Draft by Darryl Hayes
December 1995

Thoughts on the Planning for a Major Delta Fish Protective Facility

Fish Facility Design Considerations

Any proposed intake for a major Delta diversion must consider a fish protective screening facility that meets fishery agency criteria to minimize fishery impacts. Whether the screen is part of an isolated diversion facility in the North Delta or an improved intake screen in the South Delta, many of the basic facility components and design concerns are related due to the Delta hydraulic and biological environment. A screen facility must be designed to meet the needs of a diverse range of fish species and sizes including downstream migrating anadromous juveniles, weakly swimming larval fish and passage of larger adult species. If a diversion facility is part of a "Through Delta" alternative or other open ended system, additional considerations must include adult passage facilities on the downstream side of the screen.

In the mid-1970s, planning began for a large fish screen facility for the proposed Peripheral Canal. Although the planning was specific for a maximum 23,500 cfs diversion, the basic needs of that facility are similar to the needs of a range of diversion sizes that may be considered today through the Cal-Fed Bay-Delta planning process. Many alternative facilities were considered for the PC intake facility and specific studies were conducted to address pertinent issues. An Interagency Ecological Program report entitled "Delta Fish Facilities Program Report Through June 30, 1982", Technical report #6, outlines the state of facilities development until the Canal was rejected by the voters. The resulting preliminary design concept and the reasoning behind it's selection remain relevant today, even though not all the planning efforts or studies were never completed.

The Peripheral Canal-related investigations included a major cleaning and clogging study, trashrack design, physical model studies of the intake, sediment transport, fish stamina and swimming ability studies and fish pumping tests. Although many investigations led to specific criteria, many studies were incomplete or of limited scope. Additional study needs included a larger fish treadmill facility to refine screen approach and sweeping velocities, prototype fish pumping investigations and additional physical model studies.

The Interagency Ecological Study Program's Fish Facilities Development Program was essentially stopped in 1982. Although many of the design needs are still relevant, acquiring additional information for future facilities planning must be considered. Specifically, endangered species issues have changed the planning and design focus. No longer are facilities designed solely around major economically important species such as striped bass, American shad, or fall run salmon. Instead new facilities must focus on species of special interest including winter and spring run salmon, delta smelt, splittail, sturgeon and others. Species that are in decline must also be accommodated in future designs.

Several formal and adhoc fish facility groups and coordination programs are in place to develop fish screen criteria and implement new projects. These groups include the Interagency Ecological Program's Fish Facility Development Team, DFG's Fish Screen Team, the CVPIA Unscreened Diversion Technical Team and other project specific technical teams such as those for the Red Bluff Research Pumping Plant and the Glenn-Colusa Irrigation District fish screen. These projects provide information useful in designing Delta screens, however, without a directed research effort or planning study on a Delta fish facility we may not have appropriate studies for site specific solutions. Below, I have outlined several considerations that address major planning needs for a variety of screen facility options for any Delta diversion. Designing a major fish protective facility may require several years of investigative studies to reach consensus with fishery agencies on the applicability of criteria and expected fish protection of the selection. Therefore, the time is ripe to begin a formalized process where the greatest or longest lead time project needs or studies are initiated. I have outlined how some of these areas can or are being addressed within existing or proposed investigations.

Before going into the existing and proposed investigations it is important to point out that there is sufficient information available to design major new Delta fish protection facilities. Because of limitations in the data, the design may not be the best it could be but it will be adequate for planning purposes. Additional studies will help increase confidence that the screens will provide adequate fish protection at at reasonable cost.

Special Delta Design Considerations

Fish facilities development has come a long ways in the last ten years. Major developments in the northwestern United States have refined low approach velocity positive barrier screens, but several unique and site specific issues relative to a Delta diversion facility must be considered. These issues include special river hydraulic considerations, protection of a variety of Delta fish species in which little information is known, a need for fish friendly pumps within a fish bypass system for some alternatives, screen velocity uniformity considerations, reliability, flood damage potential, sedimentation, upstream fish migration facilities, the application of new developments in the Delta where little experience exists, and of course cost concerns. These are described in more detail below.

Site Specific Hydraulic Considerations

All areas within the defined boundaries of the Delta are significantly influenced by tidal action, widely fluctuating water surface elevations and flows, and a minimal river gradient. Debris loads, suspended sediments, bed load transport issues and water turbidity add complexity to the proposed diversion facility's operation. Most existing larger fish facilities are adjacent to diversion dams and do not have to deal with many of these variables.

Daily average flows in the Sacramento River below Sacramento can range between 5,000 - 120,000 cfs. Water surface fluctuation between these extremes can approach 20 feet in this region. With tidal influence, a period of net negative river flow occurs during low outflow periods. These ranges of flow and water levels must be considered in designing a fish protective facility.

A range of flow and operational scenarios can be modeled for the diversion site which may point out problem areas. Modeling is an essential component to any investigation. A numerical 2-D model, such as RMA-2V, is a very useful investigative tool for preliminary facility selection and siting purposes. It is relatively easy to manipulate by testing a wide range of flow variables and facility configurations. The Department of Water Resources has used this modeling tool to investigate a 2000 cfs Hood diversion that was considered in North Delta planning efforts. A digitized Sacramento River cross section was compiled for this study between the Freeport gage and two miles below Hood. The USBR also has used this modeling tool extensively in hydraulic facility planning studies. In conjunction with other methods, it can determine the magnitude of potential sedimentation concerns as well as demonstrate flow and velocity patterns at a site.

A scaled physical model can expand upon these efforts and look in greater detail at selected alternatives after initial studies are completed. A 1:50 scale model was investigated at U. C. Davis for the PC and could be revived to look at some facilities in the future. Similar model studies conducted at the USBR's Denver Research Facility have been constructed for fish facility design studies, including those for GCID and RD108. The level of comfort gained from these studies goes a long way in the decision making for any facility.

Planning for the proposed GCID screen facility is a good example of the effort required to design design alternatives for a major facility with similar hydraulic concerns. Recent physical modeling efforts have significantly moved the promising alternatives along. These model studies have helped the design team gain insight into flow discontinuities, headlosses, effects of submerged screens, intake orientation, effects of isolating individual intake bays, debris problems, sedimentation, operational flexibility and ability of the facility to meet velocity criteria under all possible conditions.

Hydraulic control solutions can also be learned from the hydraulic performance of existing facilities and by the measures taken to correct their flow imbalances. The present flat plate fish screen at GCID's intake, for example, is undergoing hydraulic evaluations in conjunction with biological testing. Hydraulic measurements under different flow scenarios demonstrate the difficulty in maintaining a uniform screen velocities on a real time basis. Questions that need to be evaluated relative to a Delta diversion screen are, "How quickly can a proposed facility realistically respond to changing conditions", or "What kind of discontinuity is acceptable or achievable".

Hydraulic control at a facility is best achieved by careful planning, site selection and modeling. Hydraulic Control can be improved by adding louvers or baffling plates behind screen panels to even the flow distribution across the screen surface, but they should not be counted on to solve all hydraulic problems. Adjustments can be difficult and their use comes with a high headloss price. Advancements in automated porosity systems could assist in hydraulic control. Such systems are under consideration for the proposed GCID fish screen.

To facilitate hydraulic uniformity within the screen facility, multiple bays which can be designed and operated according to diversion conditions may also be a solution for consideration. Such a multiple bay system is utilized at the J. E. Skinner Fish Protective Facility since diversion flows through the facility can vary between 375 and 10,300 cfs. Again, careful planning can address many of the hydraulic concerns.

Biological Criteria

Fish screen designs are based on the need to protect a variety of fish species and lifestages. An effective screen will minimize the entrainment and impingement of fish and allow for safe transport of fish away (i.e. downstream) from the facility. Effective facility design is therefore a function of fish behavior and swimming ability. While low screen approach velocities minimize impingement, a sweeping velocity (flow component directed parallel to the screen face) is also necessary to move fish past the screen and reduce their exposure. From experience and some limited studies, criteria have been established for several species, such as salmon and some bass, but for most species this information is limited.

Swimming stamina can be measured in the laboratory using several standardized techniques, but these data are not easily translated into determining appropriate relationships between screen approach and sweeping velocities for optimal fish protection. During the PC investigations, a circular screened flume or "fish treadmill" (endlessly long screen surface) was used to establish these relationships for some salmonids and American shad. Limitations due to the apparatus size and it's flexibility in testing different environmental and hydraulic conditions led the recommendation that a larger and better hydraulically controlled device be constructed. This facility was designed and construction started, but it was never completed due to the rejection PC.

Because of the long lead time required to develop biological criteria for newly listed species and with an anticipation of a relook into Delta diversion alternatives, there is a new impetus for this research. A fish treadmill was jointly designed by IEP Project Work Team participants and endorsed by a panel of experts on fish protection (IEP Fish Facility Advisory Panel). A functional 1:2.5 scale model of the prototype was evaluated and findings from this study were used in the final design. The apparatus is currently under construction for installation at U.C. Davis in early 1996. Biological and engineering study plans have been developed and are currently under review. A three-year study plan is outlined for tests on several Delta species. These tests will be performed under the direction of an interagency team at the U.C. Davis facilities. If approved, biological testing will commence in summer 1996. These investigations will help refine operational requirements and necessary channel hydraulics for a facility.

Field experience is also a useful tool in determining appropriate hydraulic criteria for fish protection under various environmental conditions. Many screen installations in the northwest have undergone biological evaluations to determine their effectiveness. These evaluations have been conducted to verify a screen's biological effectiveness and "fine tune" hydraulic conditions as needed. Much of the testing has been focused on juvenile salmonids at low velocity positive barrier facilities. The Bonniville Power Authority has published many of these findings which have been used by the fishery agencies in verifying their screen criteria.

Several large facilities in California have also been evaluated for verification purposes and future planning. Recent investigations include those at the Tracy Fish Facility (a louvered screen), the Tehama-Colusa Canal Screen (a 3000 cfs rotary drum screen), and the Glenn-Colusa Irrigation District's new "interim" screen (a 1200 cfs vertical flat plate screen). Problems with large facility operations are also being addressed by these studies. Many biological problems relate to poor hydraulic conditions which are difficult to control in large facilities.

The GCID testing has significant relevance to planning for a large screen facility in the Delta. The GCID screen is the world's longest vertical plate screen (440 ft) without an intermediate bypass built to date. The biological testing at the screen has been conducted with low and high pumping rates and various river conditions. The study is primarily directed at determining the screen's level of fish protection under different hydraulic conditions. It also is examining the need for intermediate bypasses that are currently mandated in the NMFS criteria, but not required by State standards. Coordinated study plans at this facility are necessary if results are to be transferred to a proposed Delta facility.

Research on high velocity screen concepts, such as the Eicher screen and Modular Inclined Screen, has also given insight into appropriate criteria or at least tested the limits of hydraulic criteria for successful fish passage. Two prototype installations of the Eicher screen have shown good passage and survival for salmon and trout. The MIS has undergone prototype laboratory testing with many fish species and variables and is currently undergoing field tests at a diversion in New York State. This testing improves our understanding of fish screen design and is applicable to the planning of any proposed facility since many principles are similar. These promising designs can have significant cost savings over conventional facilities and deserve our continued support.

Fish Pumping Considerations

The present fish screen criteria outline the need for appropriate screen sweeping velocities and minimized fish exposures to the facility. Delta hydraulics are not suitable to satisfy these criteria under most conditions. Problems are associated with a minimal river gradient and potential reverse flow conditions in the river. Any diversion will adversely affect the river hydraulics necessary for fish protection. A fish bypass facility must be considered to operate under these conditions. A fish screen constructed along the bank or within the river could use the river as the bypass, but a significant diversion may point to the need for an off river screen facility and fish bypass. Considerations for on-river screen concepts are presented later.

For a fish bypass facility to be effective, it must swiftly collect the concentrated fish at the end of a screen and place them back into the river downstream of the facility's influence without harm. Overcoming the headlosses associated with a diversion facility and the bypass system will require some sort of fish friendly pump within the bypass. The fish pumps must pass all species and lifestages of fish expected to be diverted at the screen. For example, pumps may be required to safely pass larval striped bass as well as adult sturgeon (or the maximum size fish that may go through the diversion's trashracks).

In planning for the PC, initial tests on a "fan pump" were conducted. A four foot prototype pump was installed in a flume at Hood to test the passage of large fish. Prototype testing with large ten foot diameter fan pumps was planned after this, but was never implemented due to the PC project's fate. At that time, the screen design required the pumps be designed for heads of less than one foot and flows about five percent of the diverted flow (1000 cfs bypass design). Using today's screen criteria, the pump head requirements may be greater due to higher bypass channel velocities (higher headlosses) and increased bypass flow requirements (to reduce fish concentrations).

"Fish friendly" pump designs have been considered or implemented on several projects. The fish screen bypass at PG&E's Potter Valley project is utilizing a ten foot diameter Archimedes screw fish pump. This design was based on tests conducted by DFG using a smaller modified pump. This type of positive lift pump has been considered by GCID and Contra Costa Water District for their proposed facilities. Existing fish screen criteria do not accept the use of pumped bypass, but do recognize that on a case by case basis, it may be an acceptable alternative.

Constructing a diversion dam or increasing a river gradient are generally unattractive alternatives.

A multi-million dollar research pumping facility adjacent to the Red Diversion Dam was recently constructed to address these fish pumping concerns. The 300 cfs pump station was constructed to investigate the use of pumps to lift water and fish into the TC canal when the dam gates are opened for other fish passage needs and water deliveries are necessary. Pump designs being tested include a variable speed enclosed Archimedes pump and Hidrostal internal helical pump (volute). These pumps are the largest of their kind in the world. The basic difference between the Red Bluff pump arrangement and that required in a Delta fish bypass relates to their position in the facility (one pumps water and fish first, then returns a portion of the water and all the fish to the river by a gravity bypass).

Cooperative, coordinated evaluations are necessary to design and conduct study programs for projects beyond the scope of their project. The Red Bluff research facility can be used to test passage of Delta fish species through intentional introductions. The programs are just beginning and the USBR is willing to cooperate with the resource agencies on study programs.

Sizing Considerations

It is appropriate to consider a wide range of fish protection facilities for any diversion alternative. Local hydraulic conditions surrounding a facility are important, but not the only considerations. The magnitude of a facility's impact depends on percent of flow diverted, the design being considered, potential predation around the facility intake and bypass exit, fish concentrations, debris, and etc. Simple designs may be warranted for small diversions. On-river screens, for instance, may be appropriate when screen exposure can be tolerated by the fish and sweeping flows are generally present. As diversion sizes are increased, however, an off-river design may be appropriate.

Practical considerations of screen maintenance, operations, screen removal (accessibility), navigation, sedimentation removal, flood concerns and flow control methods must be considered. A network of several smaller diversions linked together for a large diversion should consider the cumulative impacts and additional operational measures necessary. Trade-offs between flexible designs, operation and maintenance should be balanced with expected fish protection.

Upstream Fish Migration Considerations

A fish collection, trapping and transportation facility is integral to the proper operation of an open or "Through Delta" type water transfer facility. Flows from the Sacramento River could possibly attract several upmigrating fish to the outlet of the pumping plant at the upper end of Snodgrass Slough.

The facility must be designed to attract and collect several species. These would include fish of vastly different sizes and swimming abilities. Fish needing to be collected include chinook salmon, steelhead, striped bass, American shad, green and white sturgeon, longfin smelt and splittail. Most fish ladder facilities have been constructed for salmon, but some passage information on other species is available. The Canadian Freshwater Institute is collecting data and determining appropriate parameters for passage by a variety of species. More of this information is needed if a ladder is considered.

Due to the fluctuating hydraulics and water surface elevations at a Delta site, a "false weir" type fish ladder could be considered. The U. S. Army Corps of Engineers has proposed this type of ladder arrangement for fish passage over the closed Stone Locks at the head of the Sacramento Deep Water Ship Channel and into the Sacramento River. This design may not pass all species, so a "fish elevator" or "fish lock" arrangement should be considered as other solutions.

Fish elevators have been used at several dams in the United States for passing striped bass, American shad and salmon. High velocity flows attract fish into a rectangular channel adjacent to a bar rack which passes the majority of the diverted flow. Periodically, the channel is closed off and a fish crowding device concentrates the fish into a holding pen filled with water. This pen is then sealed off and lifted to a higher level where it mates into an upper water channel. Fish passing into this channel are then sluiced into a another fish collection device or transport vehicle.

Development of an upstream migrant facility needs considerable planning attention and little is being done to develop site specific solutions to date.

Prescription for Fish Facility Development

The following is a list of actions that should be taken to develop the best fish screen design for a particular site. As mentioned earlier, considerable information is available to be used in preliminary designs. Collection of additional data would allow for more refined designs and would increase the comfort level of fish protection and water management agencies. We need to develop a process through the CALFED Bay/Delta program and its member agencies to put together preliminary design concepts and identify (and assign priority) to additional data needs. We particularly need to make decisions on the treadmill studies, physical and mathematical modeling and any additional fish pumping tests at Red Bluff.

- Identify diversion requirements (Delta wide modeling, planning, etc.)
- Formulate Interagency technical team with Biologists, Engineers and expert advisors
- Conceptualize alternatives
- Collect site data (hydraulic, fisheries, water quality, etc.)
- Identify data needs and site specific study needs

- Conduct numerical model studies - narrow alternatives
- Conduct physical model studies of selected alternatives
- Begin preliminary and final design
- Construct fish facility and evaluation facility (in stages if necessary)
- Evaluate and adjust facility operations for real time needs