Scoping Paper: Investigation of Fish Refugia Concepts at Hydraulic Structures

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Purpose

This scoping paper discusses refuges for small fish at hydraulic structures. The paper was funded by the Bureau of Reclamation's (Reclamation) Science and Technology Program for the purpose of evaluating potential future research directions. Published research on this topic is scarce at this time, so information in this paper is based on the informed perspectives of the author, reviewers, and other colleagues regarding fish refugia.

Introduction

Hydraulic structures, including fish screening facilities and pump intakes, produce regions in a river where hydraulics are altered and fish habitat may be limited. The concept of creating fish refuges for increased fish protection at screens and other structures is relatively new. Fish refugia provide resting areas for juvenile and small-bodied fish as well as providing protected cover from predation. Predators, however, will opportunistically hold in favorable hydraulic conditions, so refuge areas should be designed to minimize predator use.

Fish refuge pockets at multiple locations along the length of a screen are currently being developed as an alternative to intermediate bypass systems on long screens. Intermediate bypasses provide relief for small fish from exposure to hydraulic conditions. Fish are guided through bypasses to outfall locations downstream of the structure. However, hydraulic conditions are not appropriate at some locations for the intermediate bypasses to operate properly. Bypasses may also consolidate small fish into one outfall location where predator fish and birds can opportunistically feed.

As an example, intermediate bypasses were utilized on the old and new fish screens at Glenn-Colusa Irrigation District (GCID, Willows, California). Intermediate bypasses in the old GCID rotary drum screens provided relief for small fish from exposure to the screens; however, flow and velocities into the bypasses were unbalanced and proper bypass flow could not be maintained (GCID et al., 1989). When new flat-plate fish screens were installed at GCID, intermediate fish bypasses were incorporated into the design. As a result of extensive biological testing at the site, the bypasses were permanently closed and a downsteam weir necessary for operation of the fish bypasses was removed due to predation-related concerns at those structures (Vogel, 2008). Predation at the GCID fish screen has been observed with underwater cameras, DIDSON^{TM} sonar cameras, direct surface observations, and acoustic telemetry. When the old fish screens were in operation, predators (striped bass (*Morone saxitilis)* and Sacramento pikeminnow (*Ptychocheilus grandis)*) were observed holding in areas adjacent to convolutions in vertical sheet pile walls (Vogel and Marine, 1995). Convolutions in sheet pile walls in the new screen structure were sealed by welding flat-plate steel on the walls which eliminated predatory fish habitats. At the new fish screens, predators have opportunistically taken residency in eddy zones behind screen cleaner arms, at the screen base, and at the bypass outfall location (Dave Vogel, personal communication and Vogel, 2008).

Fish refuge pockets on long fish screens may be an improved alternative to intermediate bypass systems. The pockets provide hydraulic and predation refuge at several locations along the screen, thereby breaking up long expanses of screen. Since this concept has not been thoroughly tested and applied to fish screen projects, benefits to fish have not been quantified. Fish refugia could also be installed in locations where there is a unique predation opportunity because of both the lack of cover and the addition of features such as a cleaning system which could allow for predator holding. This could include smaller screens where hydraulic refuge is not necessary, but refugia may reduce predation. This type of predation refuge may consist of artificial features for small fish protection at a number of locations on and near fish screens and other structures.

Sheet pile or concrete transition walls upstream and downstream of screens and intakes produce bank lines without natural cover and therefore could be a logical location for engineered predator refuges. The sill at the base of the screen or the blanking panels at the water surface are other possible refugia locations. Predation refuges can also be constructed on support structures and support walls. It may even be possible for refuges to be included in channelized sections of river to support river restoration efforts such as large wood structures, rock barbs and weirs, boulder clusters, rip rap, or other artificial river features.

Investigations are needed to determine the effectiveness of artificial refuges for fish to rest or evade predators. Further attention should also focus on whether refuge elements can be designed to minimize debris retention.

Current Applications of Fish Refuges

Since this is a relatively new concept, little information was available from a literature review. Most information was gathered by talking to federal and state agencies, and consultants. Dan Meier (U.S. Fish and Wildlife Service), Steve Thomas (NOAA Fisheries), George Heise (California Department of Fish and Wildlife), Don Portz (Reclamation), and Dave Vogel (Natural Resource Scientists, Inc.) provided information about current applications and suggested alternative designs and concepts for research.

The first fish refugia installation was Red Bluff fish screen (Figure 1) in 2010 at Reclamation's Red Bluff Diversion Dam, Red Bluff, California. NOAA Fisheries recommended fish refuges in lieu of intermediate bypasses. A physical model study was conducted at Reclamation's hydraulics laboratory in Denver, Colorado to provide guidance on the fish refuge design for the Red Bluff fish screen (Lentz, 2009). Hydraulic parameters such as velocity and turbulence were measured and fish behavior of specific species and size classes was observed. Juvenile Chinook salmon (*Oncorhynchus tshawytscha,* 3-4 in), white sturgeon (*Acipenser transmontanus*, 5-7 in), and rainbow trout (*Oncorhynchus mykiss*, 1-2 in) were used for model testing. Bar spacing at the entrance to the refuge was selected based on fish size. The tested refuge length was 8 ft and 10 ft and the depth was 3 in and 6 in (depth was restricted by the Red Bluff screen design). Roughness elements were added to the back of the refuge pocket to reduce velocities, but turbulence was significantly increased. A divider wall was added to segment the pocket, but this also increased turbulence.

Figure 1. Bar rack at the entrance to the Red Bluff fish refugia panel in dewatered condition.

The final recommended configuration was 8 ft long and 6 in deep with horizontal ¾ in-diameter bars spaced 1.75 in on center at the entrance to the refuge. The distance between the bottom bar and the floor was 1 ¼ in to accommodate the entrance of juvenile sturgeon. The upstream 4 ft of length were open with bars, the next 3 ft were blocked with a solid panel, and the final foot was open with bars (Figure 2). This configuration reduced velocities inside the refuge while minimizing turbulence. Four fish refuge pockets were constructed along approximately 1,100 ft of screen.

Figure 2. Red Bluff fish refuge panel with blocked section. The direction of river flow is from right to left.

A similar type of design is planned for construction at the Reclamation District 2035 fish screen on the Sacramento River just northwest of Sacramento, California. The original design included a single refuge pocket located at the midpoint of the intake structure (Figure 3). In the modified design, NOAA Fisheries, Reclamation, and U.S. Fish and Wildlife Service recommended 2-ft-long refuge pockets between each screen panel in the concrete support structure (Figure 4). Refuges consist of ¾-in-diameter bars spaced at 1 ¾ in on center. The agencies also recommended incorporating juvenile fish habitat elements into the intake's upstream and downstream sheet pile training walls and the sloped soil areas above the training walls. Grating material with 2 in by 4 in openings will be attached to the sheet pile walls to prevent larger fish from using the corrugations for holding. This area may also provide some cover for smaller fish. Earthen areas that will be submerged at high flows are being planted with several species of willow.

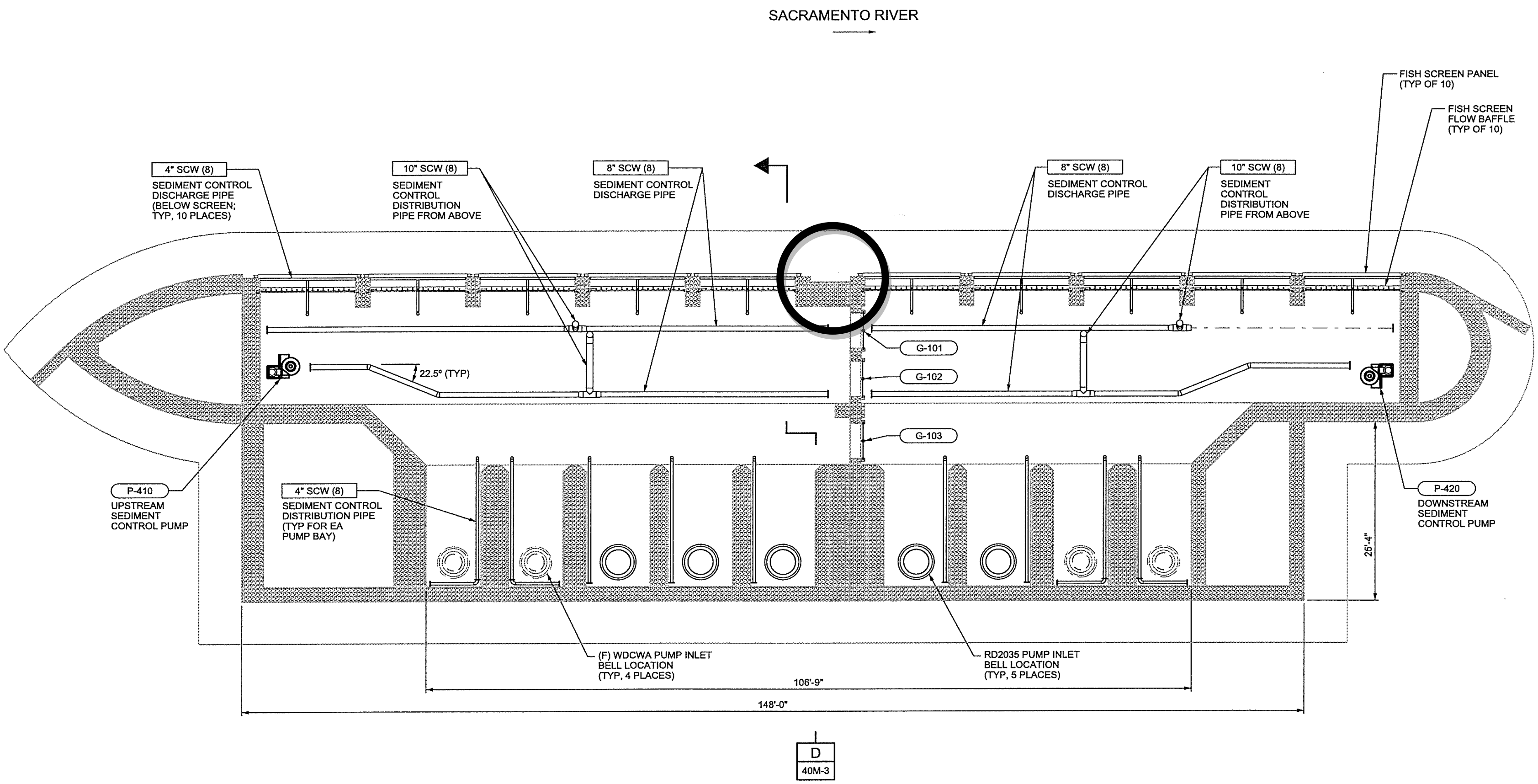

Figure 3. Plan view of Reclamation District 2035 intake structure showing a single fish refugia pocket at the midpoint of the screen (circled in figure).

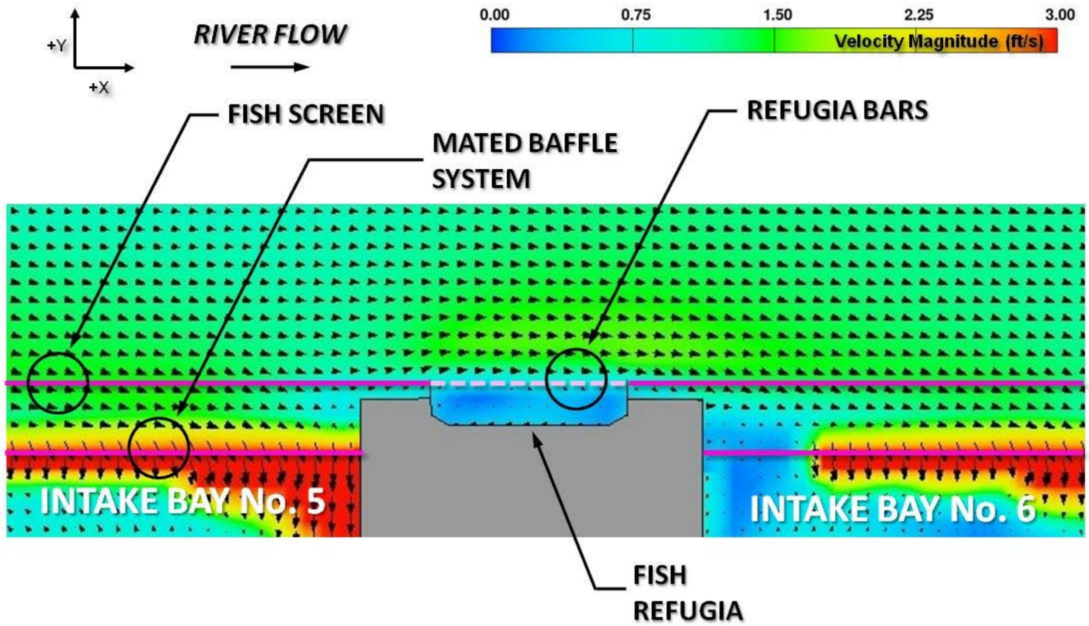

Figure 4. Numerical modeling of Reclamation District 2035 intake shows an example of one fish refuge pocket midway along the fish screen in the concrete support structure. Multiple fish refuges were designed along the length of the screen.

Other fish refuge designs have been suggested. The Anadromous Fish Screening Program (AFSP) has identified some preliminary concepts for fish refugia that could be deployed in proximity to existing screens. These designs warrant further investigation. One possible design uses hanging chains on a panel (Figures 5 and 6).

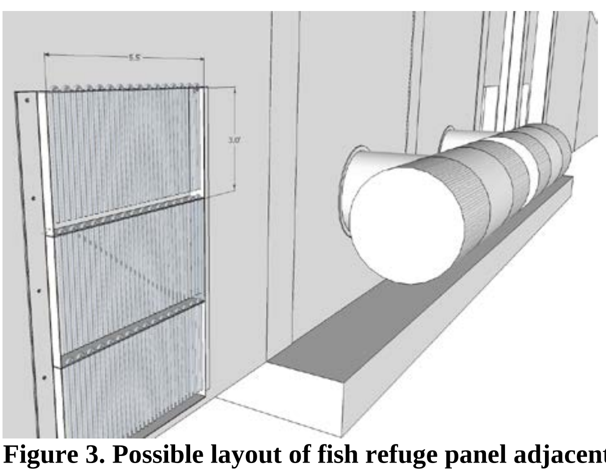

Figure 3. Possible layout of fish refuge panel adjacent to a screened water intake.

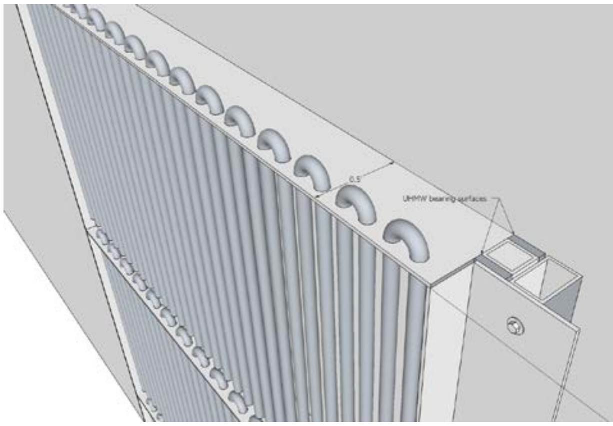

Figure 4. Detail of proposed fish refuge panel with hanging chains.

Fish refuge designs could also consist of a trashrack-type system for small fish refuge. Dave Vogel (Natural Resource Scientists, Inc.) has recorded underwater footage showing juvenile salmon rearing between a trashrack and a vertical fish screen. These videos can be viewed at the following links:

http://www.youtube.com/watch?v=kxzDCtTRiVo&list=UUL1jhaAjPfvV5FWEqnx1nCg

http://www.youtube.com/watch?v=4pGXO-5-42o&list=UUL1jhaAjPfvV5FWEqnx1nCg

Potential Applications of Fish Refuges

Reclamation is required to provide fish protection at existing and new facilities. Fish screens are designed and installed on water intakes where entrainment of endangered species is of concern. Fish screens may also need to be installed in locations where endangered species are not currently present, but populations are being restored or existing populations are declining. Facilities with older fish screens may need to be retrofitted with predation refuges to improve survivability of vulnerable species.

There are several large screen locations where fish refuges could be demonstrated in the future. The Bay Delta Conservation Plan may include three screened intakes over 1,000 ft long on the Sacramento River in California. Refugia pockets have been recommended by the multi-agency team overseeing this project (Bay Delta Conservation Plan, 2011). Restoration efforts on the San Joaquin River, California may require new screening facilities (on-river or off-river) to protect salmon. Similarly, new screens will likely be needed to support efforts to return a historic salmon run to the Klamath River, California and Oregon.

Research Needs

Additional studies are warranted to optimize fish refuge design for fish usage and effectiveness. Potential future studies should include both laboratory and field tests. Objectives for testing include:

- Will small fish use refuges as cover?
- Will refugia reduce overall predation?
- Will refugia significantly delay movement of juvenile anadromous fish? What is residence time inside refuges?
- What material types and design configurations are best?
- How do different fish species respond to refuges? Can the design be optimized for use by different species and size classes?
- What velocity range is required for successful use of refugia (sweeping and approach velocities)?
- Can materials be chosen to minimize maintenance?
- What are potential locations for successful refugia installation (on-screen, near bottom sill, in transition walls, on-river)?
- Do juvenile fish utilize refugia without the presence of predatory fish?

Fish refuge zones can be modeled in a hydraulics laboratory. Small fish behavior, usage of refuge zones, and residence time for various flow regimes can be identified during laboratory tests. Predators can be added to the model to observe where they hold in reference to refugia and whether refuge zones allow small fish to evade predators. Design elements can be easily modified and fish usage and predation for a set number of small fish and predators can be directly compared. A Passive Integrated Transponder (PIT) tag array could be used to record where fish enter and depart and their residence time. The primary benefit of the laboratory approach is the controlled laboratory setting. Fish are released so that contact with refugia is likely and monitoring fish movement is easier in a fixed, low turbidity environment. The primary detriment of this approach is that fish may behave differently in laboratory setting due to lighting, water quality, and handling stress.

Field testing can also provide real-world information about this conceptual idea. During field tests, an underwater camera can be used to record natural fish behavior (predator and prey) near the refuges. Design elements can be altered in the field to compare fish usage, including various types of refuge pockets and corrugated sheet pile refuge zones. The downside to field testing is that the presence of naturally occurring small fish or predators cannot be guaranteed in the river. Therefore, results would consist of qualitative assessments of usage and effectiveness.

It is possible that field testing could occur near scheduled fish releases in the Sacramento-San Joaquin Delta for other studies. Known release locations of juvenile salmon in the past include the Sacramento River near Freeport and the San Joaquin River at Durham Ferry. Fish refuges could be located on-bank, at docks, or off a piling near a release location. It has not yet been determined whether these releases will be scheduled in the future. It may be beneficial to conduct a field study in a location where existing predation studies have already been conducted (e.g. Freeport and City of Sacramento). Another possible location for a field test is Tracy Fish Collection Facility, Byron, California. Refugia pockets could be placed along the right training wall inside the primary channel or between the trashrack and boom before fish enter the facility. It may be possible to coordinate this work with other studies at the facility.

Several types of designs should be tested in the field or laboratory:

- Deeper pockets (greater than 6 in)
- Vertical bars with wider spacing like a trashrack
- Wedgewire-shaped triangular bars or flat bars (instead of round bars) to minimize clogging
- Internal matrix inside refuge with various sizes of cover for different sized fish (e.g. rods of various lengths and diameters, hanging chains or ropes, similar to a natural arrangement like a rootwad)
- Several small refuges versus one or two longer refuges
- Refuge mats with deep matting material that roll up into a spool and submerge with weights on the bottom
- Alternatives for building refuges inside corrugated sheet pile

Many different types of materials can be used to create refuges. Possible materials include ropes, hanging chains, pegs, artificial plant strands, astro-turf (woven or punched), and chicken plucker fingers (rubber fingers). Ideally, the material should be flexible without catching debris. Fish refuge material may permit algal growth or retain some debris. Materials and designs should be selected so that algal growth and debris retention does not clog the refuge or restrict access to the refuge.

Recommendations

A Bay Delta Conservation Plan Fish Screen Working Group was convened in 2012 to refine the study scopes of 11 pre-construction studies recommended by the Fish Facilities Technical Team (Bay Delta Conservation Plan, 2011). Among these recommended studies are fish refugia laboratory and field components. If implemented, these studies will likely address many of the information gaps identified in this paper. Design concepts gathered during research for this scoping paper will be shared with the Fish Screen Working Group for incorporation into their study plans. If these studies are not implemented, a full proposal for research of fish refugia will be submitted for consideration to Reclamation's Science and Technology Program to address these research gaps and potential technology developments.

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