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Non-Salmonid Fish Passage for Small Diversion Dams

by

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Abstract--During its history, the Bureau of Reclamation has designed and constructed many small irrigation diversion dams throughout the Western United States. Most of these diversion dams reside on rivers that are home to mainly non-game fish species. Thus, little attention has been focused on the fishery impacts imposed by these barriers. Many of these diversion dams are approaching 100 years of age and only now are we realizing the detrimental impact small dams have on many resident fish species. Reclamation is now involved in research, construction, and evaluation of fish passes designed for native fish species of the Western United States. This paper discusses several approaches that are currently undergoing research, implementation, and field evaluation including fish locks, low gradient ladders, and design riffles. Bio-engineering physical models, three-dimensional computational fluid dynamics models and field evaluation studies used to improve fish pass designs are discussed.

INTRODUCTION

There are hundreds of fish passage structures in the United States. Most are found on coastal rivers inhabited by anadromous fish, and are mainly for salmonid passage. There are far fewer fish passage structures designed to provide passage for non-salmonids, although the number is growing. Diversion dams are common features associated with agricultural water use. Small, often unobtrusive-looking diversion dams are found on nearly all rivers in the western United States. Only in recent years has the impact of these structures on native and sport fisheries been realized. Recent declines of native western fish species have resulted in numerous listings of species as threatened or endangered under state and federal laws. During the past 100 years, some 21 species and sub-species among 6 fish families have become extinct from the 17 western states and some 64 species and sub-species are now threatened or endangered (Minckley and Deacon, 1992). Although not wholly responsible for the decline, barriers to habitat and spawning migration are known contributors.

Good fish passage performance is derived from a well integrated marriage of engineering and fishery science. However, a common problem experienced by Reclamation in the design of non-salmonid fish passes is a lack of fishery data and passage experience for many species. This requires fish passage structures be designed with considerable flexibility in how they function.

A summary of recent non-salmonid fish passes constructed by Reclamation can be broadly defined by dam height:

DAM HEIGHT	FISHWAY TYPE	TYPICAL GRADIENT
≥ 10 m	Fish locks or fish trap and hoist systems	Vertical
Between 3 m and 10 m	Baffled fish ladders	3 to 4 percent
≤3 m	Roughed channels	≤ 1.5 percent

Examples of each of these types of fish passes have been built by Reclamation in recent years for non-salmonid species.

Fish Locks

The Borland fish lock is named for J. T. H. Borland who developed fish lock designs for a number of dams in Northern Scotland and Ireland in the 1950's. Fish locks have since been constructed in many countries. In concept, a fish lock operates in a cyclic pattern much the same as a ship lock. During the attraction phase, the lock is at its low water level. Flow is passed through the lock to attract migrating fish into a chamber (called the attraction chamber) near the base of the dam. After a period of time, a gate at the entrance to the attraction chamber is closed and a conduit or open well is filled until the water level in the lock nearly matches that upstream of the dam. Fish trapped in the lock are then released into the upstream reservoir pool.

Fish locks are an active system that, as a minimum, require operation of flow control gates to function. Fish locks are seldom used where more passive systems like fish ladders are applicable. However, fish locks can provide fish passage for a wide range of species, with low stress to the fish, for nearly any dam height. The major design considerations for a fish lock are:

- Attraction conditions - Attraction is of special concern for fish locks as fish must not only locate and enter the attraction chamber, they must then hold in the attraction chamber until the lock cycles. Many investigators (Aitken et al, Pavlov, Quiros) have found attraction flow patterns, flow depth, light conditions, entrained air, water quality of auxiliary attraction flow (turbidity, temperature and nutrient levels) and predation can influence passage performance. Water quality issues are often easier to resolve at low dams as compared to high dams with large reservoirs where water quality can vary substantially between turbine, outlet works and spillway releases.
- Lock operation - The lock must be filled without creating undue stress or disorientation of the fish. While cycling, adequate attraction flow must be maintained downstream of the closed lock entrance to maintain fish guidance to the facility. Open or free surface locks have proven to perform the best as fish are not subjected to rapidly changing light conditions in the attraction chamber or during cycling. In many designs, a fish crowder is used to ensure fish are moved through the lock quickly and do not remain in the lock.
- Lock exit - The design of the upstream exit depends on the potential fluctuation of the upstream reservoir and position of other water intakes such as turbine penstocks. Fish must be released where there is minimal chance of being entrained into another downstream flow passageway.

The Bureau of Reclamation recently designed a Borland-style fish lock to pass several fish species of vastly different swimming and behavioral characteristics at Marble Bluff Dam near Reno, Nevada. Marble Bluff Dam and fish passage facilities are located near the end of the Truckee River, approximately 3 miles upstream of Pyramid Lake, a terminal lake with no outflow. Pyramid Lake supports several fish species including the endangered cui-ui (*Chasmistes cujus*) and threatened Lahontan cutthroat trout (*Oncorhynchus clarki*). Both species historically migrated up the Truckee River to spawn during high spring flows. In 1973 a dam and fish passage facilities were built to stabilize an incising river and improve fish passage. Prior to the dam's construction, fish passage up the Truckee River was often blocked by shallow braided flow over a large sediment delta at the entrance to the lake's mouth and by rapids at upstream headcuts. The original fish passage facilities at the dam were a fish trap and hoist system and a separate fishway channel with multiple half-Ice Harbor style ladders. Neither system as originally designed has proved effective for passing cui-ui.

Cui-ui are a large lakesucker that can weigh up to 3.5 kg and reach lengths of 70 cm. Large numbers migrate from Pyramid lake up the lower Truckee River to spawn in late spring. Cui-ui often school near the mouth of the Truckee River prior to moving upstream. This behavior leads to sharp peaks in the number of fish migrating upriver. The Fish and Wildlife Service (FWS) estimates that upwards of 100,000 cui-ui per day can move up the river during the peak of the spawning run.

In 1996 a study was initiated to identify and construct fish passage improvements at the dam. A team of fishery biologists, resource managers, and engineers selected the fish lock concept after reviewing a number of fish passage options. Instrumental to the selection process was the 20-plus years of experience FWS has working with fish passage at the existing facilities. FWS recognized cui-ui vary greatly in their swimming strength, endurance, and behavior as a function of gender, age and spawning stage. Experience had shown that fewer of the older egg laden females are able to negotiate the existing fish ladders compared to young males. Also, cui-ui will densely pack together at locations where passage is blocked or difficult. Overcrowding has resulted in fish kills in the fish trap and ladders in the past.

A free surface fish lock design was selected (Figure 1). Important in the lock concept was the addition of a fish crowder (false floor). The crowder ensures that fish can be quickly moved out of the lock during the exit phase. Fish passage using the lock will begin in the spring of 1998.

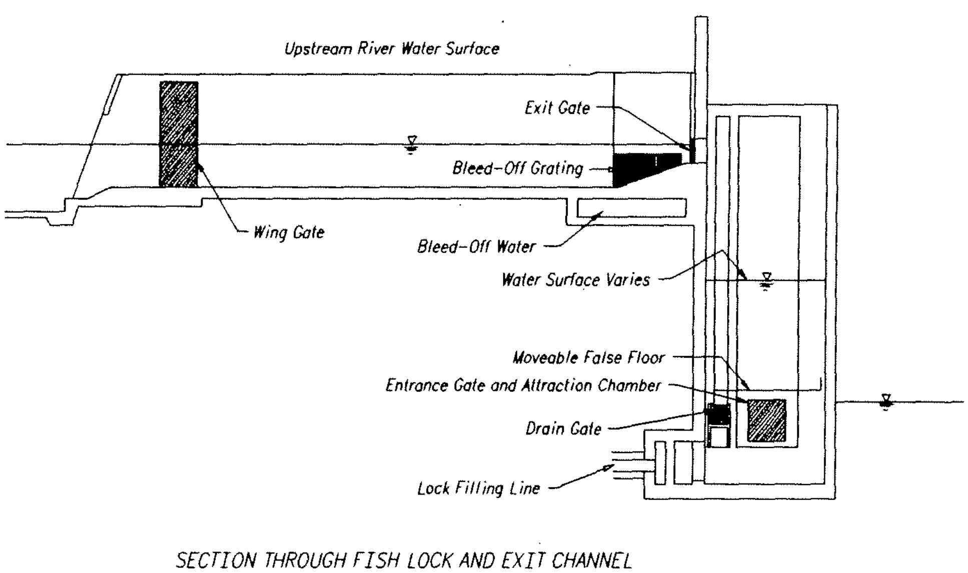


Figure 1 - Elevation view of Marble Bluff Dam fish lock.

Fish Ladders

Some of Reclamation's early experience with non-salmonid fish ladders was again at Marble Bluff Dam. In 1976, four half-Ice Harbor style ladders were constructed to pass cui-ui up the Marble Bluff Dam fishway channel, figure 2. The ladder design was based on then typical salmonid style ladders and available biological studies (Koch, 1972, 1973, 1976; Ringo and Sonnevil, 1977) of the cui-ui physical and behavioral attributes. The ladders were constructed on a 10 percent slope with combination weir/orifice baffles spaced every 305 cm of run. The head drop over each baffle was 30 cm as originally designed. The ladders quickly proved to be near total barriers to cui-ui passage. The ladders have since been modified by FWS. Intermediate baffle walls were installed to reduce the drop per pool to 15 cm. Cui-ui passage improved; however, FWS has found that, of those fish passing up the ladders, a high percentage are young male cui-ui. Reclamation in 1995, working with FWS, started investigating ladder designs for improving cui-ui passage. A number of ladder baffle designs and gradients were studied using laboratory models and numeric simulations. The design objectives for the project were; hold passage water velocity to ≤ 1.2 m/s and minimize eddy areas. Field observations indicated that fish tend to school densely and hold for long periods in the eddies downstream of ladder baffles when flows are turbid. It is speculated that significant disorientation may occur when visual orientation is limited by water turbidity.

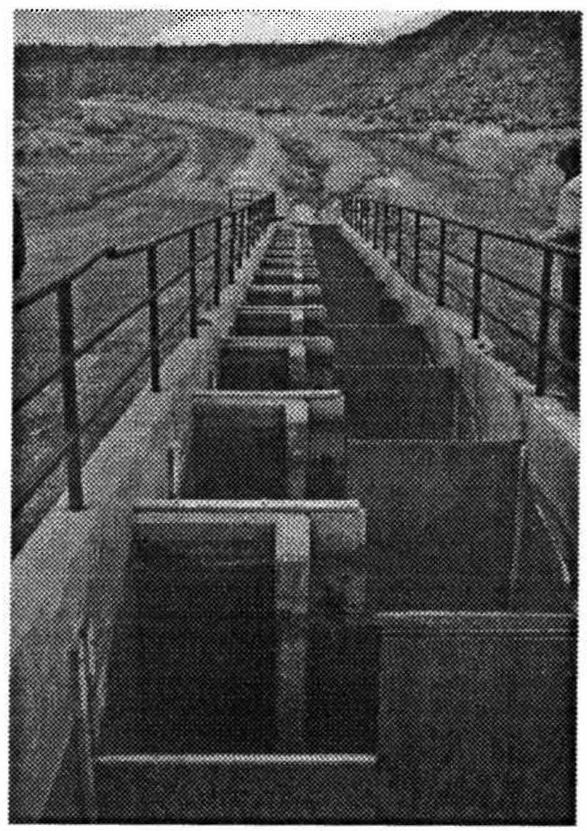


Figure 2 - A Marble Bluff Dam fishway ladder. As shown, the ladders are modified with intermediate temporary baffles.

In 1997 Reclamation is replacing one of the Marble Bluff Dam fishway ladders. The new ladder will be 8 ft wide, 6 ft deep, with baffles placed every 8 ft of length. To improve flow conditions, the ladder gradient is being reduced to 3.125 percent and new baffles are being designed. Baffles were designed to enhance cui-ui passage by maximizing the downstream flow field within the pools, providing passage opportunity at any elevation within the water column, maximizing flow within the ladder while meeting the passage velocity criteria, and avoiding strong vertical turbulence. A baffle design was developed using both a physical model and a computational fluid dynamics model (CFD). A dual-vertical-slot chevron shaped baffle was chosen. Figure 3 shows a typical CFD generated velocity field for a ladder with a 15 degree (offset angle) chevron shaped baffle. Models were used to investigate the flow field as a function of slot width, chevron angle, and slot wing wall lengths. In the prototype, slot widths will be adjustable between 0.75 ft and 1.0 ft. Short wing walls were required on the upstream inside edge of each slot to achieve the desired flow pattern. The wing walls turn the flow from each slot to the center of the downstream pool creating a large centered downstream flow within each pool. Without wing walls, flow through the slot attaches to the downstream pool walls creating a large eddy in the center of the pool. The new baffle design will be field tested in spring of 1998.

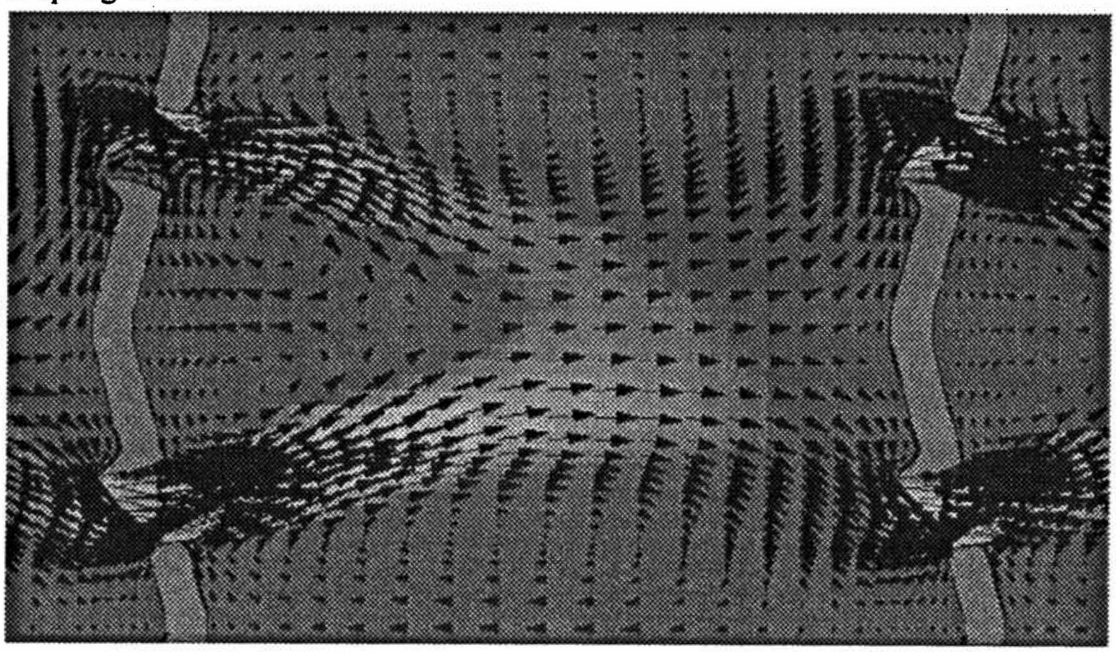
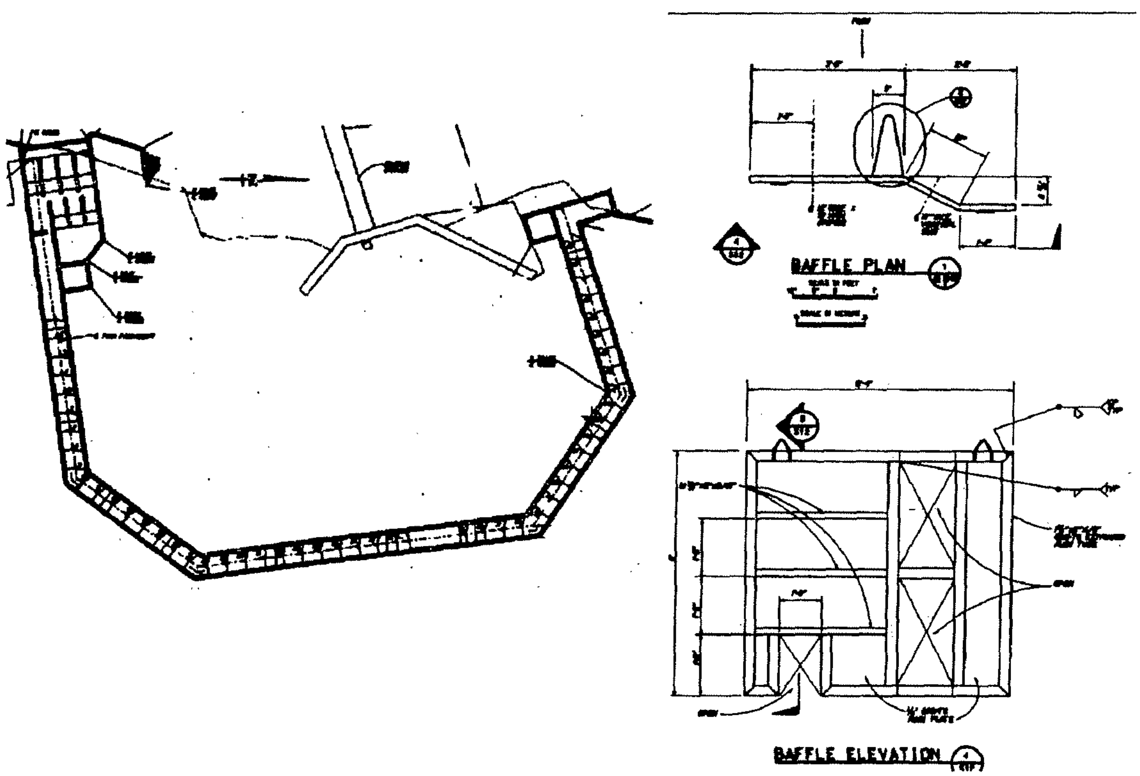


Figure 3- CFD velocity vector plot showing the flow pattern within a ladder with dual-vertical slot style ladder baffles.

Redlands fish ladder is another example of a recently completed non-salmonid fishway. The ladder is designed for passing Colorado squawfish (*Ptychocheilus lucius*) and razorback suckers (*Xyrauchen texanus*). The ladder is located adjacent to Redlands diversion dam on the Gunnison River near Grand Junction, Colorado. The ladder was designed on a 3.75 percent grade with vertical slot and orifice baffles spaced every 1.8 m, figure 4. The total elevation difference across the ladder is about 3 m. The ladder has been operating for two years with mixed results. Initial operation of the ladder saw a large number of flannel mouth suckers (*Catostomus latipinnis*) move through the ladder. Few of the target fish species have used the ladder to date. However, there is



uncertainty as to the number of target species reaching the dam. Several more years of field evaluation will be required before the fish passage effectiveness of the ladder can be determined.

Figure 4 - Plan view of Redlands fish ladder (Merrick, 1995).

Due to the many small diversion dams now being identified as barriers to native species, Reclamation has initiated research on the design of non-salmonid fish ladders. Numerous new fish pass concepts have been tested in a laboratory flume. The focus of the research is on blending low gradient pool and riffle concepts with that of steeper gradient baffled ladders. The design concept currently under investigation is a continuously baffled channel that provides a low velocity path along the downstream side of angled baffles coupled with a higher velocity skimming or surface flow. Flume tests have shown velocities of about 2.0 ft/s can be maintained for channel slopes of up to 4 percent (the steepest slope tested thus far). Two examples of baffle configurations under study are shown in figure 5. Juvenile razorback suckers are placed in the ladder to evaluate their response to flow turbulence and observe how they use the flow patterns to move upstream. In all tests the fish move upstream in the shadow of the baffles using the low velocity zone along the baffle's downstream side. The design provides low velocity resting areas in front of the baffles while nearly all flow is in a downstream direction. The design can be built in a riprap or concrete lined channel. Tests of this design are continuing with a focus on baffle angle and ladder gradient.

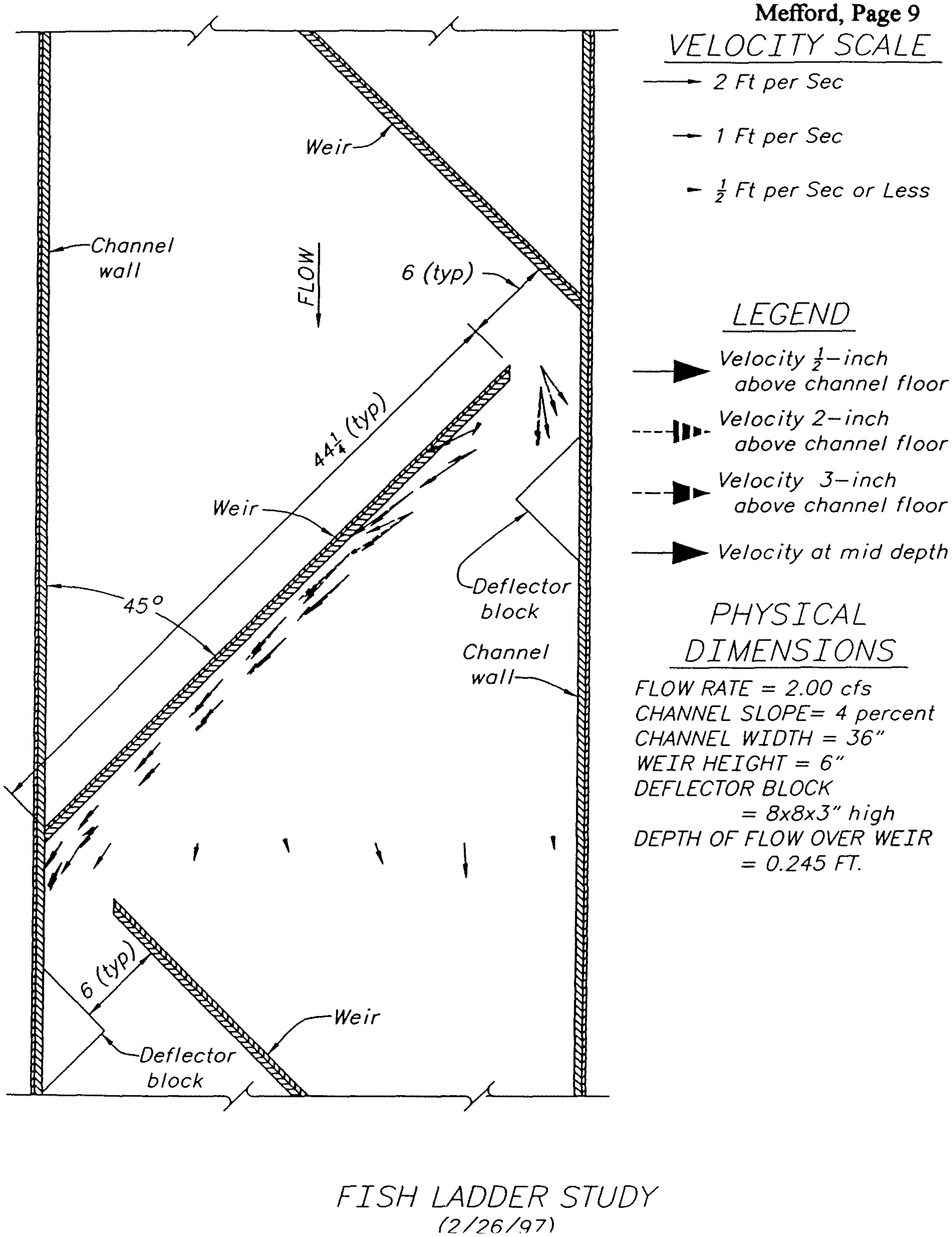


Figure 5a - Velocity vector field for a 45° angle continuous baffle design.

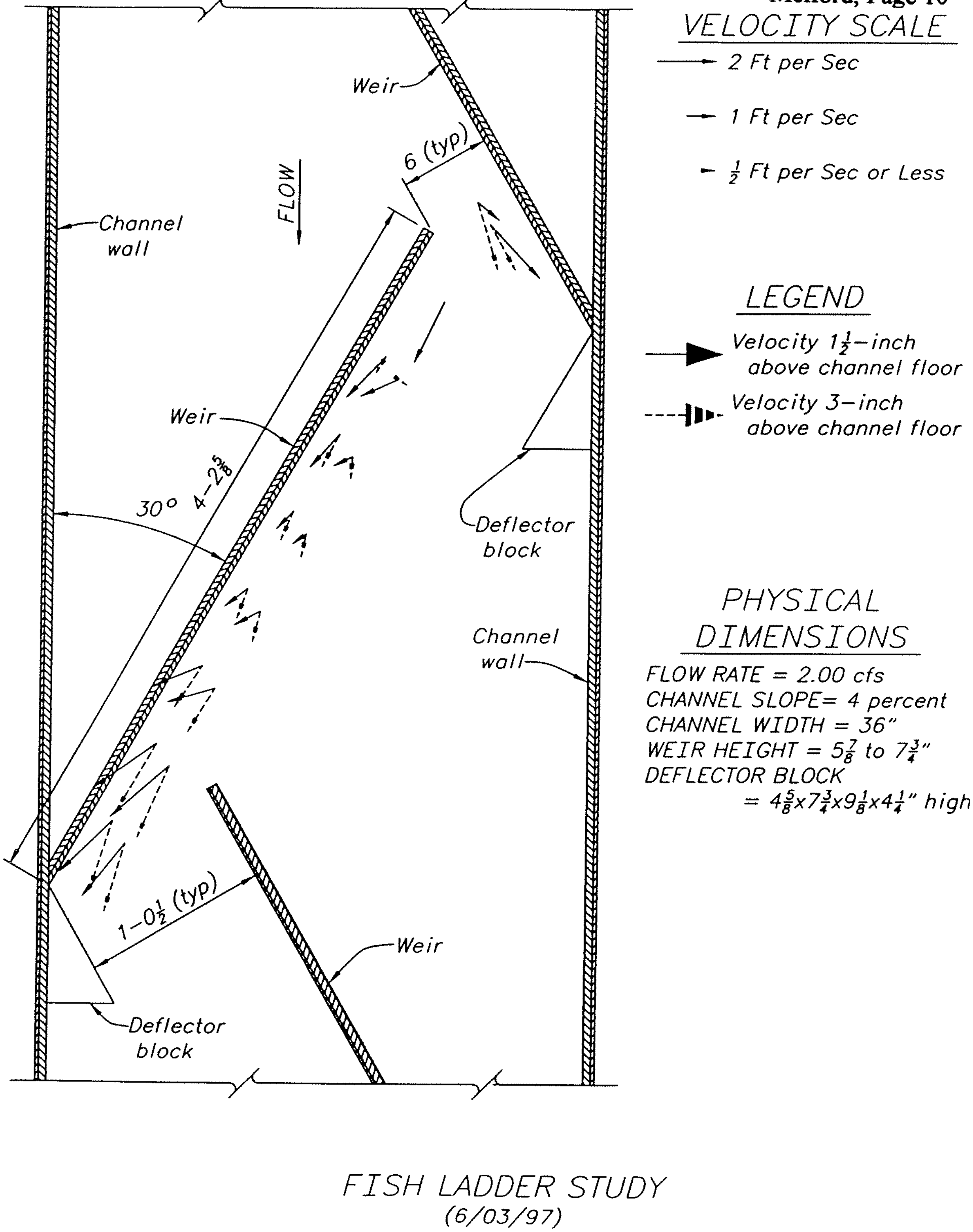


Figure 5b - Velocity vector field for a 30° angle continuous baffle design.

Roughened Channels

Roughened channel fishways are typically low gradient riprapped channels that combine alternating riffle and pool sections. These types of fishways are designed to mimic natural riffle and pool sections of a stream. Roughened channels can be built around dams similar to a ladder design or instream. Instream fishways are generally used where small dams are barriers during low stream flow and become submerged during flood flows. A recent example of this type of passage structure is the proposed Grand Valley Irrigation Company fishway near Grand Junction, Colorado, figure 6. The fishway is designed to provide passage for native species of the Colorado River over a 1.5-m-high run-of-river dam. The riffle sections are designed for an average velocity of 1.2 m/s at a minimum flow and depth of 2 m^3/s and 0.5 m respectively. The design gradients for the fishpass are; riffle slope = 1.3 percent; thalweg slope = 0.7; and channel slope = 0.9 percent. The thalweg slope differs from the channel slope by the sinuosity of the channel. The channel will be constructed using riprap laid on a filter fabric. During construction, voids in the riprap will be choked with finer material to minimize interstitial flow. The channel was designed assuming a Manning's roughness n value of 0.05 following construction. With aging, the channel roughness is expected to decrease to roughness value about 0.04. The sinuous pattern (meandering channel form) is used to maximize the energy loss along the channel and minimize the overall reach length. This fishway is scheduled for construction in the fall of 1997.

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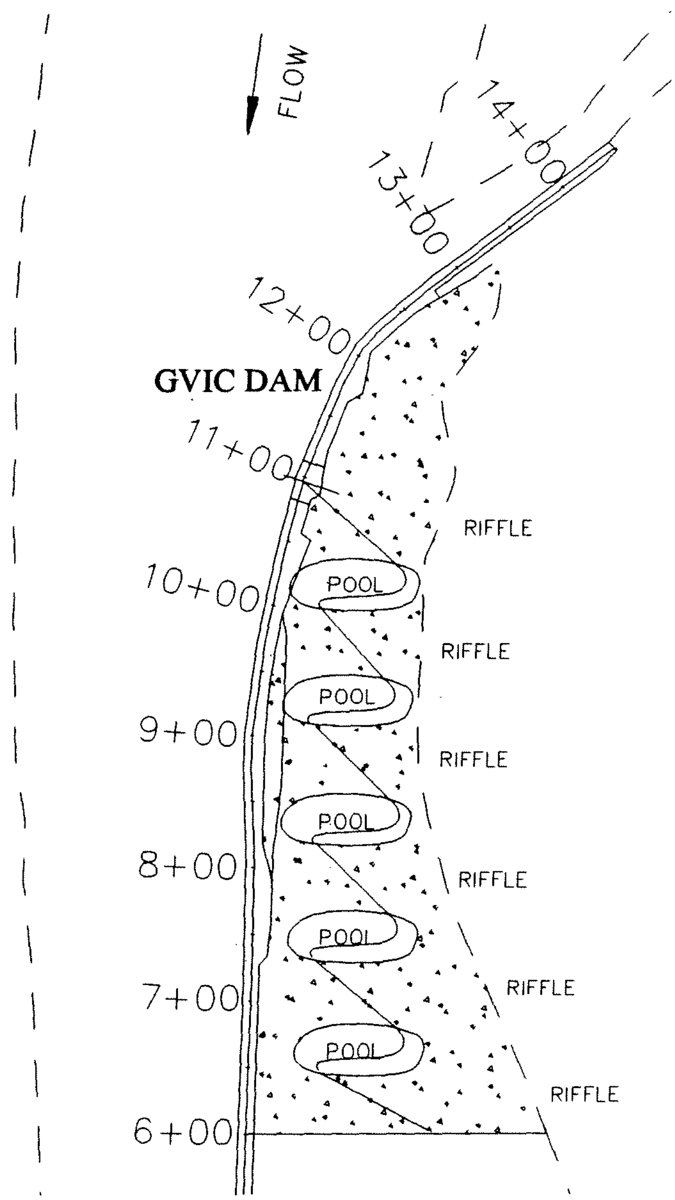

Figure 6. - Roughened channel fishway proposed for Grand Valley Irrigation Company Dam.

Keywords - Fish passage, fish ladder, non-salmonid, Marble Bluff Fishway, cui-ui lake sucker, fish ladder hydraulic evaluation, computational fluids model