS, and Reclamation to adjust the baffle system, document screen performance and compliance, and monitor intake and bypass channels. Several site-specific issues have made data collection difficult at the GCID fish screens. It is important to design a monitoring program after site-specific issues are identified, so that a generic test plan does not lock the evaluators into a test procedure that is not appropriate for the facility. More information on GCID's Evaluation and Monitoring Program is available on their Web site (GCID, 2009).

Figure 23. GCID's Hamilton City diversion facilities located in an oxbow along the Sacramento River.

The GCID flat plate screens are an unprecedented 1,100 ft long. According to the California Department of Fish and Game (CDFG) screening criteria, approach velocities for in-river screens should not exceed 0.33 feet per second (ft/s) over the entire screen face (CDFG, 2000). Measuring multiple locations on each of the 85 screen panels to ensure adequate uniformity is prohibitively time consuming. However, one single velocity point measurement per screen does not adequately represent the flow patterns over the entire screen because a single measurement can be affected by localized debris effects or recirculating flow patterns. In this situation, the number of screen measurements that can be collected during a single evaluation is dictated by the design and flow conditions for the facility. The oversight agency should be contacted to discuss potential options.

Screening criteria state that the sweeping velocity should be at least two times the allowable approach velocity at GCID. The flat plate screens were designed to have high sweep to approach velocity ratios, often around 10:1 or more. This larger ratio provides good hydraulics for safe fish exclusion, but it complicates screen evaluations. When mounting instruments in high velocities, the mount may vibrate or bend, particularly if the support is long or cantilevered (CH2M HILL, 2003). If a boat is necessary for installation, high velocities may make it difficult to maintain a steady boat position in the channel. High sweeping flows accentuate the influence of boundaries and obstacles in the flow. Since the approach velocity is a small component of the channel velocity, slight changes in flow conditions can substantially alter the magnitude of the approach velocity.

Unlike controlled canal systems, on-river screening facilities face dynamic flow conditions. The GCID screens are located on an oxbow with a curved intake channel. Flow conditions such as upwelling, eddies, and recirculation currents are common. For these conditions, data repeatability may be problematic.

Both ADVs and EM meters have been used successfully at the GCID site. Initially, the support structures for the screen cleaning brush masts were used to deploy multiple velocimeters. However, field tests at GCID have shown that the brush masts affected near-screen velocities up to 10 ft upstream from the masts, thereby skewing velocity data (Thomas, 2004). Consequently, a magnetic mount (shown in figure 24) was designed to be independent of the support structure in order to eliminate the hydraulic effects generated by the brush masts (Thomas, 2006).

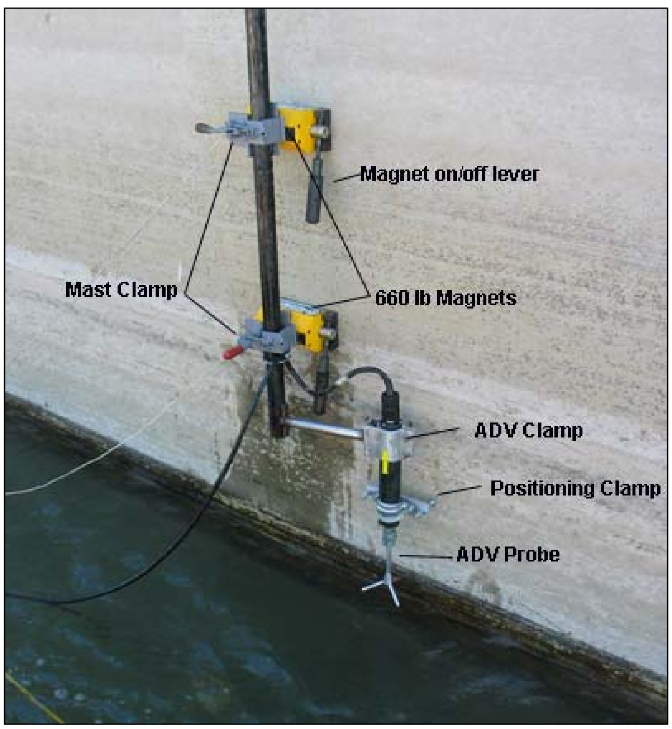

Figure 24. Magnetic ADV mount used at GCID (photo courtesy of National Marine Fisheries Service).

An ADCP was successfully used as a support instrument at GCID during a field evaluation (Vermeyen and DeMoyer, 2002). Along with bathymetric and velocity data collected in and around the gradient restoration facility, cross sectional current profiles were collected across the GCID pumping plant approach channel and along the length of the fish screen. An example of the high resolution bathymetric and velocity field information collected by the ADCP is shown in figure 25.

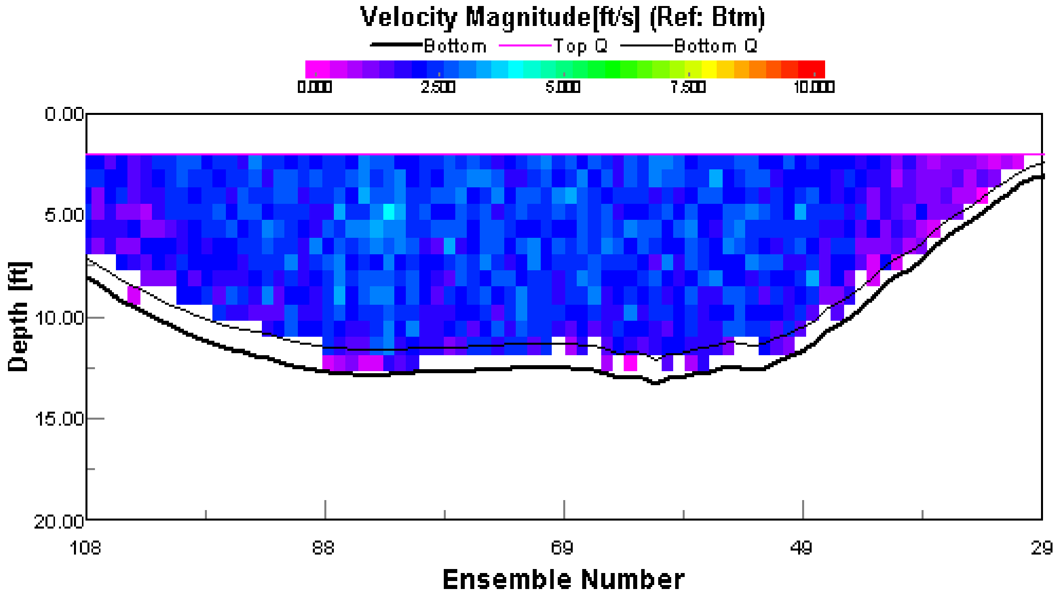

Figure 25. Cross section of velocity magnitudes collected in the GCID pumping plant approach channel.

Roza Fish Screens Facility

Facility type: In-diversion drum screens

Challenges: Access to drum screen face, defining velocity uniformity for a large facility

Roza Diversion Dam is part of the Roza Division of Reclamation’s Yakima Basin Project. The dam diverts water from the Yakima River into the Roza Canal, which provides water for irrigation and power generation. Located at the canal headworks, a series of rotating drum screens protects fish from being entrained in the canal. The Roza Fish Screens Facility consists of 27 drum screens (17 ft in diameter and 12 ft wide) in five bays with a primary fish bypass at the downstream end of each bay (figure 26).

Hydraulic evaluations have been conducted at the fish screening facility since 1985 to document postconstruction performance (Abernathy et al., 1989) and to evaluate potential operational changes such as reducing primary bypass flows (McMichael et al., 2003; DeMoyer, 2004) and using sluice gates behind the drum screens for velocity control (DeMoyer and Vermeyen, 2004). Anadromous salmonid criteria are governed by the regional NMFS division (1995). Although governing approach velocity criteria specifies 0.4 ft/s, the facility was originally designed for an approach velocity of 0.5 ft/s. Evaluations have been conducted with consideration of the design criteria.

Figure 26. Rotating drum screens in one bay of Roza Fish Screens Facility.

There are unique challenges for measuring velocities near drum screens. Drum screens are designed for the expected approach velocity based on the vertically projected open area; however, for velocity evaluations, criteria require that the measurement occur 3 inches from the cylindrical screen face. A velocity meter can be easily positioned close to the screen face at or above the centerline of the drum. However, access to the screen face below the curvature of drum screens is difficult, particularly for large diameter screens such as the Roza screens (figure 27).

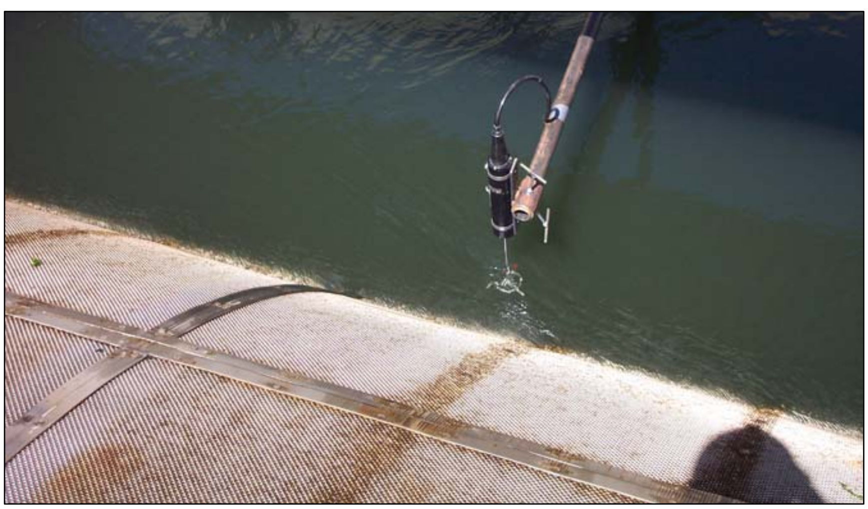

Figure 27. A cantilevered steel mount with a horizontally adjustable arm was used to measure velocities close to the screen face near the surface (as shown) and under the curvature of the screen (DeMoyer, 2004).

Due to limitations in the body shape of the ADV instrument, standard down-looking ADVs cannot measure velocities at 3 inches from the screen at depths far below the screen curvature while maintaining a vertical probe orientation. At the Roza Fish Screens Facility, the velocity instrument may be as far as 30 inches from the screen face at 0.8 times the depth (figure 28). Inverting the probe may be possible, depending on the distance from the floor, sturdiness of the instrument mount, and debris and silt accumulation on the floor, but it is not recommended for large diameter screens where lack of visual cues increases the probability for probe damage. If an ADV cannot be positioned at the required location, the evaluation report should include the actual measurement location. Depending on the geometry of the site, EM meters may be placed slightly closer to the screen face under the curvature of the screen, but the use of multiple instruments may require separate mounting devices.

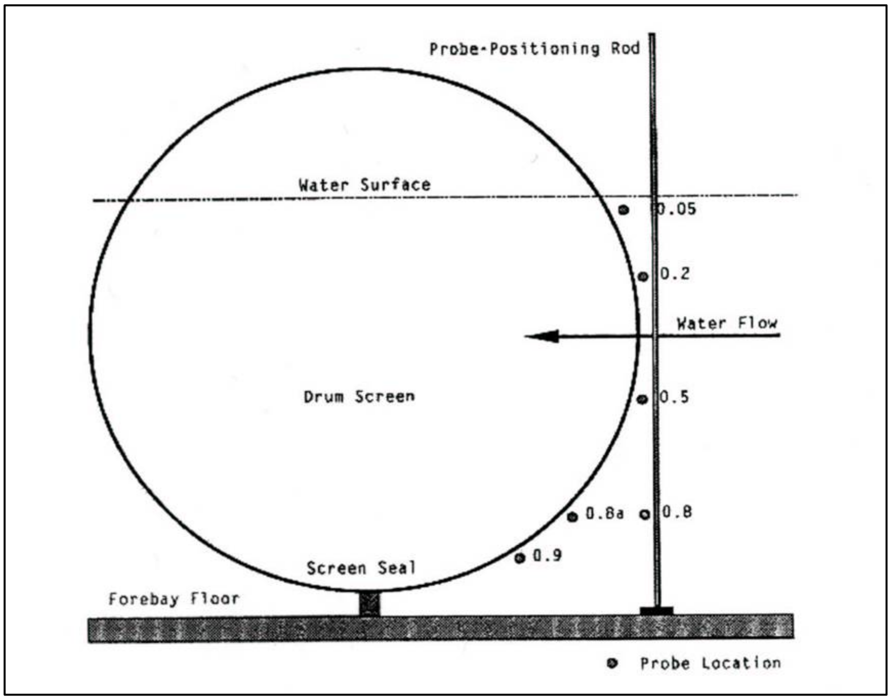

Figure 28. Schematic of measurement locations at a distance of 3 inches from the screen face and along the vertical projection of the screen (Abernathy et al., 1989).

If the definition of velocity uniformity is not specified in the screening criteria, it is important to determine which data locations are required to adequately map velocities over the face of the screen. In a 1989 Pacific Northwest National Laboratory study at the Roza Fish Screens Facility (Abernathy et al., 1989), velocity measurements were collected at depths of 0.2, 0.5, and 0.8 on a vertically projected plane and at 0.05, 0.08a, and 0.9 near to the drum screen face, as shown in figure 28. Results indicated that velocities measured at 0.05 and 0.5 were accurately represented by measurements at 0.2 and 0.8 on the vertically projected plane. Limited velocity data collected near to the screen face at 0.8a and 0.9 indicated that velocities may be higher at those locations, possibly due to a 1-foot drop in the floor elevation at the drum screens or the influence of the sluicing panels.

Judgment should be used when selecting appropriate measurement locations for the evaluation under schedule and budget constraints. A hydraulic evaluation was conducted in March 2004 to determine the effects of sediment sluicing panels on drum screen performance. Data were collected on all 27 screens in 5 bays for 2 different operational conditions. Changing the position of the sluicing panels was time intensive and required a significant equilibrium period before data collection could continue. In order to collect a full suite of data during similar diversion rates, six measurement locations were chosen per screen (two depths and three lateral locations). In an August 2004 evaluation, detailed velocity data were collected on representative screens in order to document the effect of lowering bypass flows. For this evaluation, 35 locations (5 depths and 7 lateral locations) were measured at 6 representative screens.

Red Bluff Research Pumping Plant

Facility type: In-diversion V-screens

Challenges: Baffle installation due to high approach velocities and poor uniformity, flow deceleration into bypass

Starting in 1966, Red Bluff Diversion Dam allowed gravity diversion from the Sacramento River into the Tehama-Colusa Canal for water deliveries. Operation of the diversion dam adversely impacted the fisheries resources in the river. In 1995, Red Bluff Research Pumping Plant (figure 29) was constructed downstream of the Red Bluff Diversion Dam to test a new concept in fish protection at a pumped water diversion. This “pump first, screen second” method employed existing technology such as fish-friendly pumps (Archimedes lifts and an internal helical pump), vertical wedge-wire screens, and fish bypass structures.

The fish-friendly pumps discharge water, fish, and debris into a concrete sluiceway. A V-shaped (or chevron) screening structure consists of twelve 5.25-ft by 5.25-ft steel panels. The screening structure concentrates the entrained fish into a bypass that conveys 10 percent of the total pumped flow (figure 30). The open channel bypass moves fish into the evaluation facility or back into the river, while the water passing through the V-screens continues into the canal. No baffles were included in the original screen design. Continuously operating brushes sweep both sides of the screen to minimize debris accumulation.

Figure 29. Overview of Red Bluff Research Pumping Plant.

Figure 30. Flat plate V-screen with a terminal fish bypass.

Hydraulic evaluations were conducted throughout the facility to test the new fish protection methods employed at Red Bluff. In order to evaluate fish passage through the two types of pumps, the V-screens needed to be operating properly. An acoustic Doppler velocimeter was used to collect velocity data in front of the screen panels. The V-screens were designed to meet the CDFG approach velocity criteria of 0.33 ft/s maximum at 3 inches from the screen face. In 1997, CDFG accepted a fish screening criteria modification published by the Southwest

Region NMFS (1997) specifying that approach velocities 3 inches from the screen face should not exceed 0.4 ft/s in canals. Initial screen measurements with no baffles resulted in approach velocities in excess of 1.25 ft/s. To reduce approach velocity magnitudes and improve flow uniformity, several baffle configurations were subsequently installed and tested.

Screening evaluations were conducted from 1995 through 1998 to determine which baffle configuration produced the best screen performance (Frizell and Atkinson, 1999). Both fixed area baffles and adjustable porosity baffles installed behind the downstream half of the screen panels on both sides were not successful at meeting criteria. In order to affect the entire flow field, fixed area baffles were also installed behind the upstream half of the screen panels. A full set of baffles was needed to produce acceptable velocities in most areas of the screens (figure 31). Even with baffles, surface waves caused inconsistent velocities at the water surface due to the pump outlet conditions and short approach channel length to the screens.

Figure 31. Adjustable baffles located behind fish screen panels.

Mean channel velocities were measured at three locations approaching and inside of the screening structure. Results showed an undesirable deceleration of flow into the bypass. The bypass intake design produced a recirculation zone in the bottom 2 ft of the water column, causing the velocity to decrease. Although retrofits were difficult for this facility, structural modifications may be made at other sites if fish are not accelerated into the bypass.

Submerged Cylindrical Screens

Facility type: In-river or in-diversion submerged cylindrical screens

Challenges: Instrument mounting, requires divers, variable approach conditions

A specific case study will not be presented here, but the challenges of collecting cylindrical screen measurements will be discussed. Field evaluations of cylindrical screens on small diversions (less than 40 ft^3/s) are not common because the impact to fish is likely to be minimal. Field evaluations of large submerged cylindrical screens (above 40 ft^3/s) may be required by regulatory agencies.

Alternative screening technologies, such as submerged cylindrical screens, are becoming more commonplace because of the lower installation costs. Cylindrical screens are fixed in place either on a buried manifold system or to flanges on civil works projects. Other designs incorporate screens on retractable rails attached to the diversion pipe or the pumping plant structure, allowing maintenance to be carried out in the dry. When planning for the installation of submerged cylindrical screens, the approach conditions should be conservative to simulate the worst-case operational scenario. The screen should be placed in a location with uniform approach flow conditions, and the long axis of the screen should be parallel to the sweeping flow direction. Internal baffling is used to create more uniform velocity distributions over the screen face. Since baffles are not adjustable in most cylindrical screens, postinstallation modifications are typically limited to adjusting approach conditions or the angle of the screen.

Laboratory tests at Reclamation’s Hydraulics Laboratory in Denver, Colorado, have shown that flow separation and eddies are generated off of the leading edge of the screen, causing water to flow out of the screen near the upstream end (Mefford and Hanna, 1997). During the screen tests, outflow occurred in the upstream 10 to 15 percent of the screen, producing higher approach velocities along the rest of the screen than the screen was designed to accommodate. With this in mind, additional open area should be provided to account for flow separation effects at the leading edge.

Submerged cylindrical screens are often evaluated by manufacturers in a hydraulics laboratory for fisheries compliance under a range of flow conditions. Although these are good baseline evaluations of screen performance, changes in river flow and stage affect the flow angle and sweeping velocities near the screen in the field. Therefore, field evaluations should be conducted for a wide variety of flow conditions to fully evaluate screen performance. Submerged cylindrical screens are difficult to test in the field because of the complexity of installing and mounting velocity meters and uncertainties about the instrument location and percent of area tested. Retrievable screens can provide more flexibility than fixed screens in designing an evaluation plan. Regardless of screen type, divers will likely be needed to ensure proper placement of the velocity instrument and to reduce the possibly of damage to the instrument. When high sweeping velocities exist, the risk associated with having divers in the water is heightened. Holding the velocity meter in place is not a viable option; therefore, the diver must either move the instrument and reattach it between measurement points or an instrument mount must be designed to move the meter along the screen without obstructing flow patterns.

Tracy Fish Collection Facility

Facility type: Louver system

Challenges: Maintaining high bypass flows, flow deceleration and eddying near bypasses, debris loads

The Tracy Fish Collection Facility (TFCF) is located at the head of the Delta-Mendota intake channel at the south end of the Sacramento-San Joaquin Delta near Tracy, California. The facility was constructed in the 1950s to collect fish before entrainment at the C.W. "Bill" Jones Plant. The facility was designed to guide fish from the canal into one of four primary bypass intakes by way of a diagonal line of louvers in the primary channel. Two sets of louvers in a secondary facility guide fish through a bypass into the holding tank area. A schematic of the facility is seen in figure 32.

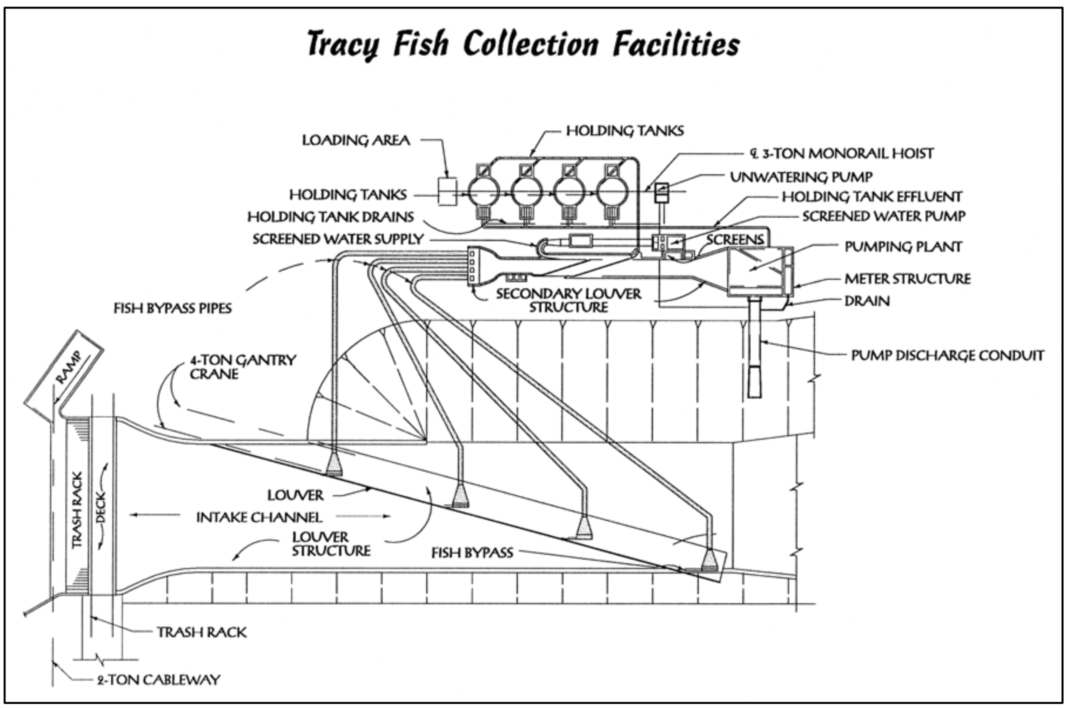

Figure 32. Plan view schematic of the Tracy Fish Collection Facility near Tracy, California.

Fisheries criteria for louver systems have not been published by regulatory agencies; however, standards for operation of the TFCF are published in Decision *1485 Water Quality Standards for the Sacramento-San Joaquin and Suisun Marsh* (State Water Resources Control Board, 1978). According to table II, the secondary channel velocities should be held at 3.0 to 3.5 ft/s from February - May, while salmon are present, and less than 2.5 ft/s from

June 1 - August 31 for striped bass, shad, and catfish. The bypass entrance velocity should exceed the local channel velocity to guide fish into the bypass. This ratio, defined as the bypass ratio, should be greater than 1.0 to achieve efficient bypass conditions and to eliminate eddies and slack water zones that hold up fish movement.

Like screening facilities, to achieve effective fish exclusion, the fish must be moved efficiently along the louvers with gradual flow acceleration into the bypass. Strong accelerations and decelerations can cause fish avoidance of the bypass (Bates et al., 1960). In 2004, the primary bypass intakes were replaced with a new design based on physical and computational hydraulic studies (Kubitschek, 2003). The new bypasses were designed to produce a near-uniform vertical flow distribution throughout the water column to improve the hydraulic conditions for fish collection. Laboratory modeling also showed that vertical approach flow velocity distributions strongly influence velocity distributions within the bypass intake, so it was anticipated that the bypass intakes would perform best when debris fouling was minimized (Johnson et al., 2004). Hydraulic field evaluations were conducted to verify the performance of the new primary bypass intakes (DeMoyer, 2007).

Vertical velocity profiles were collected at the bypass intake with an acoustic Doppler velocimeter. Since the bypass channel is only 6 inches wide, an instrument mount had to be designed to minimize flow blockage and disturbance to flow patterns. An angled rail was attached to the louvers with a vertically traversing sled (figure 33). The ADV was mounted on the end of an arm extending from the moveable sled to measure vertical velocities at the bypass intake. An acoustic Doppler profiler was used to measure velocity field distributions upstream of the intake. The instrument was tethered to the louver cleaner platform in order to position the instrument properly in front of the bypass (figure 34).

Figure 33. Mounting an ADV to the louver line.

Figure 34. Positioning the ADP in front of the bypass intake.

Field results showed that bypass ratios greater than 1.0 minimize flow disruption and eddying and promote gradual flow acceleration into the intakes, indicating that the facility should be operated in this manner whenever possible. However, tidal fluctuations, high pumping rates, and low water levels in the Delta prevent achievement of bypass ratio objectives at times, regardless of facility operation. High debris loads adversely affected bypass performance by degrading uniformity in the vertical velocity profiles at the bypass entrances. This shows the importance of debris management at fish protection facilities.

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