APPENDIX G

DAVID A. VOGEL. 1992.

ASSESSMENT OF THE FISH PASSAGE FACILITIES AT THE LAKE LODI IN THE MOKELUMNE RIVER (DRAFT)

ASSESSMENT OF THE FISH PASSAGE FACILITIES AT LAKE LODI IN THE MOKELUMNE RIVER

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INTRODUCTION

This is an assessment of potential problems with upstream and downstream anadromous salmonid passage facilities associated with Lake Lodi on the Mokelumne River (Figure 1). Recommendations to improve the effectiveness of the fish passage facilities are provided in this report.

A site visit was made on March 23, 1992 to inspect the Woodbridge Irrigation District (WID) fish screens, fish bypass system, supporting structures, and Woodbridge Dam and fish ladders (fishways) prior to filling of Lake Lodi. A second site visit was conducted on June 2, 1992 following the filling of Lake Lodi to observe operational characteristics of some of the fish facilities. An earlier site visit was conducted on January 25, 1991 and some relevant information from that visit is included in this report.

DESCRIPTION OF UPSTREAM FISH PASSAGE FACILITIES

A description of the upstream migrant salmonid passage facilities at Woodbridge Dam is provided in the California Department of Fish and Game's (CDFG) "Lower Mokelumne River Fisheries Management Plan" (CDFG, 1991). Because of the relevance of that description to this assessment, the CDFG description is extracted from their report as follows:

> "Woodbridge Dam creates Lodi Lake, and supplies water to Woodbridge Canal. The dam is 164 ft wide with earth-filled abutments on either end with rubble placed as riprap downstream of the apron along the dam face to prevent undermining of the dam with the exception of the first two bays nearest the fishways and left abutment (Figures 2 and 3). Flashboards are installed in late February or early March to begin raising the level of the lake and fill the irrigation canal. When irrigation is over in October, flashboards are removed to lower the level of the lake to below the canal. Pool-and-weir and Denil fishways are installed near the left abutment (looking downstream) at the Woodbridge Dam to provide upstream passage depending on the water level in Lodi Lake. The pool-and-weir fishway is used when the flashboards are at the both the high and low level while the Denil fishway is used only at the low level. The Denil fishway operates into January for steelhead trout upstream migration."
>
> "The two fishways installed at the Woodbridge Dam provide upstream passage depending on the water level in Lodi Lake. An upper pool-and-weir fishway operates when the lake is at its summertime level while a Denil and the lower pool-and-weir fishway operate after the lake level has been lowered."

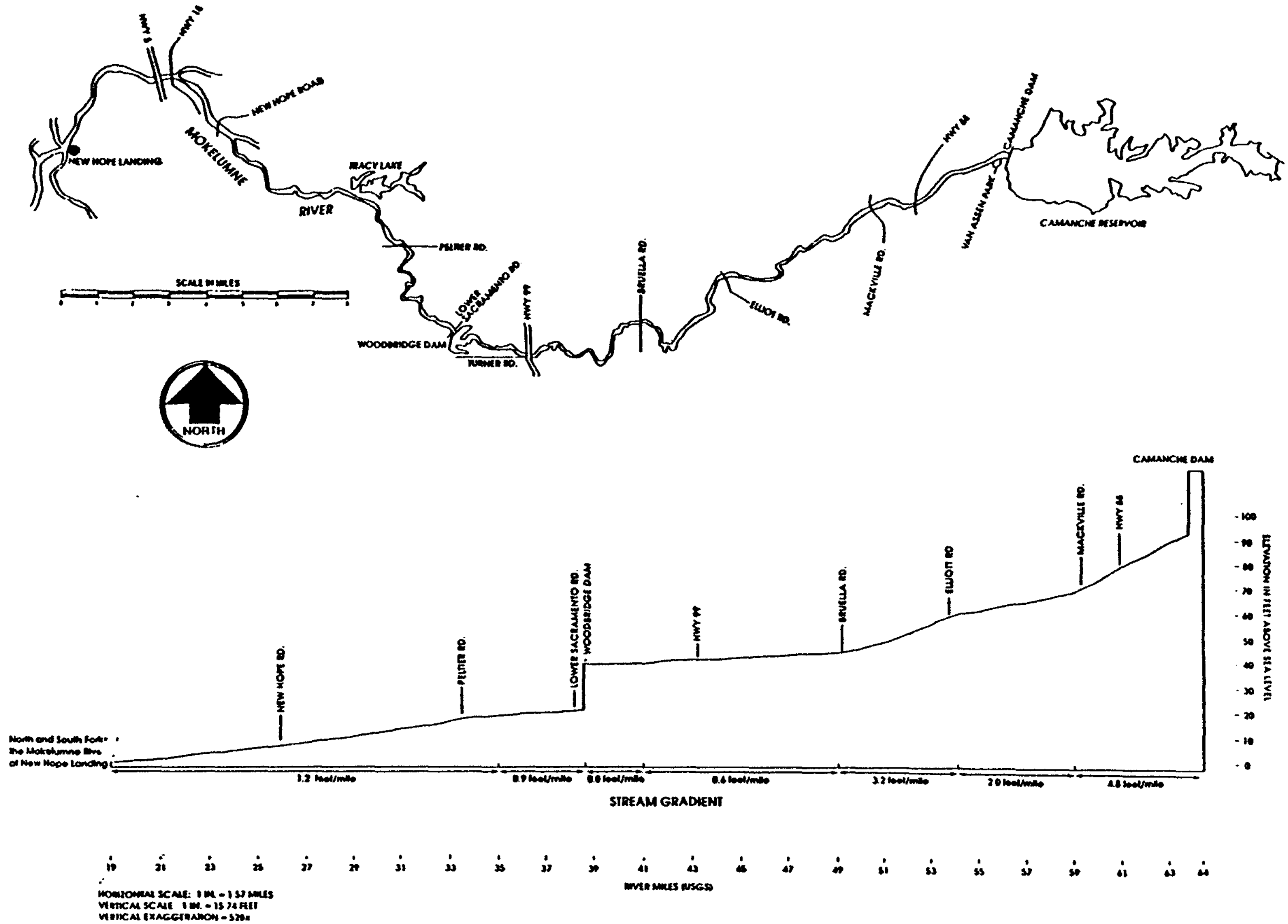

Figure 1. Lower Mokelumne River Elevations and Gradients (from EBMUD, 1991).

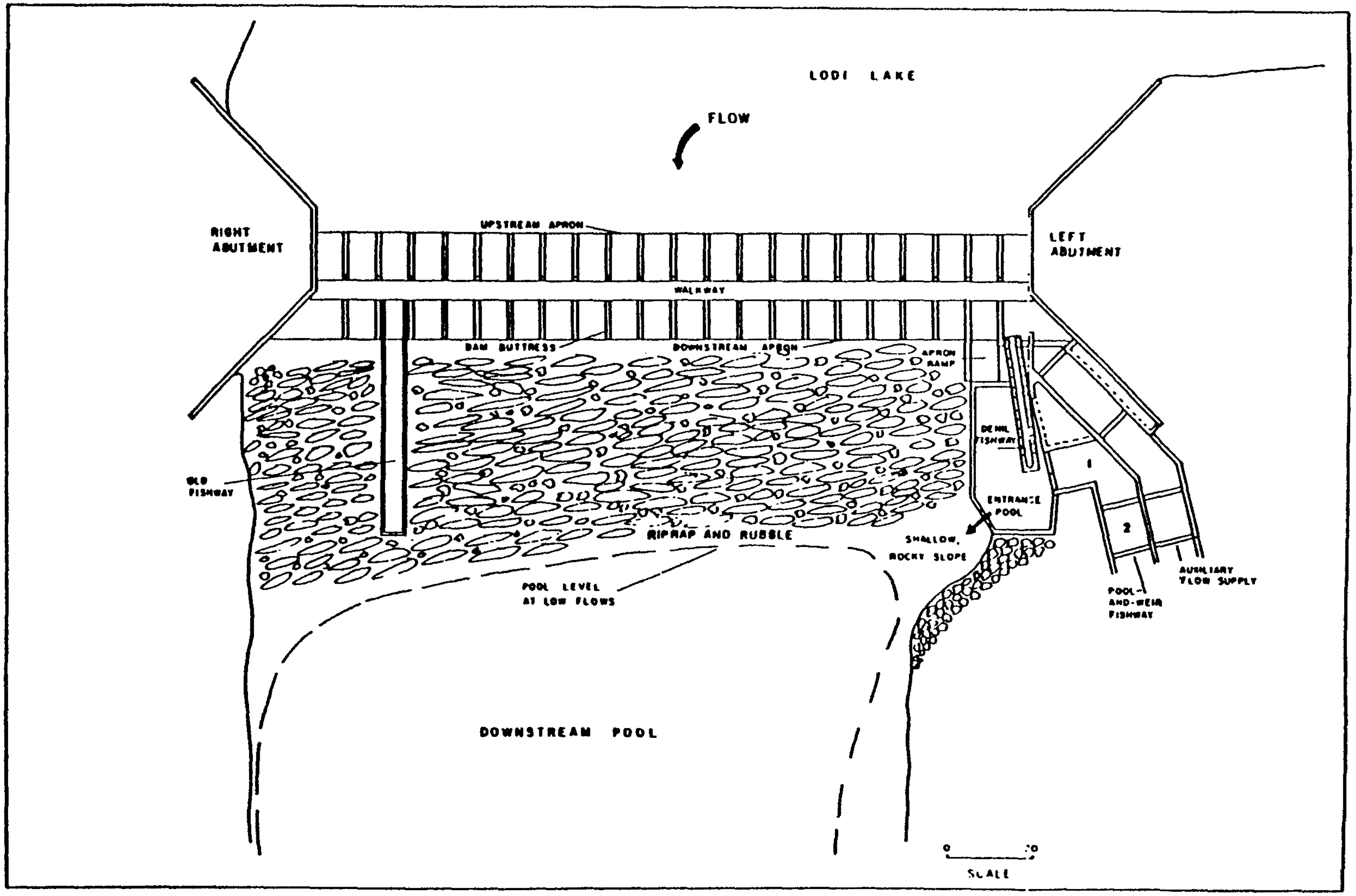

Figure 2. Plan view of Woodbridge Dam, lower Mokelumne River, California (from CDFG, 1991).

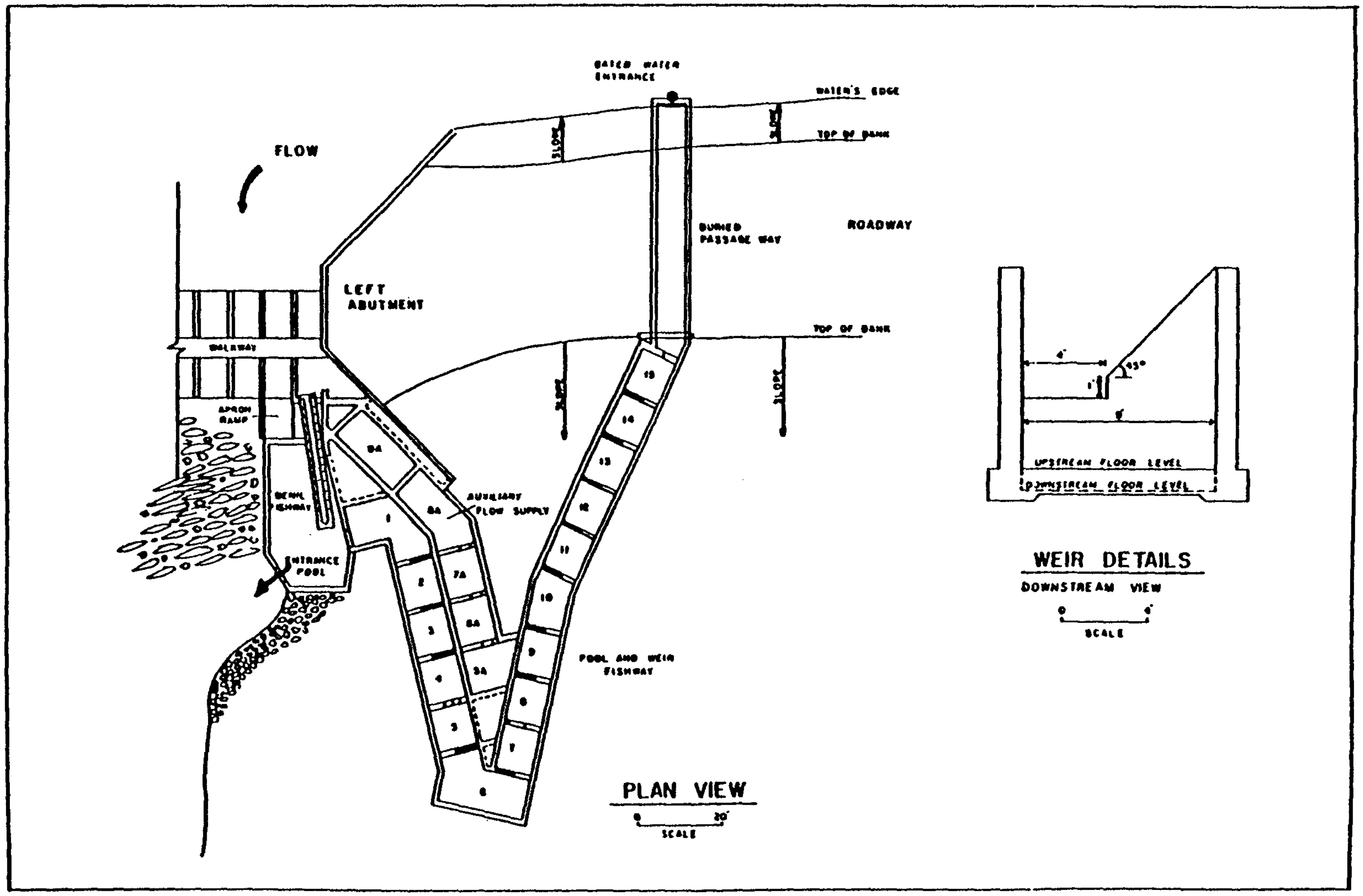

Figure 3. Plan view of left abutment of Woodbridge Dam containing Denil and pool-and-weir fishways, lower Mokelumne River, California (from CDFG, 1991).

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Pool-and-Weir Fishway

"The pool-and-weir fishway is located near the left abutment. The upper pool-and-weir fishway consists of 16 pools and 16 wiers (pools 1 through 15) beginning at an entrance pool and ending with a conduit through the left earth-fill abutment and is used when the dam is at the high flashboard level (Figure 4). Auxiliary flow can be added to the first and/or fourth pools by a series of pools (9A through 5A) beginning at the first bay near the left abutment. During the low flashboard level condition, the lower pool-and-weir fishway, pools 1 through 4 and 5A through 9A, can be used in conjunction with the Denil fishway. Typical fishway pool dimensions are 10 ft in width and 9 ft in length. Two of the pools (pools 1 and 6) are turn pools with larger dimensions. The wiers are 4 ft wide and are located along the left edge of the fishway. The conduit through the earth-fill abutment is a 7-ft wide by 9-ft high tunnel with a gated entrance extending into the lake to control flow into the fishway."

"Additional water can be added to fishway Pool 4 as an attraction flow in the lower portion of the fishway. This additional water flows over weirs already full with water from the upper portion of the ladder. While the addition of auxiliary water is necessary for attraction into the ladder, Pool 4 is not the ideal location. Additional water produces additional turbulence in the downstream pools creating the potential for disorientation. A better location to add attraction water is in fishway Pool 1 where the added flow will not affect flow conditions in the lower ladder. This would create uniform flow conditions throughout the fishway and reduce the amount of disorientation and delay during passage."

Denil Fishway

"The Denil fishway at Woodbridge Dam is constructed from angle iron and plywood to form the chute with the roughness template inserts built from 2 x 12-in lumber (Figure 5). Inside the plywood sidewalls, the fishway is 43.5 in wide. With the templates extending from each sidewall 11 in, the space down the center of the fishway is 21.5 in wide. The templates are spaced 38 in apart and are installed at a 45° angle with the floor. The fishway is 32 ft long and sits at a 11% slope."

"Chinook salmon and steelhead trout use the Denil fishway at Woodbridge Dam after the flashboards have been removed in late October or early November. The lower pool-and-weir fishway (pools 1-4 and 5A-9A) can be used at the same time if sufficient flow is available. This fishway passes fish through January. Water flowing through the first bay next to the left abutment fills the chamber upstream of the fishway to provide a resting pool after the fish leave the fishway. Water leaving this pool flows down the Denil fishway and exits into the entrance pool. After the migration season, near the end of January, more flashboards are removed leaving 1.5 ft of flashboard in place in

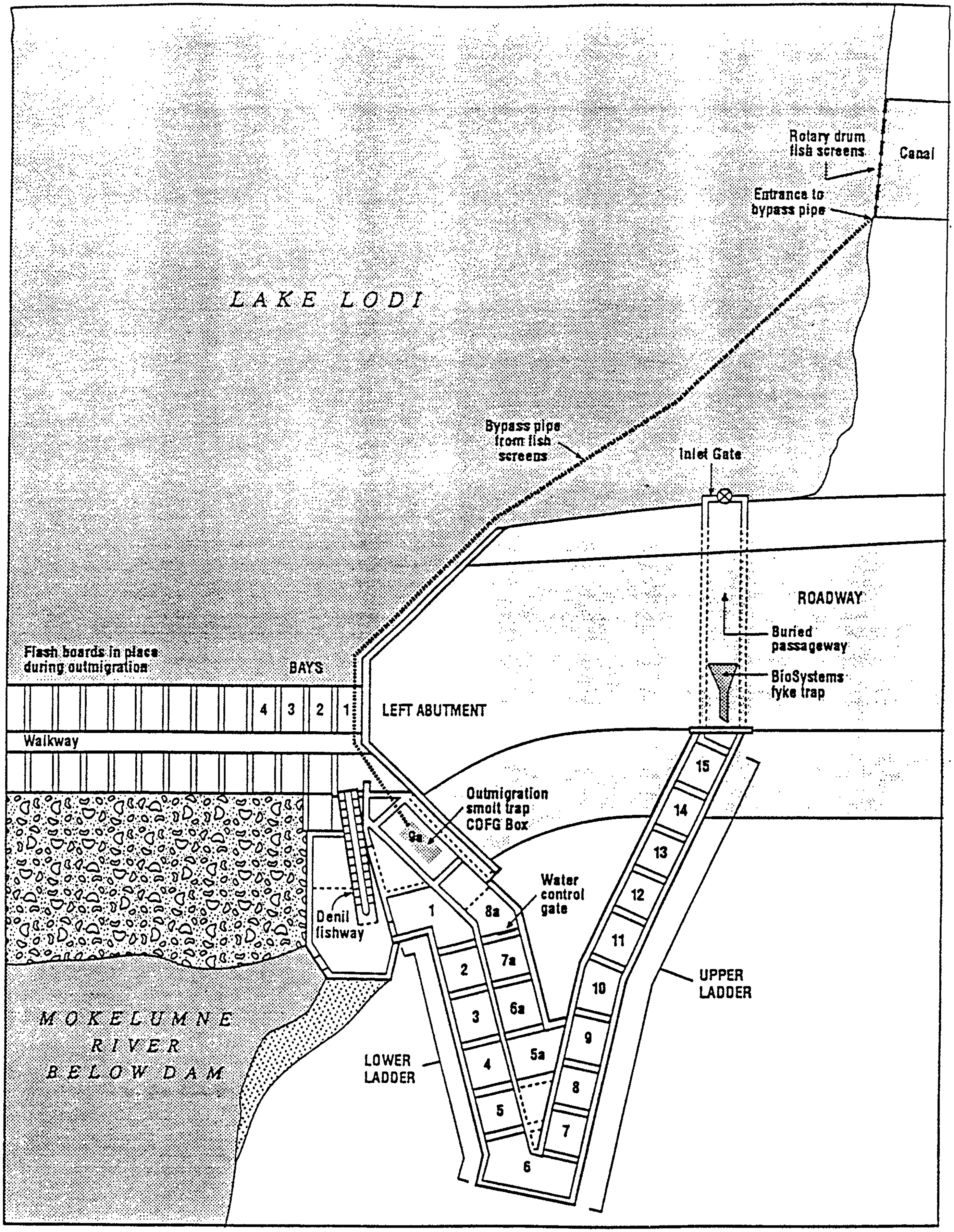

Figure 4. Plan view of Woodbridge Dam showing fish ladders, smolt outmigration traps: CDFG box and BioSystems fyke trap.

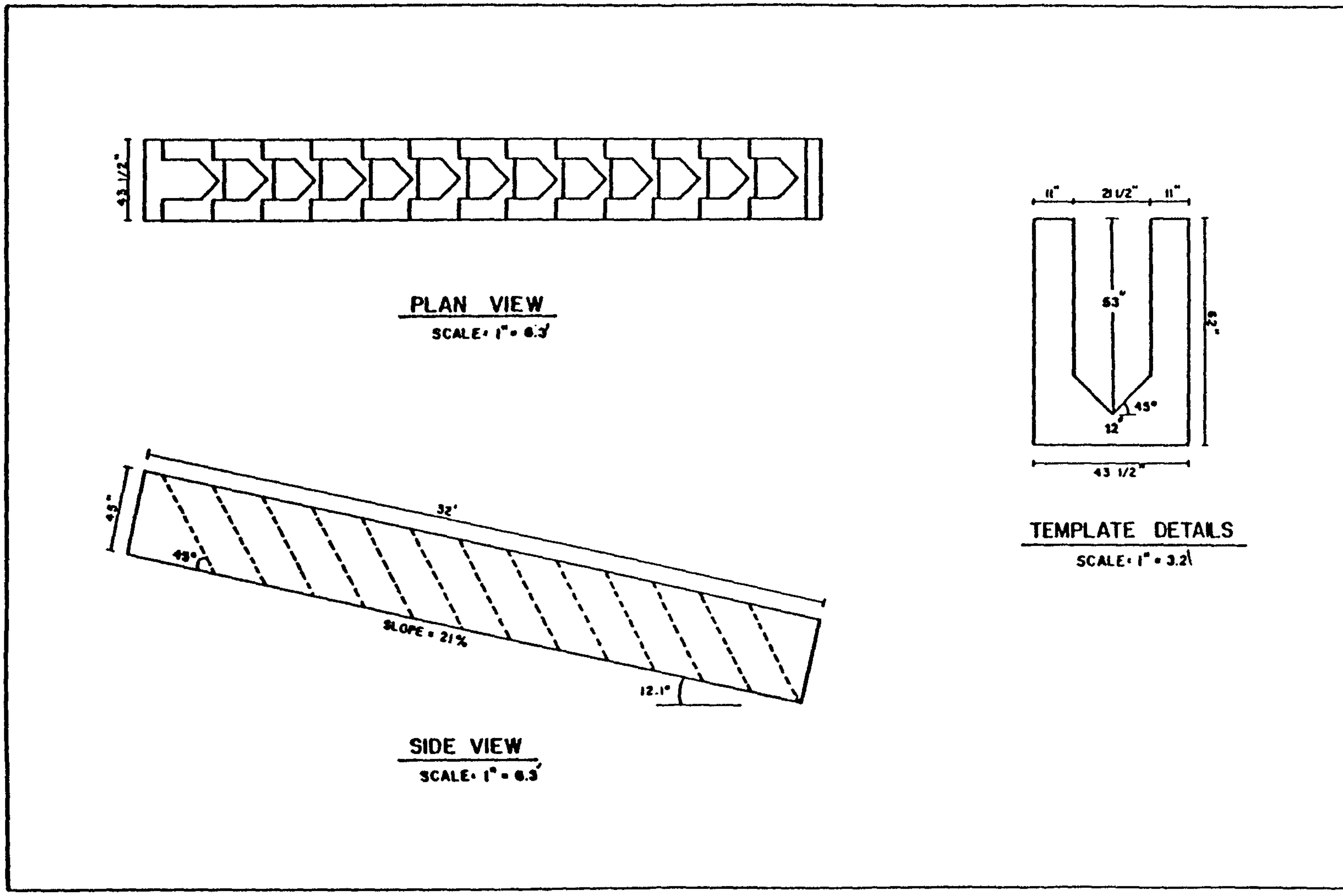

Figure 5. Denil fishway details, Woodbridge Dam, lower Mokelumne River, California (from CDFG, 1991).

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anticipation of any winter floods."

"Normal fish passage under high flashboard/spill conditions is through the upper pool-and-weir fishway. However, water can enter the Denil fishway under these conditions and create detrimental conditions to the passage of fish around Woodbridge Dam. Under these conditions, spill fills the resting pool upstream of the Denil and provides water to the Denil fishway. Water exiting the Denil disrupts flow from the pool-and-weir fishway causing a false attraction into the Denil which has no upstream outlet during these flow conditions. Fish ascending the Denil fishway into the resting pool are blocked from further upstream movement by the high flashboards and must fall back through the Denil to find the entrance to the pool-and-weir fishway."

In the fall of 1990, a pipe-rack barrier was installed at the base of the Denil fishway to prevent upstream migration through this fish passage route. The barrier was placed at this location to allow upstream migrant fish passage only through the pool-and-weir fishways where video monitoring equipment was installed to obtain counts of fish passing Woodbridge Dam. Therefore, the Denil fishway was not available for the principal upstream fish migration period after that time (Anders Christensen, WID Manager, personal communication).

ASSESSMENT OF UPSTREAM FISH PASSAGE FACILITIES

Based on the descriptions provided in CDFG (1991) and observations made during the site visits, there are several factors associated with the Woodbridge Dam which likely reduce the fishways' effectiveness for good fish passage.

Entrance Configuration

The entrance to a fishway is the single most important part of any fishway system (Powers et al., 1985). A combination of fishway entrance location, entrance configuration, and insufficient water discharge all likely contribute to suboptimal upstream fish passage conditions at Woodbridge Dam. Extensive evaluations of fishways in France during the 1980s found that, in most cases, failure in fish facilities efficiency resulted from the lack of attraction into the fishway, due to a bad location of the entrance or an insufficient water discharge (Larinier, 1990). Location and hydraulics are two factors which are considered in the design of fishway entrances (Powers et al., 1985). Vogel et al. (1988) concluded that fishway entrance configurations at the Red Bluff Diversion Dam (RBDD) were contributing factors to reduction in fishway performance.

As described in CDFG (1991), the shallow entrance configuration to the fishways at Woodbridge Dam results in suboptimal conditions for attraction because fish attempting to enter the ladders have to swim over a shallow gravel bar under low flow conditions (Figure 6). Vogel et al. (1988) believed that surface entrances to fishways at RBDD may inhibit attraction of salmonids into the fishways. The entrance to the fishways at Woodbridge Dam is much

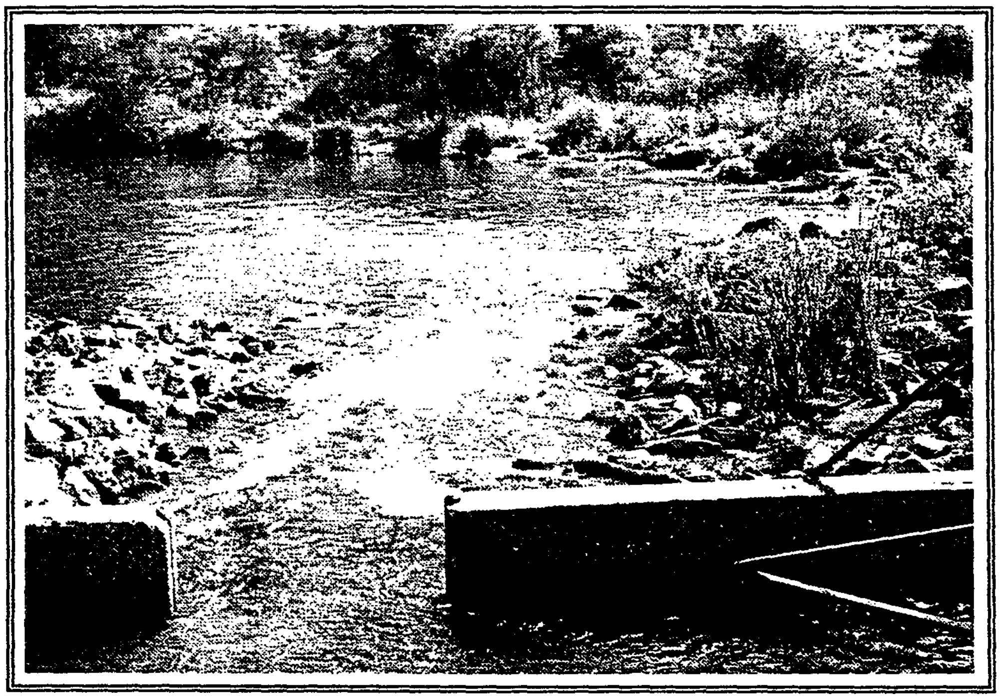

Figure 6. Fish entrance and flow exit for the Woodbridge Dam fishways, June 2, 1992.

shallower than those at RBDD. Rainey (1991) recommended avoidance of shallow, high-velocity conditions near a fishway entrance. He suggests that a minimum of a 5-ft pool depth outside the entrance is essential because it provides excellent holding water, aids in reducing spill turbulence, and reduces fish passage delay.

Although not observed during the site visits, high flow conditions probably make it difficult for fish to find the entrance because of the orientation of the fishway entrance to the base of the dam. The description by CDFG (1991) for fish passage under high flows with spill over Woodbridge Dam is probably an accurate characterization of conditions for fish. The riprap downstream of the dam could easily cause physical injury to fish attempting to negotiate the riprap and ultimately falling back through the riprap material (Figure 7). Because the proportion of flow from the fishway to spill at the dam under high flow conditions is low, the attraction to the fishway entrance is likely poor under those conditions. Either direct observations of high flow conditions or a hydraulic model analysis would be necessary to determine if high flow conditions create a backwater influence on the fishway entrance; a backwater effect would likely reduce the attraction of fish into the fishway. In addition, dam tailwater eddys could be created in the vicinity of the entrance; such conditions could disorient and confuse fish (Rainey, 1991). At Rosa and Easton Dams in the Yakima River basin (Washington), fishways were designed to allow the addition of auxiliary water through diffusers in pools above the fishway entrance pool to provide a minimum attraction velocity of 2.5 ft/s over each submerged weir to induce upstream fish movement (Rainey, 1991).

During low flow conditions, the fishway flow is the largest component of the entire flow downstream of the dam and therefore, flow by itself, is not likely to be a major factor limiting performance of the fishway attraction under those conditions. However, under moderate to high flow conditions, this relative low volume of water is probably a limiting factor for fishway attraction. In recent fishway projects constructed on tributaries to the Columbia River, total attraction flows from fishways ranged up to 10 percent of the total streamflow at mid to high river stage (Rainey, 1991). Vogel et al. (1990) found that radio-tagged salmon downstream of RBDD exhibited the least delay in fish passage when the total fishway flow was 8 to 10 percent of the total flow past RBDD and led them to recommend adding additional fishway flow during high flow periods to approximate 10 percent of the total river flow.

A common entrance pool is provided for both the pool-and-weir fishways and the Denil fishway on Woodbridge Dam (Figure 8). The larger fishways reported by Rainey (1991) for dams on Columbia River tributaries incorporated two to four entrances into the fishways to improve attraction of fish into the fishways. Following field investigations at RBDD, Vogel et al. (1990) recommended the addition of full-depth or multi-level orifices on fishways at the dam to improve fish attraction. The turbulence caused by both fishway flows entering the common entrance pool at Woodbridge Dam could disorient and confuse fish, particularly because each flow exit is perpendicular to the other.

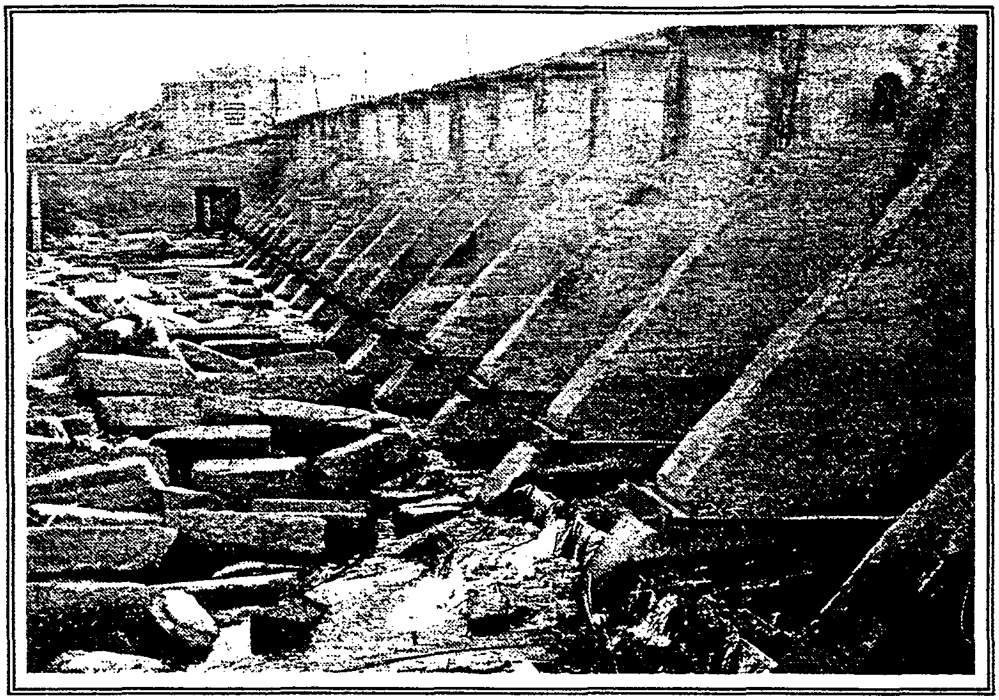

Figure 7. Downstream side of Woodbridge Dam showing riprap, January 25, 1991.

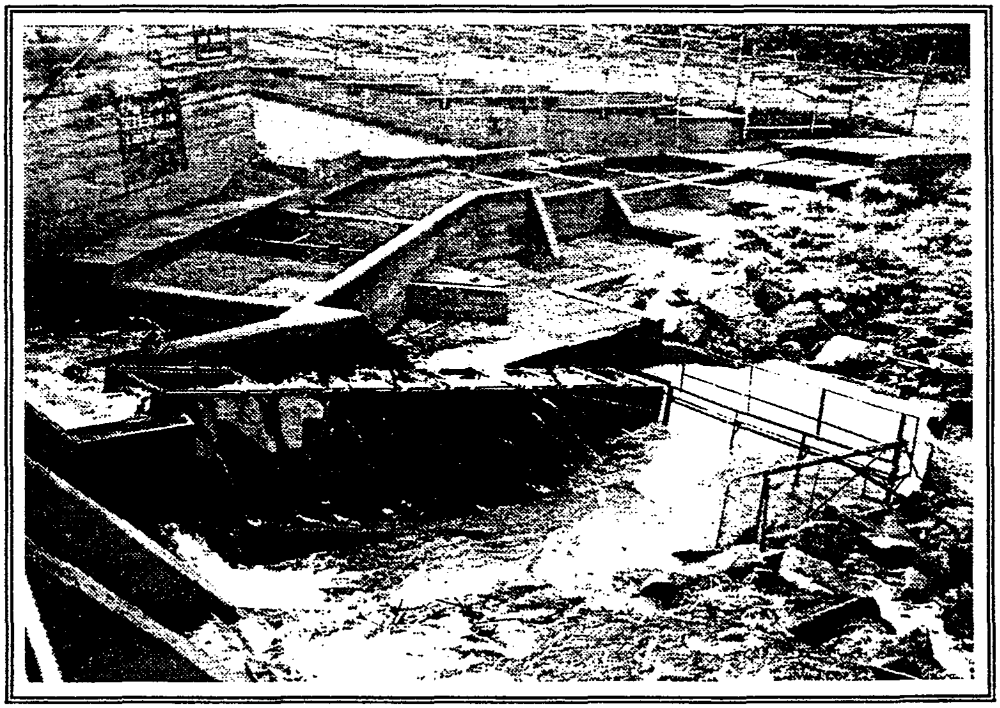

Figure 8. The fishways at Woodbridge Dam; Denil fishway in foreground, pool-and-weir fishways in background, March 23, 1992. Note the common entrance pool on the right.

The shallow entrance depth of the Woodbridge Dam Denil fishway could reduce its effectiveness for fish passage. Statick (1969), as cited by Powers et al. (1985), recommended that Denil-type fishway entrances should be submerged to a depth of 2.5 feet. The entrance to the Denil fishway does not appear to be designed or operated at recommended criteria for this type of fishway (Figure 9).

Internal Fishway Configurations

On larger fishways, auxiliary water is added within the fishway to provide additional flow to improve fish attraction to the entrance. An important consideration of the addition of auxiliary water through wall diffusers is to dissipate its energy and uniformly distribute the flow through the auxiliary water diffuser to not exceed 1.0 ft/s (Rainey, 1991). Clay (1961), as cited by Powers et al. (1985), recommended auxiliary water velocities in the range of 0.25 to 0.75 ft/s at the location where the water is added to the fishway. The Woodbridge Dam pool-and-weir fishways do not meet this criteria. Auxiliary water can be added directly to Pool No. 1 (behind and under a vertical steel plate) from Pool No. 9a (Figure 4). The water drop from Pool No. 9a into Pool No. 1 would create high water velocities and turbulence in the ladder at that location. Furthermore, CDFG (1991) described the resultant poor conditions for fish in Pool No. 4 with the addition of attraction water.

The existing Denil fishway on Woodbridge Dam was reported by CDFG (1991) as having a slope of 11 percent. However, measurements taken from design drawings for the fishway indicated the slope was approximately 23 percent. A figure of the fishway included in CDFG (1991) showed the Denil fishway at a 21 percent slope (Figure 5). It was therefore assumed that the 11 percent value was a typographical error in the CDFG (1991) report. Assuming the existing Denil fishway is placed at either a 21 or 23 percent slope, it is steeper than that reported in the literature for other fish passage facilities and could impair fishway effectiveness. The maximum suggested length for this type of fishway at a 20 percent slope is 30 feet (Powers et al., 1985). The Woodbridge Dam Denil is slightly steeper and longer than these values. In reporting on several Denil fishways used at Cowan, Saskatchewan and Fairford, Manitoba, Canada, Katopodis (1990) stated that the longest Denil fishway section negotiated by fish was 9.5 m at a 12.6 percent slope. Recent fishways installed at Freeport, Ontario had the following design characteristics: east bank fishway, 7.5 m long at 20 percent slope; west bank fishway, three segments each at 10 percent slope with resting pools between segments (Katopodis, 1990). Larinier (1990) reported that more than 100 Denil fishways have been recently installed in France (over a 12-year period), primarily for sea trout and salmon and are generally operated at slopes of between 15 percent to 20 percent.

Conditions for fish exiting the upper pool-and-weir fishway could not be directly observed. The exit structure includes a stem-valve over a pipe. If the valve is not operated to allow sufficient opening for adult fish, fish could be physically injured attempting to negotiate the small opening. Apparently, CDFG staff at the Mokelumne River Hatchery (upstream from Woodbridge Dam) have observed physical injury on fish returning to the hatchery which they attribute to passage through the stem-valve opening (EBMUD staff, personal communication).

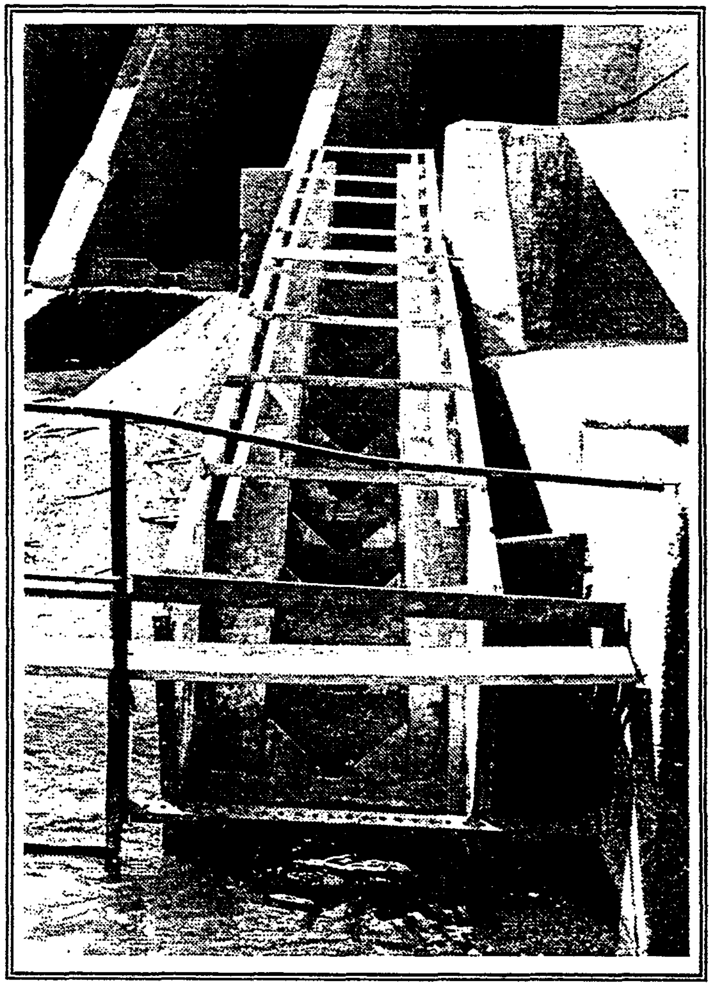

Figure 9. The Denil fishway (dewatered) at Woodbridge Dam, June 2, 1992. The bottom of the fishway is in the foreground.

Fishways Operation and Maintenance

Adequate O&M of fishways is an important consideration of fishways (Rainey, 1991). The accumulation of riverine debris can clog fishways and significantly reduce their efficiency in fish passage performance. On two of three site visits to Woodbridge Dam, riverine debris was wedged in a fishway. Vogel et al. (1988) recommended a more aggressive O&M program for fishways at RBDD as a means of improving fishway efficiency. Based on observations during the site visits and the flow entrance configuration of the Denil fishway on Woodbridge Dam, it is probable that an inadequate O&M program may contribute to reduced fish passage at the dam. During a site visit on January 25, 1991, the top of the Denil fishway (flow entrance) was jammed with riverine debris making the fishway impassible for fish (Figures 10 and 11).. During a site visit on March 25, 1992, a large board was found partially blocking the entrance to the base of both fishways in the entrance pool.

DESCRIPTION OF DOWNSTREAM FISH PASSAGE FACILITIES

A description of the downstream migrant salmonid passage facilities at Woodbridge Irrigation District is provided in the CDFG's "Lower Mokelumne River Fisheries Management Plan" (CDFG, 1991). Because of the relevance of that description to this assessment, the CDFG description is extracted from their report as follows:

Woodbridge Canal Fish Screen

> "WID's maximum entitlement for diversion to the Woodbridge Canal from the lower Mokelumne River is 116,700 AF (EBMUD 1989). If WID uses its maximum entitlement, the average flow over the irrigation diversion period April 15 through October 15 equals 321 ft^3/s. However, the maximum recorded diversion is 482 ft^3/s (July 8, 1953) while the average is 128 ft^3/s over 63 years of record, 1926-1989 (USGS 1989). Generally maximum diversion rate is considered to be approximately 400 ft^3/s."
>
> "The diversion was unscreened until 1968, when WID and DFG installed a screen facility on the canal. Currently, the Woodbridge Canal fish screen is operated and maintained by DFG and consists of 7 rotating drum screens (Figure 12). Irrigation water enters Woodbridge Canal from Lodi Lake as it flows through the screen facility. These screens prevent downstream migrating salmon from entering the canal. These screens are approximately 6.75 ft wide and 10 ft in diameter covered with rigid stainless steel woven wire cloth consisting of 4 meshes per in., 0.080 in. diameter wire, and square openings measuring 0.24 in. diagonally (0.17 in. square). The screens rotate in such a way that accumulated debris on the screen face is carried over the top and is washed off the downstream side. A juvenile chinook salmon and steelhead trout collection and

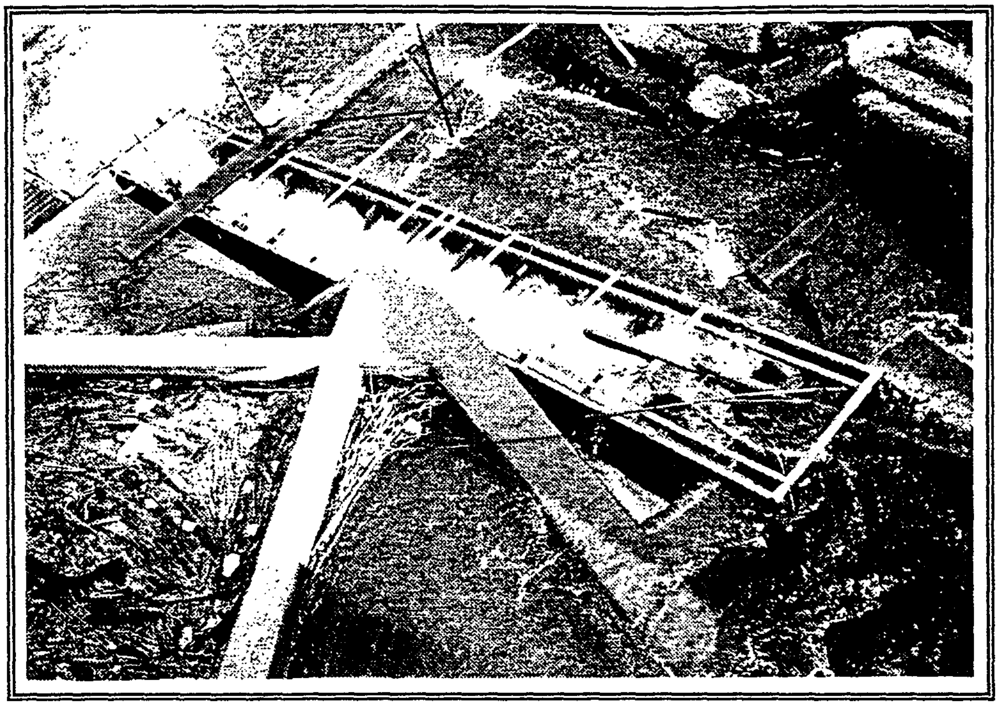

Figure 10. Denil fishway at Woodbridge Dam, January 25, 1991. Note debris at flow entrance.

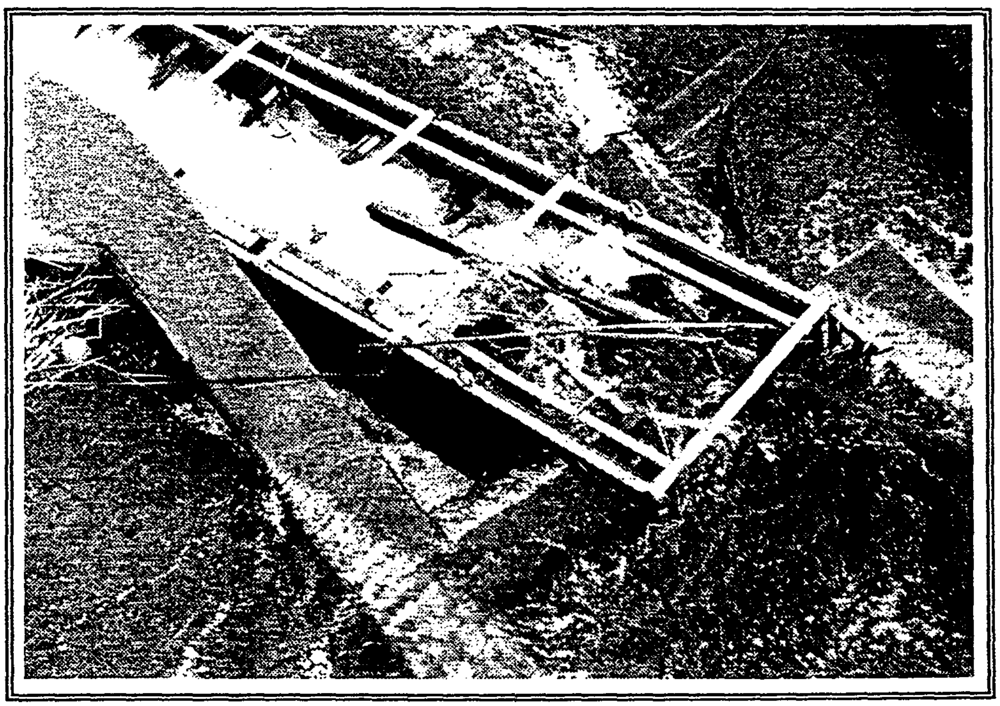

Figure 11. Top of the Denil fishway at Woodbridge Dam, January 25, 1991. Note riverine debris at the flow entrance.

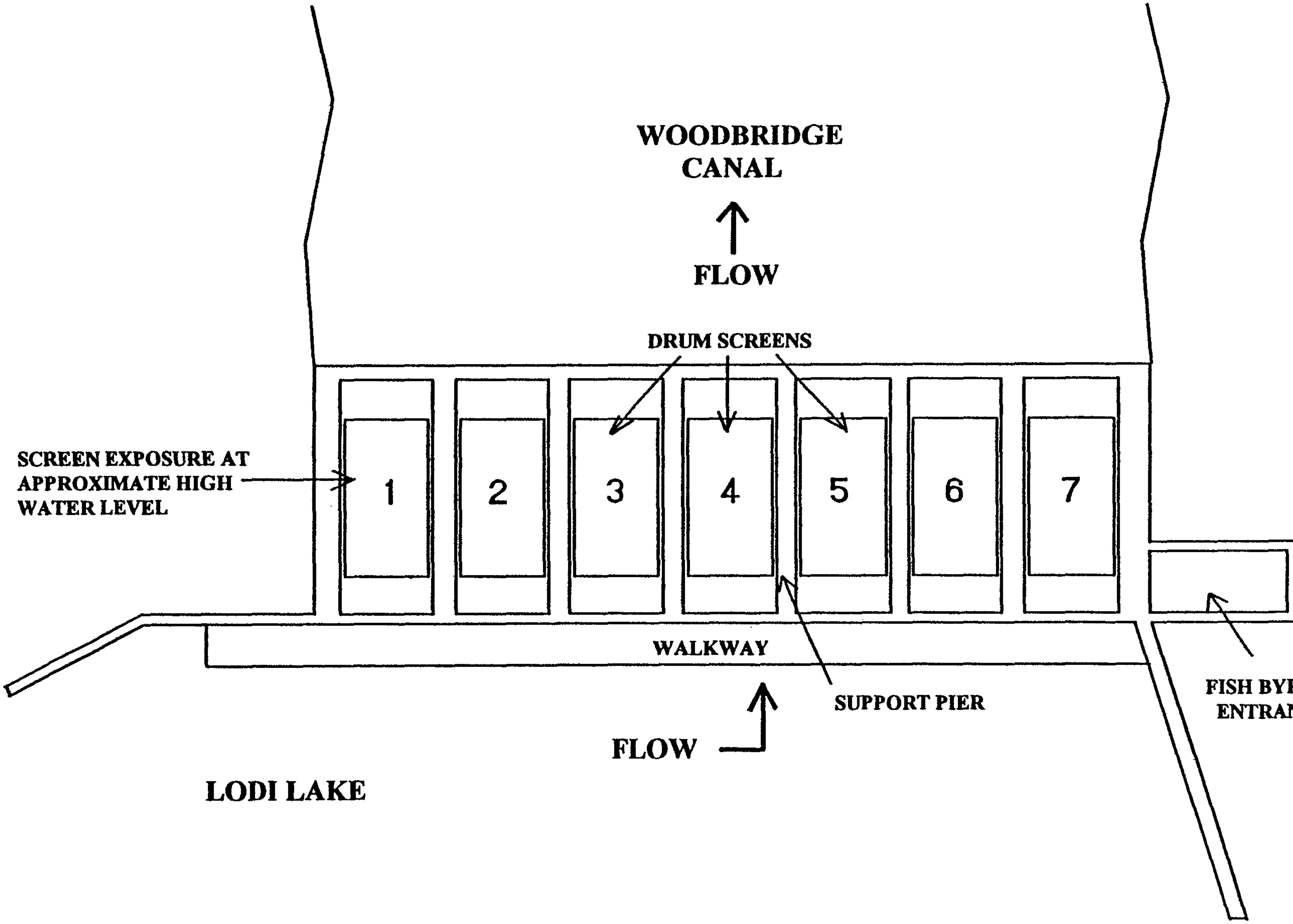

Figure 12. Plan view of the Woodbridge Irrigation District fish screens.

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bypass facility is located along the right abutment of the screen headworks. This facility shunts the young fish to Woodbridge Dam through a pipe to fishway Pool 9A (Figure 4), where they are collected and transported downstream to Rio Vista or allowed to continue downstream through the fishway into the river below the dam."

WID's permanent regulated base supply under its agreement with East Bay Municipal Utility District is 60,000 acre feet in years when the inflow into Pardee Reservoir reaches at least 375,000 acre feet or more but is subject to a deficiency of not more than 35 percent when the inflows into Pardee Reservoir are less than 375,000 acre feet of flow (Anders Christensen, WID Manager, personal communication).

ASSESSMENT OF DOWNSTREAM FISH PASSAGE FACILITIES

Fish Entrainment

During the site visit to the WID fish screens on March 23, 1992, an inspection of the CDFG screening facility was conducted to determine if any gaps in the structure were present. The inspection was conducted prior to the filling of Lake Lodi to facilitate inspection of the screens in their normal operating position. Figure 13 shows the screening facility with the screens in place and Figure 14 shows the facility with the screens raised.

Numerous large gaps were located under the screens which could entrain fish when water is being diverted into WID canal. Figure 15 shows the general location where the gaps occurred at the base of the fish screens and Table 1 gives the specific locations and dimensions of the gaps located. In all but one case, the gaps were located in the concrete keyway slots for the fish screens. These keyway slots are where the entire drum screen and frame are lifted and lowered between the concrete support piers. Fish accessing these slots can easily enter the canal behind the screens by following the slots and entering the canal on the back side (downstream side) of the screen where no seals are present. The gaps are large enough for smolt, juvenile, and fry-sized salmonids to be entrained into the WID canal. There was one instance where one of the rubber side seals was damaged and a gap of approximately 6 inches by 3/8 inch was present. Figure 16 shows the location of the latter gap; in this photograph, note the white pen positioned between the concrete pier and the screen structure. The pen is inserted at the location of the damaged rubber seal. In this photograph, you can also see the metal base of the screen structure positioned in the keyway slot to the right of the pen. This area is comparable to the diagram of the left side of the screens shown in Figure 15. Figure 17 shows the location on the right side of the screens where the keyway slot gaps are present. Note the white pen inserted into the keyway slot. This area is comparable to the diagram of the right side of the screens shown in Figure 15. Following this inspection, CDFG staff repaired the gaps between the screens and concrete piers prior to the filling of Lake Lodi (Anders Christensen, WID Manager, personal communication).

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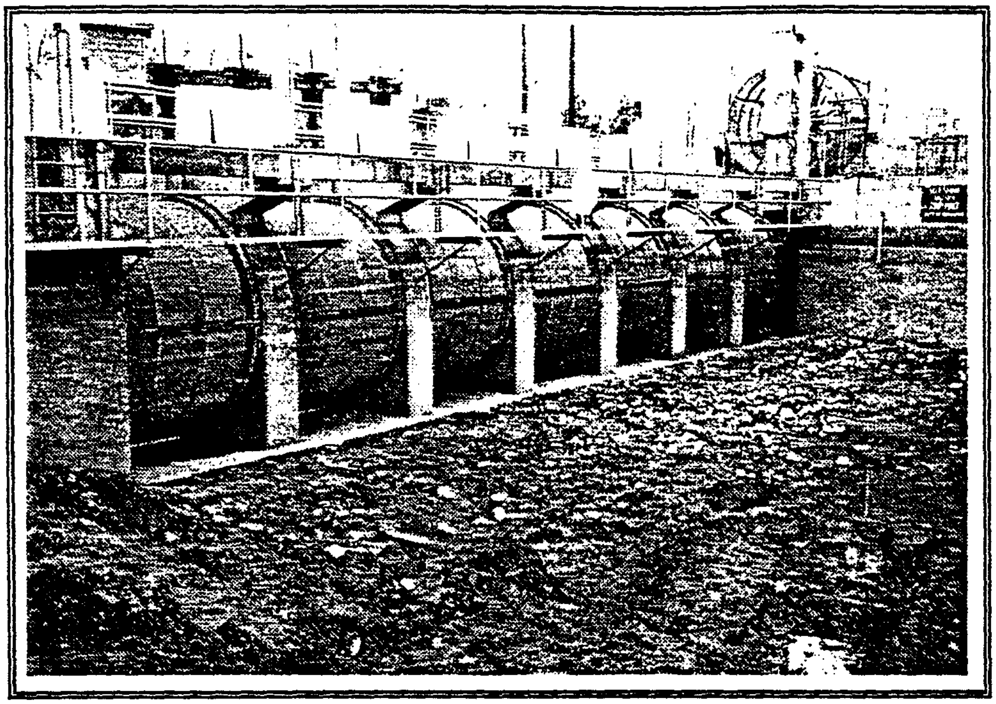

Figure 13. Woodbridge Irrigation District fish screens (screens in place), March 23, 1992.

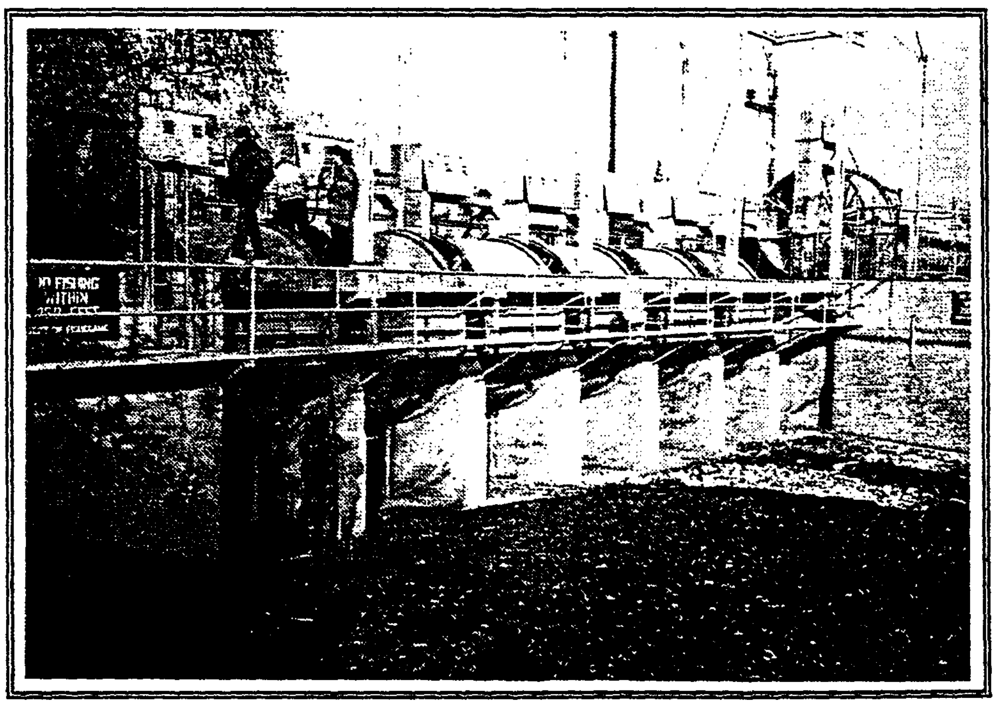

Figure 14. Woodbridge Irrigation District fish screens (screens raised), January 25, 1991.

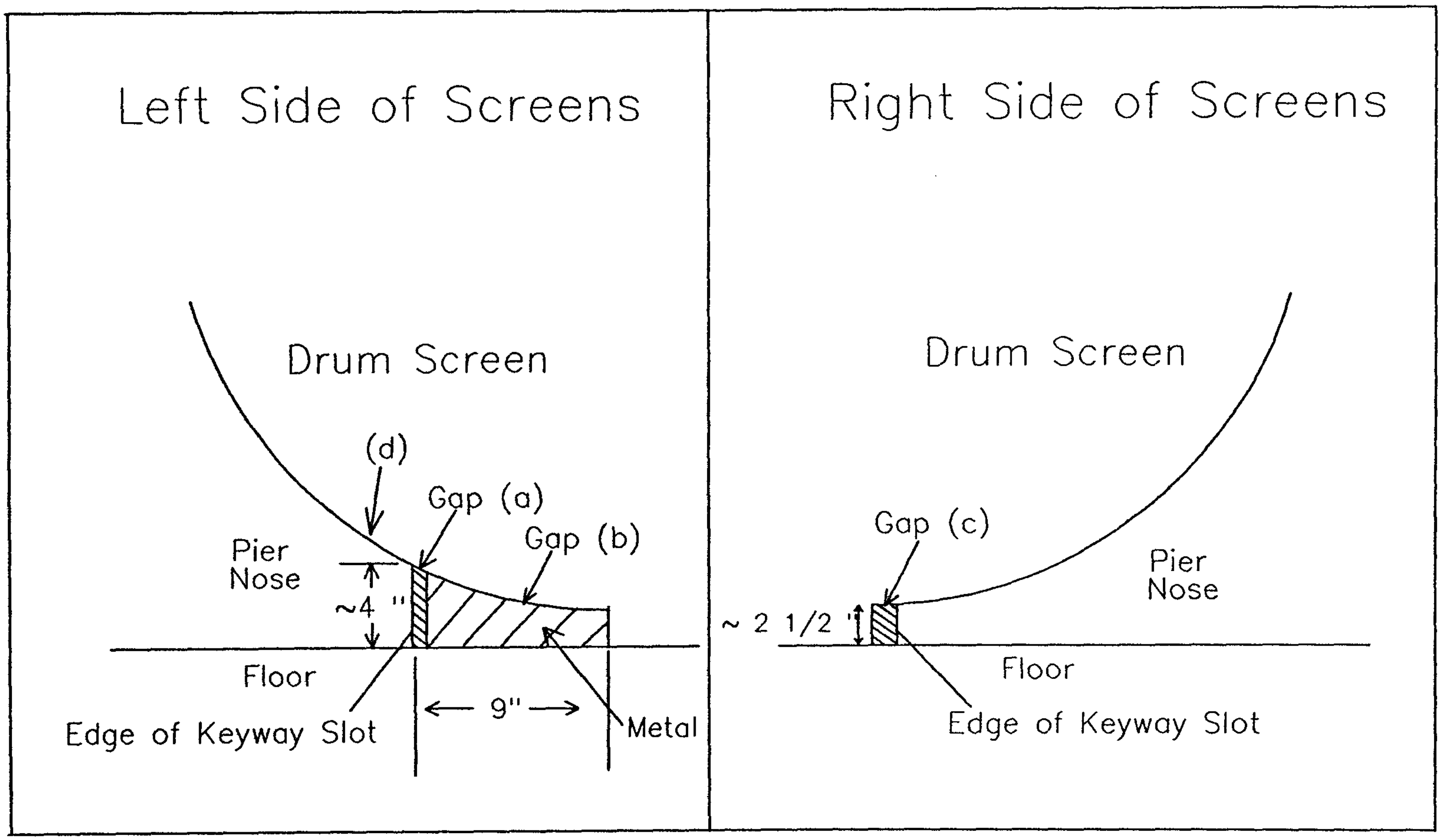

Figure 15. Side views of the Woodbridge Irrigation District fish screen bays showing locations of gaps between drum screen frame and support piers.

Table 1. **Gaps Located on the Woodbridge Irrigation District Fish Screen, March 23, 1992.**

Screen Bay Number[1]	Left Side (Facing Canal)		Right Side (Facing Canal)
	a[1]	b[1]	c[1]
1	0	0	<1" x 2 1/2" Gap
2	0	0	1" x 2 1/2" Gap
	Rubber Seal Broken (d[1]) 3/8" x ~6" Gap		
3	0	3/8" x 9" Gap	1" x 2 1/2" Gap
4	0	0	>1" x 2 1/2" Gap
5	<1" x 4" Gap	>3/8" x 9" Gap	>1 1/2" x 2 1/2"Gap
6	0	0	1" x 2 1/2" Gap
7	0	0	<1" x 2 1/2" Gap
"<" signifies "slightly less than" and ">" signifies "slightly greater than"			

[1] Refer to Figure 15 for Locations

Figure 16. WID fish screen, left side, March 23, 1992. Note pen location showing gap in seal.

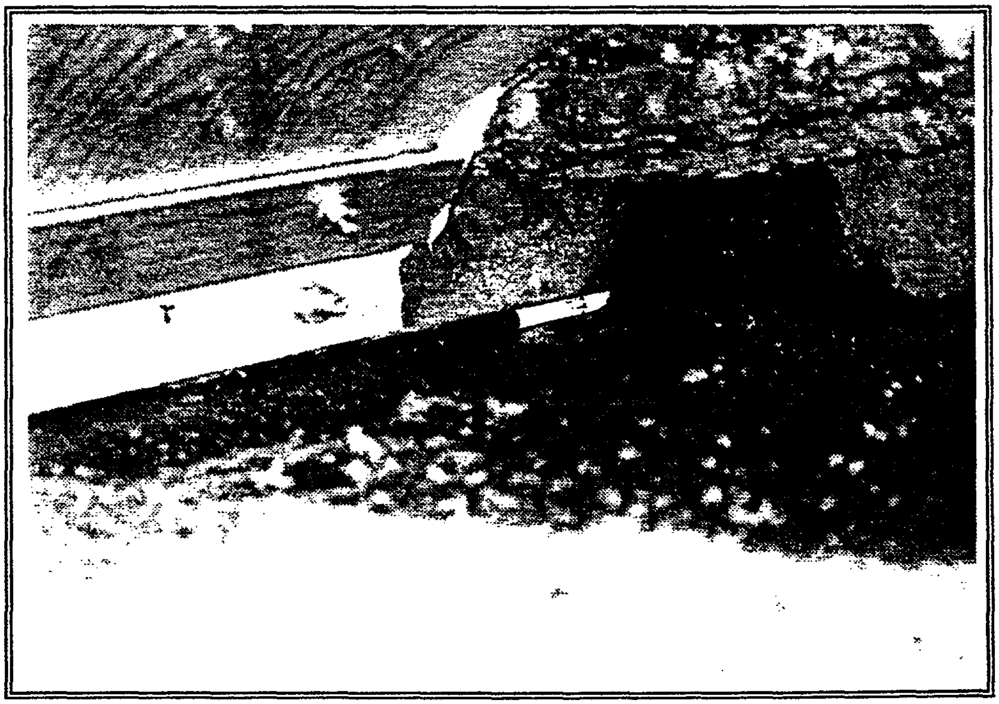

Figure 17. WID fish screen, right side, March 23, 1992. Note pen inserted into the gap at the screen keyway slot.

During the inspection, it was noted that silicone caulk had been recently applied at various locations on the screens and screen structure apparently to seal gaps. In some locations, the caulk had been applied continuously to stationary parts of the screen and adjoining parts of the structure which would move when the screen was activated. Under these latter circumstances, it is was obvious that some portion of the caulk would sever or become dislodged upon screen activation, possibly compromising the seal integrity.

Fisher (1976) conducted a limited evaluation of salmonid entrainment into the WID canal during April and May of 1974. After collecting both chinook and steelhead fry behind the screens, he concluded that fry were being entrained through the screen mesh because an underwater inspection by a SCUBA diver found the rubber seals around the screen in excellent condition. However, most of the gaps located on March 23, 1992 were not present where the rubber seals are positioned; the gaps were present in the concrete keyway slots. Because of the extremely confined location and difficult access, the keyway slot gaps would be very difficult to be observed by a SCUBA diver. It is therefore quite probable that the fish sampled by Fisher (1976) were not entrained through the screen mesh, but were instead entrained through the keyway slot gaps. The screen facility became operational in April 1968 (Fisher, 1976), so it is likely that fish entrainment through these keyway slot gaps has occurred each irrigation season since that time. It is interesting to note that Fisher (1976) captured fry-sized chinook and one steelhead fry during April and May which corresponds to the period when WID usually begins diverting water from the river. This period corresponds to the time when smolt-sized salmon are generally present in the Mokelumne River.

Conditions in Front of the Screens

Pier Noses

The most notable observation made during the inspection on March 23, 1992 was the presence of large concrete pier noses jutting approximately 5 feet out in front of the base of the fish screens (Figure 18). Those pier noses are shown in Figures 13 and 14. A closeup of the pier nose can be seen in Figure 19. The presence of these pier noses is undesirable because they create hazardous conditions for fish. Modern-day fish screen structures do not possess this feature and are designed with the concrete support piers flush with the contour or curvature of the rotary fish screens. The reason for designing the pier noses flush with the screen is to allow fish to follow a path of least resistance past the screens until they enter a downstream fish bypass. Existing CDFG fish screen design criteria states, "Screen faces shall be placed flush with any adjacent screen bay piers or walls to allow an unimpeded flow of bypass water parallel to the screen face". The presence of the pier noses interrupts tangential flow along the face of the screens toward the fish bypass system. Young downstream migrant salmonids entering a screen bay between the pier noses encounter only flow being entrained in a perpendicular direction through the screens. The fish can escape these areas only by swimming against the flow to escape these "entrapment zones" (Figure 18). This behavior is uncharacteristic of downstream migrant salmonids. Fisher (1976) believed that fish approaching the WID fish screen "sounded" in front of the screens; this behavior would make

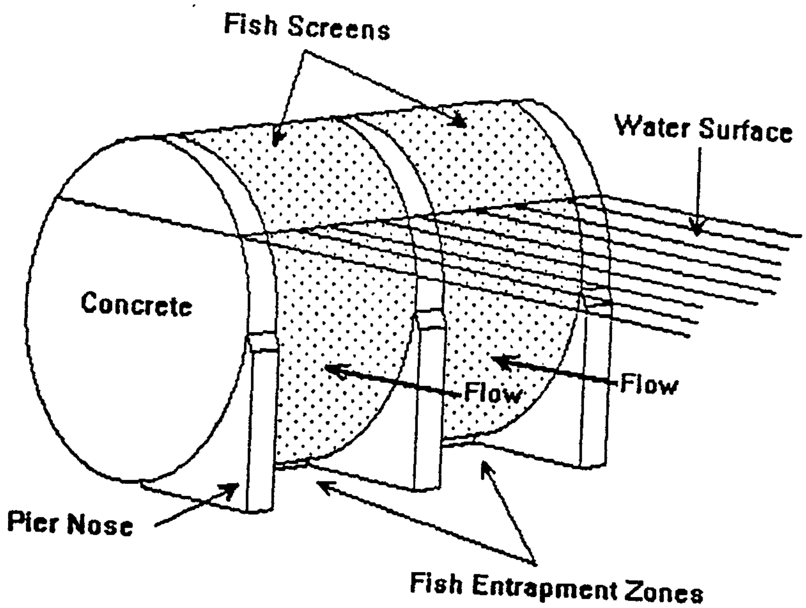

Figure 18. Conceptual diagram of two Woodbridge Irrigation District fish screens showing location of fish entrapment zones.

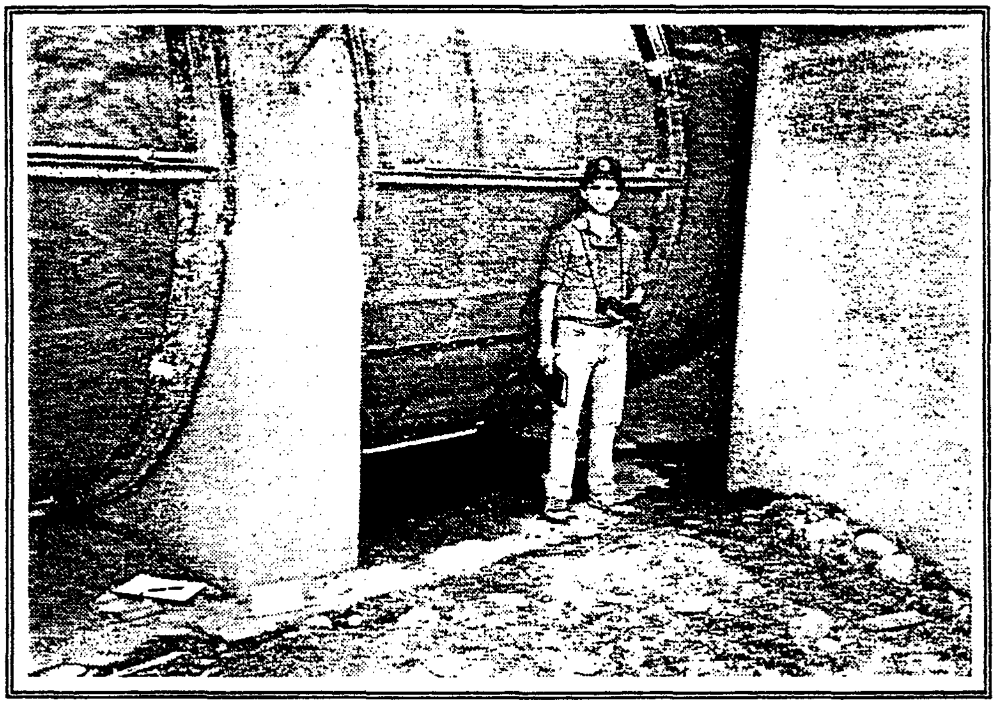

Figure 19. Entrance to the fish bypass (on the right) at the Woodbridge Irrigation District fish screens, March 23, 1992. Note the concrete pier nose on the left.

them vulnerable to the entrapment zones at the base of the structure. Rainey (1985) pointed out that under these conditions, juvenile fish must either sustain swimming velocity until a bypass entrance is found or they must seek a small opening at inside or bottom seals. Emphasizing the danger to fish, he stated, "The unfortunate reality of a screen perpendicular to flow is that fish must be strong, innovative, and lucky to survive". Similar types of fish entrapment zones were recently found on the CDFG fish screen at the Glenn-Colusa Irrigation District diversion on the Sacramento River (Thompson, 1992).

In examining the original design drawings for the WID fish screen structure, it is apparent that a relatively recent addition to the pier noses was made following original construction. The original pier noses were positioned close to the base of the fish screens whereas the addition onto the piers extended the pier noses approximately 5 feet in front of the base of the fish screens (Figure 20). It is not known why this modification was made to the structure, but doing so created worse conditions for fish than were present with the original design.

A properly designed fish screen functions in a manner to effectively allow fish to move from the upstream portion of the screen face to the downstream portion of the screen face in the least amount of time while concurrently avoiding impingement, entrainment, and predation. If conditions in front of the screens do not allow sufficient transport (tangential) flow to move fish past the screen structure, fish may ultimately weaken and succumb to the flow into the screen and become impinged (resulting in suffocation or physical injury) or entrained. In addition, under these conditions, young fish are particularly vulnerable to predation by piscivorous fish. Larger, predatory fish have a particular advantage over young salmonids in these areas because they can simply swim in and around these areas without fatigue and consume the smaller, weaker young salmonids attempting to negotiate passage at the fish screen.

Water Velocities

During the site visit on June 2, 1992, measurements[2] of water velocities in front of the screens were taken to learn more about flow characteristics in the vicinity of the structure. Although the WID can divert up to 482 cfs, we were only able to observe flow characteristics on the day of the site visit when the flow was 132 cfs. Table 2 gives the results of the velocity measurements.

Some difficulties were encountered with the use of the flow meter when an electrical connection was found severed; velocity measurements had to be taken while hand-holding the connections together to ensure proper electrical connection and careful considerations had to be given to ensure accurate velocity readings. Audible click patterns of flow meter revolutions indicated that proper meter revolution counts and velocity readings were obtained. However, as an additional check on the accuracy of the readings, computation of WID flow was

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[2] Water velocity measurements were taken with a Price AA flow meter borrowed from CH2M HILL; calibration range: 0.25-8.0 ft/s. Advance spin test normal (2-3 minutes).

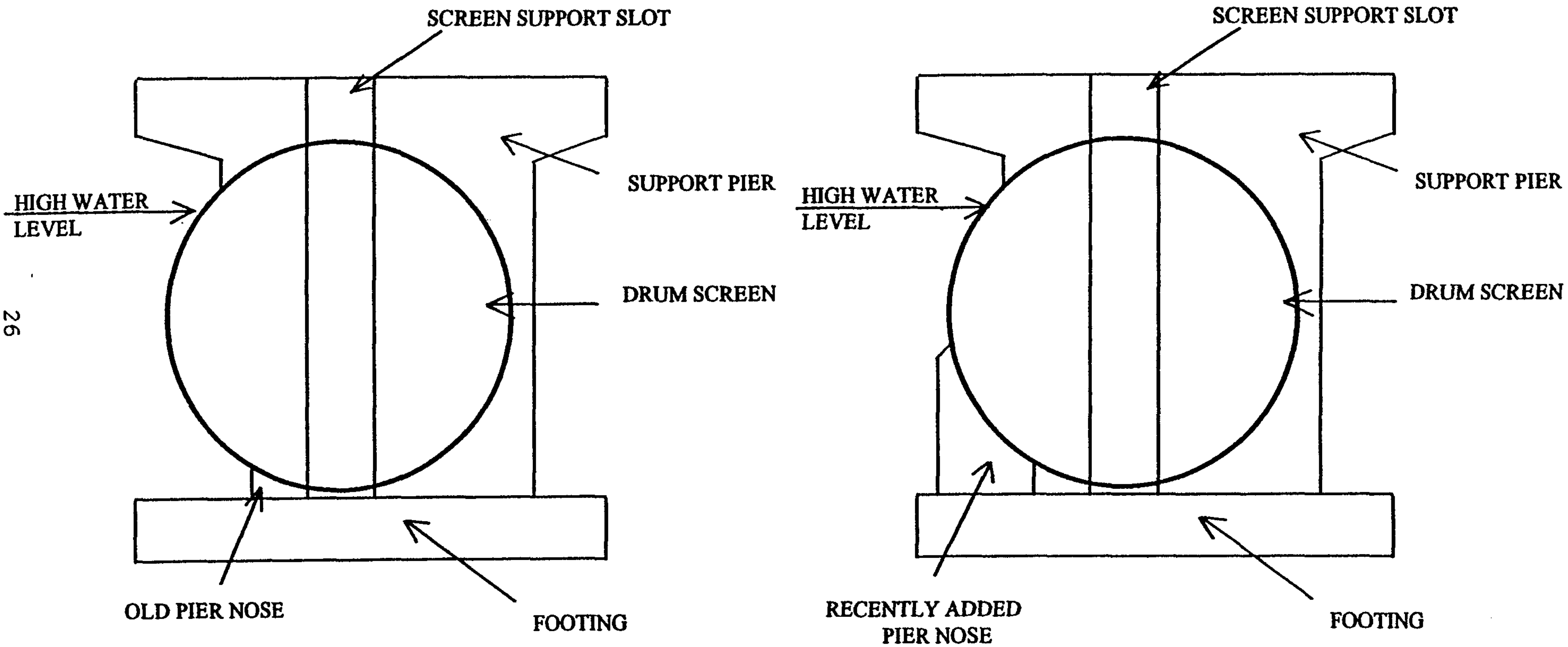

Figure 20. Cross-sectional profile of the Woodbridge Irrigation District fish screen concrete support piers showing original construction (left) and recently added pier nose (right).

Table 2. **Woodbridge Irrigation District Fish Screens Water Velocity Measurements (Canal Flow=132 cfs), June 2, 1992. (Screens numbered from left to right facing Woodbridge Irrigation District Canal).**

SCREEN #1	SCREEN #2	SCREEN #3	SCREEN #4	SCREEN #5	SCREEN #6	SCREEN #7

a = 7' 11" b = mid-depth c = surface #8=Bypass w/board in #9=Bypass w/board out

Measuring Point Screen No. and Water Depth	Velocity (ft/s)	Mean Velocity (ft/s)
1a	0.20	0.31
1b	0.40	
1c	0.33	
2a	0.25	0.33
2b	0.38	
2c	0.35	
3a	0.31	0.35
3b	0.38	
3c	0.36	
4a	0.25	0.31
4b	0.40	
4c	0.29	
5a	0.24	0.36
5b	0.47	
5c	0.39	
6a	0.19	0.36
6b	0.46	
6c	0.43	

7a		0.33	0.40
7b		0.46	
7c		0.42	
8a		0.21	0.24
8b		0.32	
8c		0.19	
9a		0.33	0.27
9b		0.21	
9c		0.26	
Pier nose between 6 and 7	a	0.15	0.30
	b	0.40	
	c	0.34	

estimated from data collected to verify velocity readings. The total square footage of WID screen area at normal water elevations is 378 ft^2 (CDFG, 1991). Using the velocities readings presented in Table 2, the estimated total flow entering WID Canal was 130.5 cfs. Actual flow was 132 cfs so it was assumed the velocity readings were accurate within the ranges meaningful to this evaluation.

As expected with the relatively low flow diverted into the WID canal on June 2, the water velocities in front of the screens were relatively low and, in most cases, near the design criteria of 0.33 ft/s approach velocity for fish screens in California. However, very little tangential flow past the screens toward the fish bypass was observed. Tangential flow past the screens is important for fish protection because downstream migrant fish have to be provided a path of least resistance to safety. Existing CDFG criteria specifies that "the component of the velocity parallel and adjacent to the screen face shall be at least two times the allowable approach velocity". These two criteria (approach velocity and sweeping velocity) are not mutually exclusive; they are used together to provide protection for fish. Although not directly measured, it was readily apparent that the tangential velocities were much less than the approach velocities, creating undesirable conditions for fish. Higher diversion rates into the WID canal than that observed would further exacerbate conditions for fish.

Fish Behavior

A noteworthy observation of juvenile salmon behavior in front of the fish screens was observed during the site visit on June 2, 1992 when the screens were operational and water was being diverted into the WID canal. A school of one to two dozen smolt-sized chinook salmon (approximately 80 to 100 mm in fork length) was observed swimming back and forth in front of the fish screens. This school of fish was seen repeatedly over a several-hour period apparently attempting to negotiate the structure; presumably it was a single school. The fish continually swam back and forth along the fish screens apparently attempting to find an escape route. Such fish behavior is undesirable at locations in front of screening structures because it makes the fish vulnerable to predation.

Fish Bypass System

Physical Configuration

The entrance to the fish bypass system was inspected during the site visit on March 23, 1992 prior to the filling of Lake Lodi. The entrance is adjacent to the downstream-most fish screen (Figures 12, 13, and 19). Within the bypass, a large vertical trashrack was present. Mounted to the trashrack was a plywood board with a notch 6 ft high by 3 1/16 inches in width (Figures 21 and 22). The bottom of the rack was positioned on top of an additional piece of wood which resulted in the bottom of the notch being positioned 2 feet off the concrete floor (Figure 21). It appears that the plywood board was not an original feature of the fish bypass system and was simply lashed onto the vertical metal trashrack grates. This added feature in front of the bypass is unusual because it is a generally accepted practice to avoid such abrupt flow transitions and narrow entrances into a fish bypass system. Juvenile fish are extremely

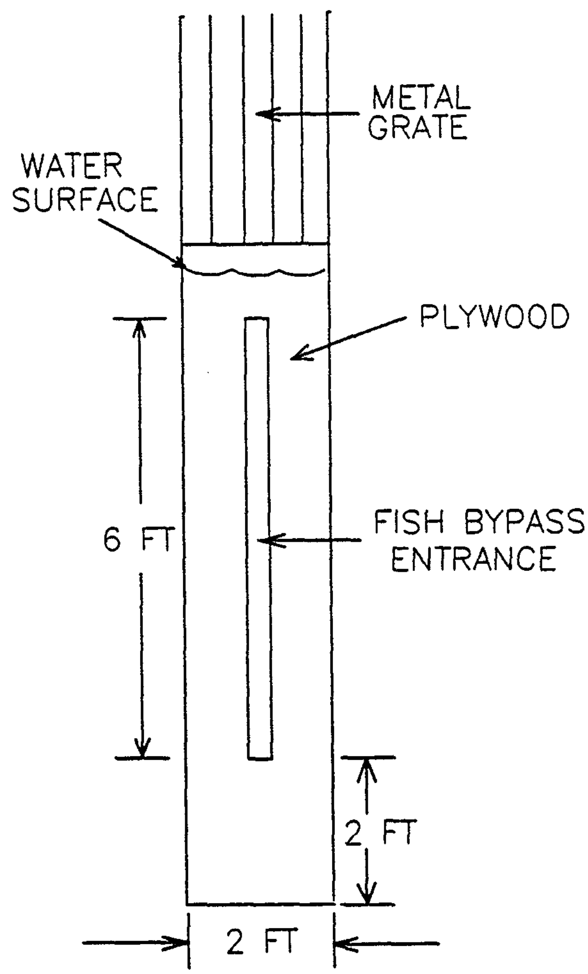

Figure 21. Front view of the trashrack and slotted board used at the entrance to the Woodbridge Irrigation District fish screen bypass.

Figure 22. Slotted board used at the entrance to the fish bypass at the Woodbridge Irrigation District fish screens, June 2, 1992.

sensitive to changes in hydraulic conditions (Rainey, 1985). Niggel (1964), as cited by Rainey (1985), found that fish response to a flow acceleration in a uniform channel with a flow constriction at the lower end resulted in fish holding upstream of the point of flow acceleration. These conditions would make the young fish highly susceptible to predation by predatory fish.

Operation and Maintenance

Upon observing this behavior of fish swimming back and forth in front of the fish screens on June 2, 1992, I inspected the fish bypass entrance and found that a large tree limb was wedged in the bypass and partially blocked the small slotted entrance through the plywood board; I subsequently removed the limb and cleaned the entrance. Based on the large amount of spider webs and cobwebs present in front of the bypass, it was evident the bypass had not been inspected for a lengthy period of time. The presence of riverine debris in the fish bypass entrance could cause fish avoidance away from the structure and very likely accounted for the juvenile salmon behavior previously described.

Trapping of downstream migrant salmon at Woodbridge Dam was conducted for EBMUD by BioSystems personnel prior to and following the removal of the large tree limb in the bypass entrance. The fish trapping is conducted at two locations at the dam which are shown in Figure 4. The lower ladder trap captures those fish passing through the WID fish screen bypass system and the upper ladder trap captures those fish entering the upper fish ladder at the dam. As can be seen from preliminary results from daily capture rates for each of the fish traps, the proportion of fish utilizing the WID fish screen bypass increased substantially following the removal of the riverine debris in front of the bypass entrance on June 2 (Figure 23), indicating that the debris likely adversely affected the performance of the bypass entrance. The fish bypass entrance has been inspected and cleaned on a continuous basis since June 2 (Anders Christensen, WID Manager, personal communication).

It was not possible to conduct an internal inspection of the fish bypass pipe for the fish screening facility as part of this assessment. However, the small diameter and long distance of the pipe (with bends) is a cause for concern because riverine debris could easily be wedged inside the pipe. These conditions could cause physical injury to young salmonids passing through the pipe. Clogging of riverine debris in a fish bypass pipe at RBDD was found to cause physical injury to downstream migrant salmon (Vogel et al., 1988).

The fish facilities are operated pursuant to an agreement between WID and CDFG. The agreement between WID and CDFG is attached as Appendix A.

Water Velocities

After the riverine debris was removed from the fish bypass entrance on June 2, 1992, water velocity measurements were taken in the bypass entrance channel with the trashrack and plywood board in place and with the trashrack and plywood board removed. These data are given in Table 2. Only a slight increase in the mean velocity was evident following removal

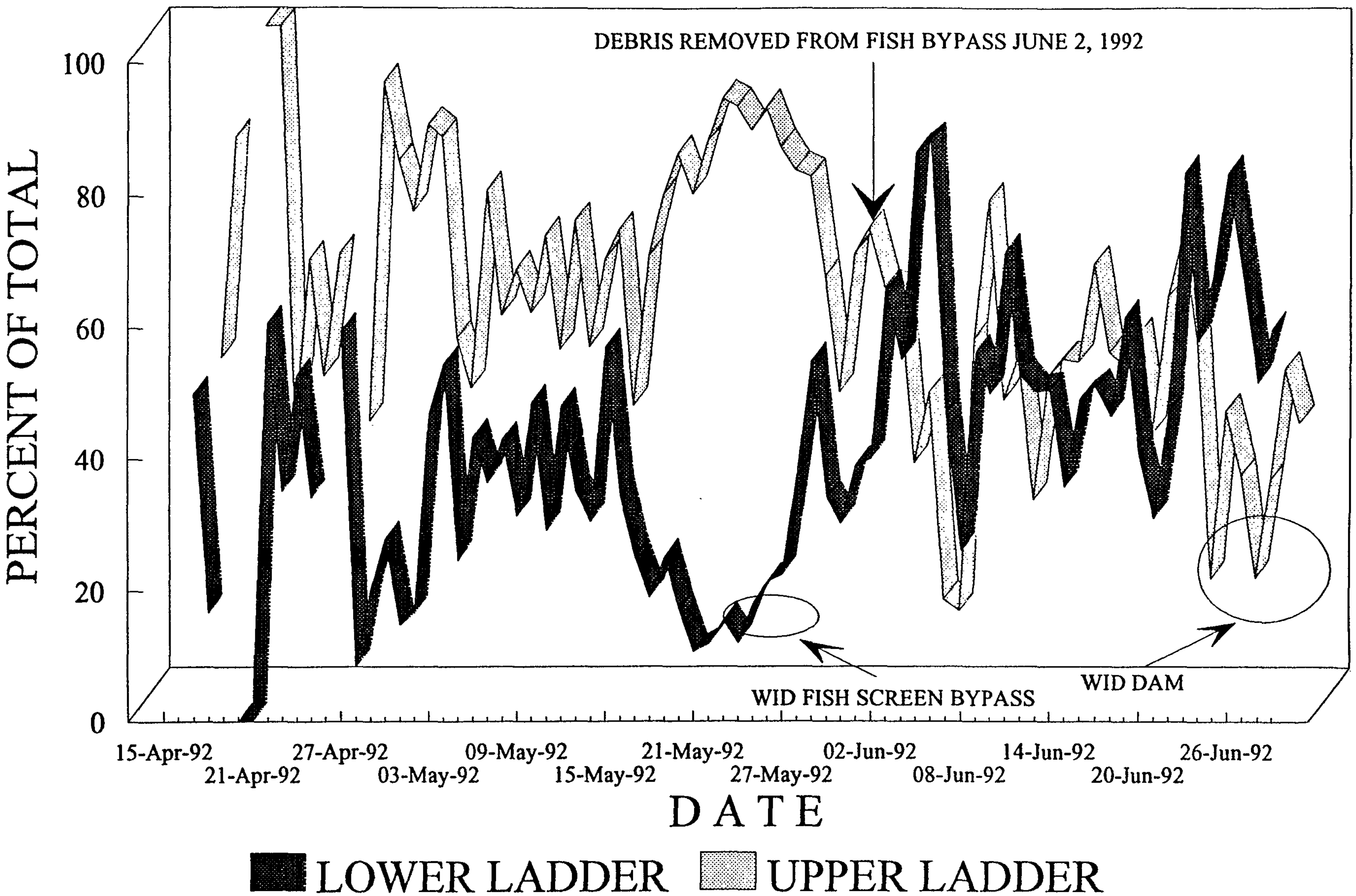

Figure 23. Proportion of downstream migrant salmon captured at Woodbridge Dam in the lower ladder (fish screen bypass) and the upper ladder, April 15 to June 26, 1992.

of the trashrack and plywood board. However, the data indicate that velocities in the bypass entrance are generally lower than those observed in front of the fish screens. Under higher WID diversions into the canal, this difference would be even more pronounced. Bates and Vinsonhaler (1957), as cited by Rainey (1985) found that fish response to flow deceleration was similar to that previously described for flow acceleration (i.e., the fish hold upstream of the point of deceleration). Either the flow acceleration through the narrow notch on the plywood board, the flow deceleration into the bypass from the downstream-most screen, or a combination of both, likely create undesirable conditions for fish. Fish holding in these areas are prone to predation. Higher diversion rates into the WID canal than that observed would further exacerbate the poor conditions for emigrating young salmonids.

Other Downstream Fish Passage Considerations at Lake Lodi

Lake Lodi Passage

The operation of Woodbridge Dam when WID canal is in operation results in a large backwater influence upstream in the Mokelumne River upstream of the dam which forms Lake Lodi (Figure 1). This lacustrine condition can create significant hazards to downstream migrating juvenile salmonids which are normally accustomed to a lotic environment. Creation of the impoundment significantly reduces the channel velocities and subsequent transport time for salmonids moving down the river channel, especially during low flow conditions. Lake Lodi creates ideal conditions for predatory fish (e.g., bass and squawfish) which may consume young salmonids. Predation losses in Lake Lodi could be severe but studies would have to be conducted to quantify those losses.

Woodbridge Dam Passage

High flow conditions resulting in spill over the Woodbridge Dam were not observed as part of this assessment. However, under those conditions, it is evident that physical injury could occur for young fish passing over the dam and into the riprap material placed downstream of the dam. Sufficiently deep plunge pools immediately downstream of the dam are not present to dissipate energy and protect fish from injury. It was not possible to quantify the level of mortality which might occur to fish under these conditions, but mortality could be high based on physical characteristics of the dam and river channel immediately downstream of the dam.

During low flow conditions, no flow over the flashboards on Woodbridge Dam occurs, but substantial leakage between the flashboards is evident. A surface inspection of the dam on June 2, 1992 revealed numerous leaks among the flashboards despite WID attempts to seal many of those leaks with plastic sheets. It was not possible to closely inspect the leaks, but some of the leaks appear to be large enough to entrain young salmonids. If salmonids are entrained through these leaks, they would be subjected to the risks of physical injury previously described for passage over the dam.

CONCLUSIONS

Upstream Fish Passage Facilities

There are numerous conditions associated with the fishways at Woodbridge Dam which likely impair fish passage at the dam. Many of these are described in CDFG (1991). Based on descriptions provided by CDFG (1991) and observations of conditions at the dam in relation to fishways employed elsewhere, it is evident that a wide variety of physical and operational constraints with the fishways likely reduce their performance and efficiency for fish passage. These include: poor fishway entrance configuration, attraction flow, internal design characteristics, the exit to the upper fishway, and insufficient O&M of the fishways.

Downstream Fish Passage Facilities

Based on observations and measurements made of the downstream fish passage facilities in Lake Lodi, there are numerous conditions for fish which likely reduce their survival. These include: numerous large gaps in the WID fish screen structure which can cause fish entrainment, inappropriately designed and modified fish screen structure which reduces or eliminates fish screen tangential flow, inadequate fish screen bypass, insufficient O&M of the fish screens, ideal predation conditions in Lake Lodi, and poor fish passage conditions at Woodbridge Dam which could cause physical injury to fish.

RECOMMENDATIONS

Upstream Fish Passage Facilities

Alter Fishway Entrance Configuration

Raise Woodbridge Dam Tailwater Elevation

Because the existing tailwater conditions of Woodbridge Dam during low flows result in low water surface elevations relative to the entrance to the fishway, the tailwater elevation could be raised to improve fishway entrance conditions. This measure could be accomplished by adding a hydraulic control downstream of the fishway in the river channel (e.g., large boulders). This hydraulic control would serve to raise the tailwater surface elevation higher than existing conditions and allow better fish access into the fishway because of the resultant deeper entrance conditions and the reduction or elimination of the requirement for fish to swim across the shallow riffle into the fishway entrance. This type of stream channel modification was implemented several years ago downstream of Clough Dam on Mill Creek[3]; the modification improved entrance conditions for salmon and steelhead into the dam's fishway. Careful

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[3] Mill Creek is a tributary to the Sacramento River which supports runs of spring and fall chinook salmon and steelhead.

consideration should be given as to the exact placement of the hydraulic control in the river channel to ensure the control, by itself, does not impede fish passage.

Add Additional Fishway Entrance Pool

An additional option for improving fishway entrance conditions may be the addition of a pool to the existing fishway to eliminate the shallow riffle over which fish have to traverse during low flows. The additional pool would allow for better entrance conditions through the creation of deeper water in closer proximity to the large riverine pool immediately downstream of Woodbridge Dam. As described for the benefits derived from raising the tailwater elevation, an additional pool would provide deeper water at the entrance and reduce or eliminate the need for fish to cross the shallow riffle at the fishway entrance. A hydraulic analysis prior to installation would be necessary to ensure the addition of a pool would not create worse fish passage conditions during high river flows.

Evaluate the Presence of Eddies Adjacent to the Existing Fishway Entrance under High Flow Conditions and Modify Entrance if Necessary to Eliminate Eddies

Because the existing fishway was only observed during low flow conditions at Woodbridge Dam, it was not possible to determine if eddys are present adjacent to the fishway entrance during high river flow conditions. If high flows create unusual hydraulic conditions at the fishway entrance (eg., reverse flows adjacent to the ladder), the fishway entrance could be relocated to avoid eddy formation. Alternatively, training wall(s) adjacent to the fishways could be added to eliminate eddies. This latter measure was implemented on the southwest fishway on Red Bluff Diversion Dam during the mid-1980s to eliminate a large eddy adjacent to the fishway entrance.

Provide Additional (Auxiliary) Attraction Flow into the Lower Portion of the Fishway

A common design feature of modern, large fishways is the provision of auxiliary water diffusers into the lower-most portions of the fishways to attract fish into the entrance. This is normally accomplished by adding the flow into enlarged pools near the base of the fishway to allow for sufficient energy dissipation (to avoid extreme turbulence and fish disorientation) and attract fish into and through the fishway. The water supply for additional attraction flow could be obtained from elimination of leaks in Woodbridge Dam (discussed in a following section). It may be necessary to enlarge the existing pools to accommodate the high flow and minimize turbulence.

Eliminate Denil Fishway

The existing Denil fishway on Woodbridge Dam does not appear to provide any additional benefits to fish passage and may actually create worse conditions for fish passage and therefore should be removed. The length, slope, and placement of the Denil fishway are sub-optimal. Fish attempting to use this fishway are subjected to a high degree of turbulence at the entrance and are likely disoriented. Substantial energy expenditure would be required for fish

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negotiating the fishway because of the fishway's slope and length; fallback though the fishway and physical injury probably occurs. Because debris can easily become wedged within this type of fishway, reduced performance of the fishway can occur. Debris can create undesirable conditions which may cause physical injury to fish passing through the fishway. Removal of the Denil fishway would also eliminate the high degree of turbulence in the common entrance pool for both the Denil and pool-and-weir fishway; this will allow for better hydraulic conditions for fish at the entrance to the pool-and-weir fishway.

Improve Operation and Maintenance of Fishways

All fishways require some degree of routine O&M to ensure the fishways are operating properly. Lack of routine O&M can result in reduced performance of the fishways when riverine debris becomes wedged within the fishway or hydraulic conditions are altered and impede fish passage. The Woodbridge Dam fishways should be inspected on a daily basis during the major migratory periods for salmon and steelhead migration to ensure good fish passage conditions.

Alter Spill Configuration over Woodbridge Dam

Under certain low flow and medium flow conditions, the spill configuration over Woodbridge Dam should be altered to concentrate flows to more favorable areas. The purpose of this measure would be to avoid attraction of fish into undesirable locations at the dam and reduce the likelihood of upstream migrating fish encountering the riprap material at the base of the dam. A hydraulic analysis would be necessary to determine how this measure could be accomplished.

Add Stilling Basin and Retaining Wall Downstream of Woodbridge Dam

Under medium and high flow conditions at Woodbridge Dam, the addition of a retaining wall and stilling basin immediately downstream of the dam would reduce physical injury to upstream migrating fish attracted to spills over the dam.

Downstream Fish Passage Facilities

Changes in Configuration of Fish Screen Support Structure

The pier noses added to the fish screen support structure since original construction should be eliminated as shown in Figure 24. This measure will improve conditions for young fish traversing the screens to the fish bypass system and eliminate fish entrapment zones. It will help improve tangential flow past the screens to the fish bypass system and thereby improve fish transport to the fish bypass. The purpose for this measure is to eliminate locations in front of the fish screens where young fish would have to swim upstream (i.e., against the current) to escape hazardous areas. Removal of the pier noses will help minimize fish exposure time to the screens and allow easier access by fish to the bypass system. Reduction in fish exposure time in front of the screens will help reduce the potential for predation, impingement, and entrainment.

Add Seals in the Bottom of the Fish Screen Keyway Slots

The gaps in the bottom of the screen keyway slots should be eliminated to avoid entrainment of fish into the WID canal. A permanent type of seal (e.g., hard rubber or brush) should be installed on the base of each side of the screen frame in advance of installation for the irrigation season. Alternatively, temporary seals could be installed once the screens are in place but prior to inundation; these seals would have to be replace each time the screen frame is lifted.

Improved Operation and Maintenance

The fish screens and fish screen bypass system should be inspected daily to ensure that the fish protective systems are properly functioning. Of particular importance is the assurance that the fish bypass entrance is free from riverine debris. If feasible, the entire fish bypass pipe should be inspected with remotely operated video to ensure the system is free from any debris or material which may constrict flow through the system and cause physical injury to fish passing through the pipe.

Changes in Configuration of Fish Bypass Entrance

The slotted plywood board over the fish bypass entrance should removed during periods when the bypass system is intended to function as designed. The constriction in flow and width of the entrance into the bypass system very likely impairs the effectiveness of the system.

The entrance to the entire fish bypass system should be open at the surface to improve ambient light penetration into the fish bypass entrance. This will allow for greater visual orientation for fish entering the system. This type of open-surface bypass entrance was designed and installed on the new Tehama-Colusa Canal fish screens.

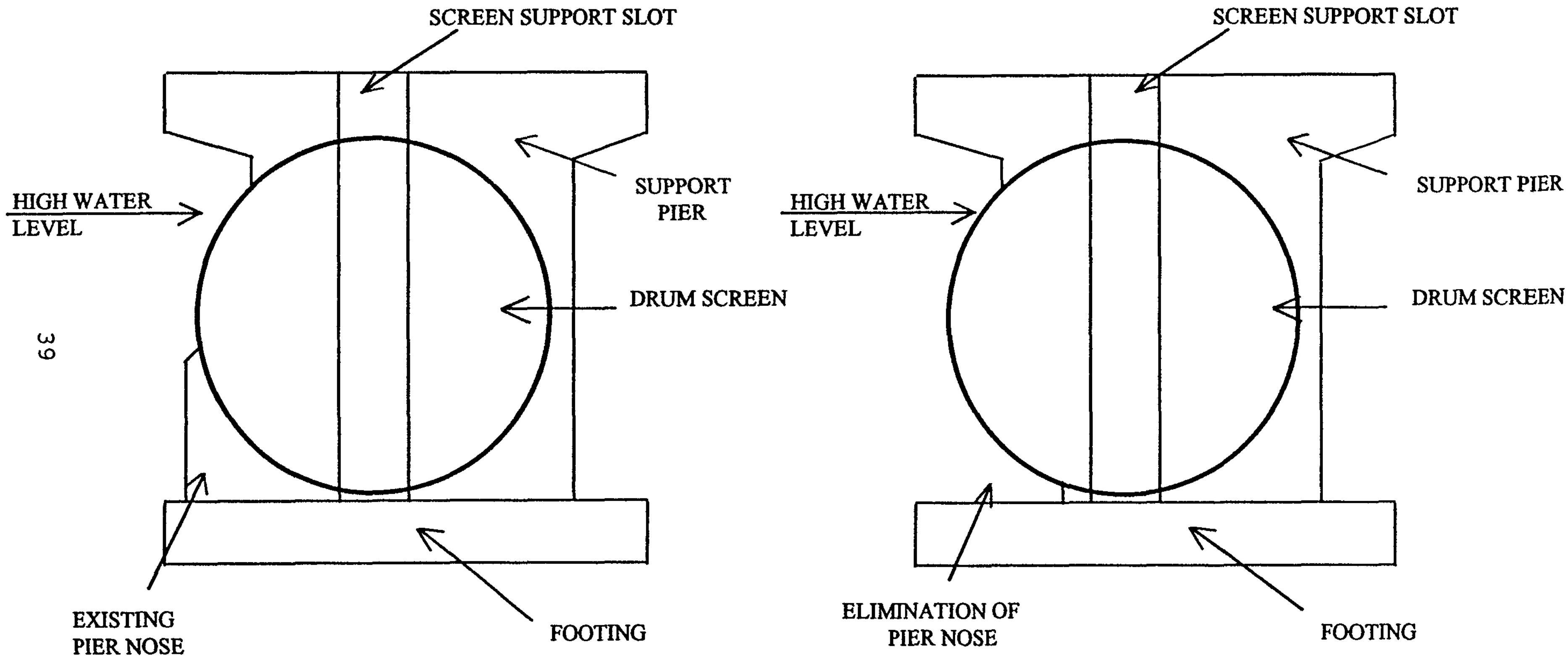

Figure 24. Cross-sectional profile of Woodbridge Irrigation District fish screen concrete support pier showing existing condition (left) and recommended modification to eliminate pier nose (right).

The configuration of the bypass entrance should be altered from a bottom water intake to a surface water intake. This will allow for more desirable entrance conditions by allowing downstream migrant fish to initially enter the system from the surface (where they are more naturally oriented through behavioral tendencies), rather than forcing an initial downward guidance of fish into the entrance.

Increase Fish Screen Bypass Flows

The feasibility of increasing the fish screen bypass flows should be evaluated and implemented if feasible. This measure would require the installation of an additional pipe to carry fish from the bypass entrance to the Woodbridge Dam fishways or the replacement of the existing pipe with a larger diameter pipe to accommodate more flow. This measure would increase tangential flow and tangential velocities along the face of the screens for fish transport and improve fish attraction into the bypass system. The additional flow required for this measure could be derived from the elimination of leaks in Woodbridge Dam (discussed in the following section).

Change in Flow Distribution over Woodbridge Dam

Leaks in the stoplogs on Woodbridge Dam should be eliminated to avoid fish entrainment into areas where physical injury may occur and to prevent fish attraction to undesirable locations where they may be preyed upon. Attraction to "false" routes past the dam could delay downstream migration and expose the young salmon to predatory fish in Lake Lodi as the salmon seek out a route past the dam. The leakage in the stoplogs on Woodbridge Dam currently accounts for approximately 12 cfs of the approximate 30 cfs that is passed downstream.[4] The water eliminated from leakage could be used for a larger fish bypass or an additional fish bypass. An improved bypass flow would replace the use of dam leakage as one of the sources of instream flow[4]; it would eliminate the potential problems of fish entrainment, physical injury, and attraction to undesirable locations at the dam.

During periods when flow over the dam does occur, the stoplogs on the dam should be adjusted to concentrate fish to the most desirable spill areas behind the dam to minimize physical injury in passing over the dam. In addition, their exposure to the extensive riprap downstream of the dam should be minimized. As assessment of the most desirable route for fish passage over the dam and past the riprap should be conducted and a determination should be made for the most feasible measures to concentrate fish to those locations. This measure would likely require altering the existing configuration of the base of the dam to ensure safe fish passage. For example, the installation of a stilling basin immediately behind the dam would help dissipate energy of spilled water and minimize physical injury to fish in passing over the dam.

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[4] Correspondence from WID to EBMUD dated September 2, 1992.

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