EXCLUSION AND SURVIVAL RATES OF EARLY LIFE STAGES OF FATHEAD MINNOWS RELEASED OVER INCLINED WEDGE-WIRE SCREENS

A final report submitted to:

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EXECUTIVE SUMMARY

Entrainment of fish into Fulton Ditch, an irrigation canal downstream of Metro Wastewater Reclamation District, may negatively affect species richness and productivity of the fish community of the South Platte River, CO. Laboratory tests were conducted to estimate exclusion and survival rates of different-sized fathead minnows *Pimephales promelas* exposed to four different configurations of an inclined wedge-wire fish screen. The goal of these tests was to determine an optimal screen configuration to reduce fish entrainment into Fulton Ditch.

Screen angle, screen slot width, and overflow rate varied among screen configurations. The first screen configuration was inclined 45° from horizontal (at the top edge of the screen), had 1 mm slot width, and a high (25%) overflow rate. The second configuration was identical to the first except had a low (10%) overflow rate. The third configuration was inclined 60° from horizontal, had a 1 mm slot width, and low overflow rate. The fourth configuration was identical to the third except it had a 0.5 mm slot width. Fathead minnows of five nominal sizes, 5.0, 7.5, 12.5, 22.5, and 45 mm total length (TL), were used as test animals. For each test configuration, fish were released at the top of the screen at both the surface and the bottom of the water column, swept over the screen by overflow water, and were captured in a fine-mesh net at the toe of the screen. Exclusion rate was the percentage of fish captured. Survival rate was the proportion of fish alive four days post screening, but was adjusted for handling and turbulence effects that we presumed would not occur outside of a laboratory setting. Adjustment was accomplished by release of additional batches of fish over the lower, taped portion of each screen configuration. Fish were recaptured in the same manner described above and thus, were subjected to the same turbulence and handling effects as fish that had passed over the screen. Survival rate of fish in those batches was used to adjust survival rate of screened fish using Abbott's correction.

Exclusion rate of fish 45 and 22.5 mm TL was 100% in a preliminary high release test of a 45°-screen, that had 1 mm slot width and low overflow rate. Post-screen mortality of 0 to 12% was not likely attributable to screen effects (Appendix II). Further tests with 45 and 22.5 mm TL fish were not conducted because of high exclusion and survival rates. Tests conducted with high overflow were also discontinued after a single preliminary trial because impingement mortality of recaptured fish was high.

Exclusion rates of fish 12.5 to 5 mm TL declined with size, and larger fish survived at higher rates than smaller ones, regardless of screen configuration. Ninety-six to one hundred percent of 12.5 mm TL fish were excluded and survival was 62 to 86% in all but one configuration. The comparatively low 15% survival rate of low release 12.5 mm TL fish with the 0.5 mm screen may be due to more frequent contact with closely-spaced screen wedge-wires, or to slightly smaller-sized fish used in that trial.

Seventy-six to ninety percent of fish 7.5 mm TL were excluded by 1 mm screens in high release treatments, but only 16 to 68% were excluded in low release treatments. Survival of fish 7.5 mm TL was moderate in high release treatments (26 to 57%) but low (0 to 9%) in all low release treatments. Eighty-eight percent of fish 5 mm TL were excluded by the 0.5 mm slot-width screen and about one-fourth of those fish survived. In high release trials, 1 mm screens excluded 48 to 68% of fish 5 mm TL. In low release trials, 1 mm slot-width screens excluded only 2 to 22% of fish 5 mm TL. Survival of fish 5 mm TL in trials with 1 mm screens was not assessed because most were dead after capture. Screen angle (45 or 60°) did not affect survival rates of fish of all sizes. Exclusion and survival rates were generally higher for the 0.5 mm screen or when fish were released at the surface.

Collectively, data suggested that the relatively large catostomid larvae (about 12 mm TL) that occur in the South Platte River, would be effectively excluded and survive at relatively high rates if a 1 mm slot-width screen were installed. To maximize exclusion and survival of recently hatched larvae of common cyprinids (e.g., 5 to 6 mm TL) in the South Platte River, a screen with 0.5 mm slot width is recommended. A simulation model that incorporates reproductive phenology of ecologically important South Platte River fishes, and entrainment rates of fish into Fulton Ditch over a variety of flow regimes, may aid in determining need and type of screen most beneficial to the fish community. Such an analysis may also aid evaluation of benefits of screening relative to other activities which may enhance the fish community of the South Platte River.

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INTRODUCTION

The ubiquitous presence of water diversion structures in streams of the arid western United States suggests that fish entrainment could substantially alter fish community structure and abundance. Metro Wastewater Reclamation District (Metro), near Denver, Colorado, has identified the diversion works of Fulton Ditch as a potential source of mortality for South Platte River fishes. Field sampling suggested that fish entrainment from the South Platte River was a major factor responsible for the relatively species rich and abundant fish community in seasonally dry Fulton Ditch (Bestgen et al. 1999). An entrainment study conducted using marked white sucker *Catostomus commersoni* larvae released into the South Platte River, suggested that loss to Fulton Ditch was approximately equal to the proportion of the river flow diverted (Bestgen et al. 1999). Thus, entrainment loss of fish into Fulton Ditch is potentially high because over half of the South Platte River may be diverted during the summer base flow period. These findings prompted Metro to investigate installation of a high-velocity inclined wedge-wire screen to reduce fish entrainment into Fulton Ditch.

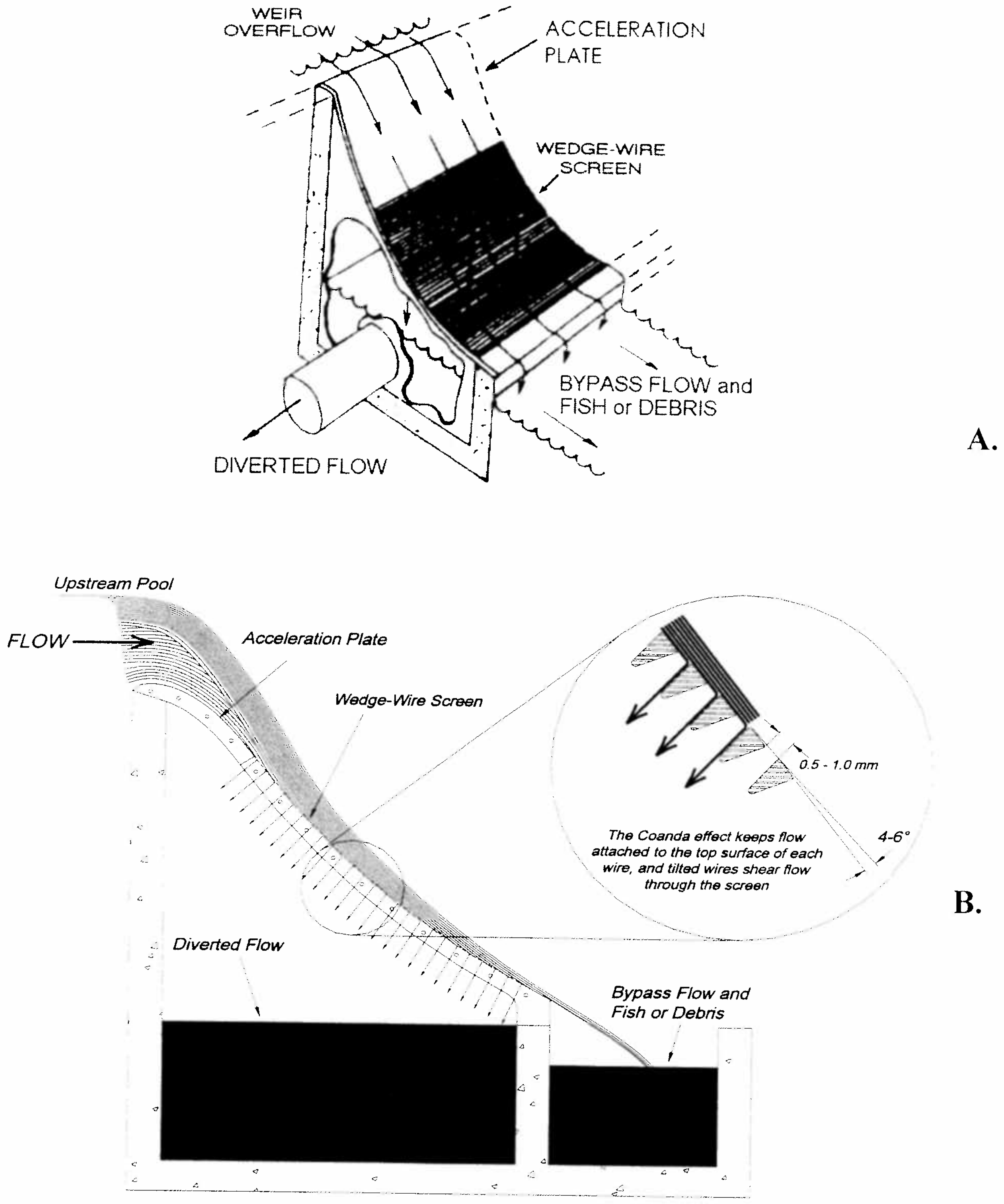
Screens are one of the few proven alternatives available to reduce entrainment of fishes into water diversion structures such as Fulton Ditch. Traditional screens are typically placed at an angle, and function as a partial physical barrier, to stream flow. Flow rate through the screen is relatively low and water is approximately the same depth on upstream and downstream sides. Optimal designs allow fish to maintain a safe swimming distance upstream of the screen mesh as they are swept downstream past the screen and conveyed back to the stream. The approaching flow vector is made up of two components usually described as the approach velocity (component perpendicular to the screen face) and the sweeping velocity (component parallel to the screen face). The magnitude of the approach velocity component must be low enough to permit the desired life stage of fish to swim upstream to avoid physical contact with the screen and impingement against it. The sweeping velocity is usually 1 to 2 times the approach velocity, so fish are quickly swept along the parallel face of the screen. Typical exposure times are on the order of tens of seconds to several minutes. Potential hazards that fish encounter with traditional screens include momentary physical contact, exhaustion as fish swim to avoid impingement, impingement against the screen, encounters with collected debris and debris cleaning equipment, passage through the screen, predation upstream of the screen, and delayed passage when fish remain in front of the screen.

When traditional screen designs are considered, cost increases rapidly as the size of the fish to be protected decreases. This is due to several factors including:

- small mesh sizes required for small-bodied fish,
- low approach velocities needed for relatively weak-swimming fish, which necessitates larger screen areas and larger conveyance channels, and
- need for mechanical cleaning devices which may damage fragile fish early life stages.

A relatively new technology for screening fish and debris from diverted water is the inclined horizontal wedge-wire screen (Fig. 1), also known as the static inclined screen, sieve bend, or Coanda-effect screen (Wahl 2001). This screen differs from traditional barrier-type configurations because water flows at high velocity over the top of an inclined surface. Filtered water falls through the screen into a conveyance channel and is diverted. The remainder of water passing over the screen (overflow), and the fish and debris that do not pass through the screen, are discharged back to the stream. The high overflow velocity across the screen surface (about 2 to 5 m/s) aids in self-cleaning.

An advantage of an inclined screen over more traditional designs is that fish usually pass the screen in less than one second. Some physical contact with the screen is expected, but impingement is prevented by high velocity flow across the screen. Screen slot openings are typically 1 mm or less, while the width of the screen wires is 1.5 mm or greater, producing a screen whose top surface is relatively smooth. Thus, fish swimming ability is not a design consideration, since fish are simply carried by the flow over the screen. Presumed hazards to fish as they encounter this type of screen include passage through the screen slots, physical contact with the screen, stranding on the toe screen due to inadequate overflow rates, delayed passage if fish remain in the reservoir upstream from the screen, predation in the holding area upstream from the screen, and disorientation and predation in the bypass area after fish exit the screen.



Typical Configuration of a Coanda-Effect Screen

Figure 1. Main features and operation of a typical inclined wedge-wire screen (panel A). Side view (Panel B) depicts detail of wedge-wire position, arrangement, and function.

Inclined wedge-wire screens were identified as the most suitable for the Fulton Ditch site because of presumed self-cleaning characteristics, lack of moving parts, and resulting low maintenance. Since such screens are relatively new, a series of biological and hydraulic tests was carried out to evaluate their potential effectiveness and to develop design data for application at Fulton Ditch. Results of the hydraulic tests are provided in Wahl (2000 and 2001).

Although limited information is available regarding effects of wedge-wire screens on survival of relatively large-bodied salmonids (Buell 1996), little is known about the capability of inclined wedge-wire screens to exclude fish early life stages. Early life stages < 15 mm TL are typical for larvae in the South Platte River, a system dominated by warmwater cypriniforms (Propst and Carlson 1986). Here, we report results of experiments to assess exclusion and survival rates of fish using inclined wedge-wire screens with 0.5 mm and 1.0 mm slot widths.

METHODS

Screen and sampling descriptions.–Inclined wedge-wire screens have a concave or flat surface and are typically angled downward 45-60 degrees from horizontal (Fig. 1). Water passes over and down an accelerator plate and then across the screen. Screen construction is with a series of parallel, closely-spaced horizontal wedge-wires. Individual wedge-wires are canted at about a 5° angle downstream so that a microlayer of water is sheared from the overlying water column, adheres to the wire (Coanda effect), and passes through the screen. Most water is diverted, while a relatively small amount of overflow water transports debris, fish, and other particles over the top of the screen and into a conveyance canal. These screens have a high filtration capacity that increases with the rate of water passage. At a moderate overflow rate of 20%, a 0.61 m-long screen with a 45° incline filtered 0.059 m^3/s of water per 0.3 m-wide section of screen (Wahl 2000). We hypothesized that overflow rate, screen angle, screen slot width, and fish length may affect exclusion rates and survival of fish. Therefore, we tested four basic screen and flow configurations. The first configuration was angled at 45° from horizontal, had 1 mm slot width, and a high (25%) overflow rate, the second configuration was identical to the first except had a 10% overflow rate, the third configuration was angled at 60° from horizontal and had a 1 mm slot width (10% overflow), and the fourth was identical to the third except had a 0.5 mm slot width.

Fathead minnows *Pimephales promelas* were used as test animals because they are native to the South Platte River system and are readily available from a local commercial supplier. Fish introduced into the model were swept over the screen and captured in a frame-mounted handheld drift net placed at the toe of the screen. Net mouth dimensions were 10 x 61 cm, bag depth was 90 cm, and mesh size was 363 µm. Net width was equal to that of the screen sideboards to prevent fish from passing by the net.

Experimental treatments.-- Flume and screen models constructed by personnel of the U.S. Bureau of Reclamation's Water Resources Research Laboratory (WRRL), Denver, CO, were used for fish screen tests. Initially we used five nominal sizes of fish, 5.0, 7.5, 12.5, 22.5, and 45 mm total length (TL). This length range was chosen to represent the size range of fish that might be entrained into Fulton Ditch. A typical test for a single screen configuration and each nominal fish size involved up to five different treatment groups because we wanted to partition potential sources of mortality. Batches of fish, 10 each except for a few early tests in which 20 fish were used, were double-counted for accuracy and held in plastic cups. The first test group consisted of randomly selected cups of control fish (3 replicates), which were placed in individual bags with oxygen but experienced no net or screen effects. In the second test group, we estimated rate of net recovery and handling mortality by recovering batches of 10 fish (3 replicates) that were poured into the capture net. Fish were carefully washed out of the cod-end of the net into a plastic pan, counted, and bagged as previously described. The goal of net recovery tests was to determine a suitable correction factor if net recovery deviated substantially (> 5%) from 100% and to estimate mortality rates due to handling during capture.

The third test group (tape treatment) was used to estimate mortality caused by capturing and possibly impinging the fish against the net as high velocity flow entered the net at the toe of the screen. In each configuration, the lower portion of the screen was covered with a smooth layer of duct tape to reduce the functional screen surface area for hydraulic tests. Batches of 10 fish each (5 replicates) were introduced over the tape, washed into the capture net by screen overflow, and held in the current for an amount of time (3 seconds) identical to that in screen release tests (below). Recovered fish were enumerated and treated as described above. Thus, tape-treatment fish were handled identically to screen fish test groups (below) except they were not exposed to the screen. Fish in the final two groups were introduced at the top of the overflow weir accelerator plate, one at the surface of the water column (5 replicates, high release) and one (5 replicates, low release) at the bottom of the water column. Fish were swept over the length of the screen and captured at the toe as described for tape trial fish. High release fish were introduced above the accelerator plate by simply pouring them from a cup. Low release fish were introduced directly over the accelerator plate by first placing the batch of fish into a stoppered length of clear flexible plastic tubing (12.7 mm diameter) attached to a steel rod. The stoppered end of the tubing was positioned at the bottom of the water column over the accelerator plate and when the net was in position, the stopper was pulled from the tube by a cord and fish were released. Data from high and low releases were used to determine differences in exclusion and survival rates of fish that approach the overflow weir at different depths. Fish were transported to the Aquatic Research Laboratory in Fort Collins, CO, in coolers, and held in 2 l overflow tanks supplied with well water at 18°C. Fish mortality was monitored daily for four days post-testing and brine shrimp *Artemia sp.* nauplii was offered ad libitum twice per day.

Data analysis.–Percent of fish excluded by the screen and percent of fish surviving releases were the primary response variables used in analyses. Fish that were not excluded by the screen (i.e., passed through) were considered mortalities because fish lost through the screen in a natural setting would be lost to the system. We adjusted mortality rates of fish in high and low releases by a portion of the mortality rate observed in the tape treatment to offset handling and turbulence effects. Abbott's correction was used as follows:

$$p_c = (p - p_o)/(1 - p_o)$$

where p_c, p, and p_o are the corrected, original, and tape treatment mortality proportions, respectively (Newman 1995). Percent of fish excluded and percent surviving $(1 - p_c)$ were compared to determine effects of two overflow rates, two screen slot widths, and two different screen angles. Average exclusion and survival rates and their 95% confidence intervals were also computed. Comparisons among screens were by a general linear model (PROC GLM SAS Institute 1988), with actual fish TL (average for the batch) used as a continuous covariate.

RESULTS

Exploratory tests with the 45°, 1 mm slot-width screen at low overflow rate showed that 100% of fish 45 and 22.5 mm TL were excluded (Appendix I). Survival of 45 mm TL fish was 88% but mortality was likely due to poor condition of fish and a secondary infection contracted prior to tests. Survival rate of 22.5 mm TL fish was 100%.

An additional 263 different batches of fish were allocated among control, net recovery, tape, and high and low release trials. Data for the 45°, 1 mm screen with high overflow was summarized but not analyzed further due to extreme turbulence and current velocity which caused high impingement mortality of fish in the capture net. Potential implications of high screen overflow rates in a natural setting are discussed later.

12.5 mm TL fish.--Tests conducted with fish 12.5 mm TL (actual mean TL = 11.9; 95% CI, 11.5 to 12.3) showed that 96 to 100% of fish were excluded by all screen configurations and no statistically significant differences were detected among exclusion rates for high (F = 1.0, df = 2, 12, p = 0.40) or low (F = 2.67, df = 2, 12, p = 0.11) release treatments (Fig. 2). Likewise, no significant differences were detected among exclusion rates for high and low release treatments when trials were pooled across screen types (F = 0.35, df = 1, 28, p = 0.56).

Average survival rate of 12.5 mm TL fish in high release tests was 86% with the 45° screen and 62 and 66% in tests with the 60° screens with 1.0 and 0.5 mm slot widths, respectively; GLM analysis did not detect statistically significant differences among those survival rates (F = 2.42, df = 2, 11, p = 0.14). Average survival rates of fish in low release treatments with 45° and 60° screens (1 mm slot width) were relatively high and similar at 62 and 71 %, respectively. However, survival rate of fish in the 60° 0.5 mm-slot-width test was significantly lower at 15% (GLM analysis, F = 14.4, df = 2, 12, p = 0.0006). The 71% survival rate of fish in high release treatments was significantly higher than the 48% rate observed in low release treatments, when trials were pooled across screens (F = 5.41, df = 1, 27, p = 0.03). The fish size covariate was a statistically non-significant effect in analyses with all sizes of fish.

7.5 mm TL fish.--Tests conducted with fish 7.5 mm TL (actual mean TL = 6.9; 95% CI, 6.6 to 7.1) showed that most were excluded by the three screen types in high release treatments (Fig. 3). The GLM detected a significantly lower exclusion rate (76%) for the 60° 1 mm screen

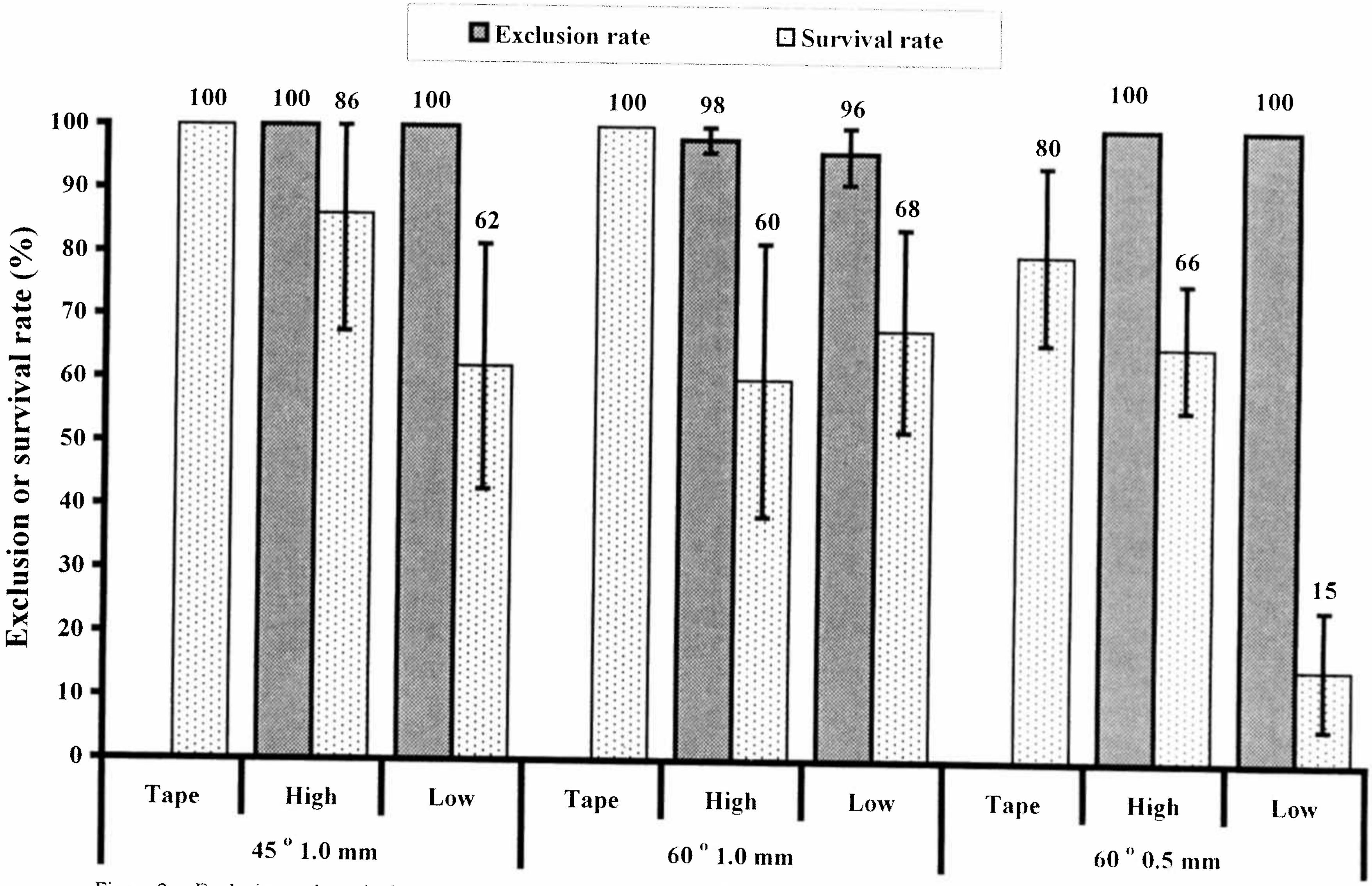


Figure 2.-- Exclusion and survival rates of fathead minnows12.5 mm TL in tape, high, and low release treatments in three configurations of an inclined horizontal wedge-wire fish screen. Tape release survival rates were used to adjust high and low release treatment survival rates (presented) for handling and turbulence mortality. Screens were inclined either 45 or 60°, had 0.5 or 1.0 mm slot widths, and low (10 %) overflow rates.

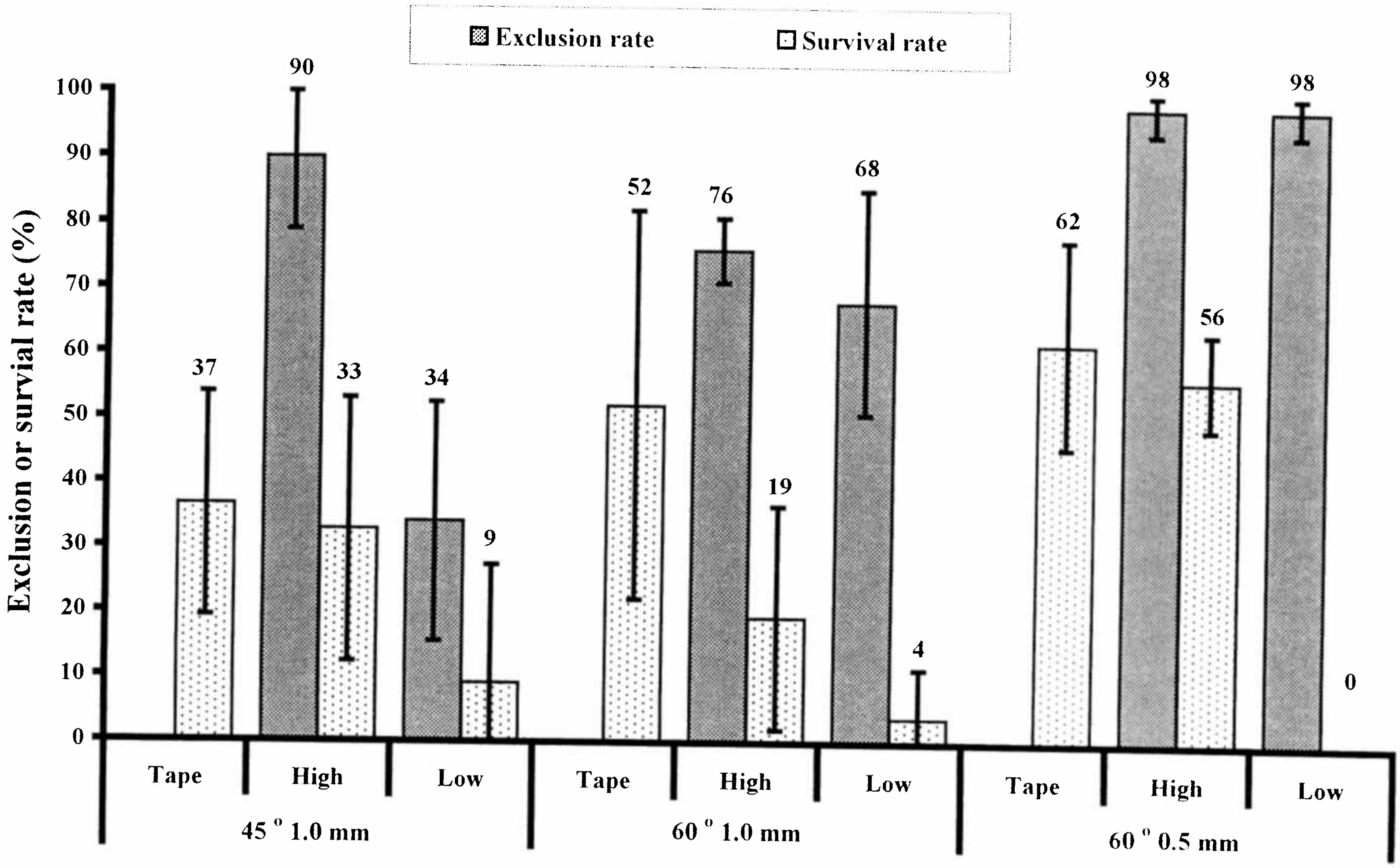


Figure 3.-- Exclusion and survival rates of fathead minnows 7.5 mm TL in tape, high, and low release treatments in three configurations of an inclined horizontal wedge-wire fish screen. Tape release survival rates were used to adjust high and low release treatment survival rates (presented) for handling and turbulence mortality. Screens were inclined either 45 or 60°, had 0.5 or 1.0 mm slot widths, and low (10 %) overflow rates.

(F = 9.3, df = 2, 12, p = 0.004) compared to the exclusion rate for the other two screens (90 and 98%). Average exclusion rate of fish in low release tests was relatively low (34%) for the 45° 1 mm screen, intermediate (68%) for the 60° 1 mm screen, and highest (98%) for the 60° screen with 0.5 mm slot width; each rate was statistically significantly different from each other (F = 18.8, df = 2, 12, p = 0.0002). Exclusion rates were significantly greater (88%) in high than in low (67%) releases when trials were pooled across screen types (F = 6.14, df = 1, 28, p = 0.02).

Survival rate of fish in high release tests was similar and relatively low for 45 and 60° screens with 1 mm slot width (36 and 26%, respectively), but higher (57%) for the 60° 0.5 mm slot width screen (F = 3.13, df = 2, 12, p = 0.08). Average survival rate of fish in low release treatments for the three screen types was low at 0 to 9% and no significant differences were detected among those rates (F = 0.62, df = 2, 12, p = 0.56). Survival of fish in high release treatments was 40% and significantly higher than the 4% survival rate observed in low release treatments when trials were pooled across screens (F = 26.9, df = 1, 28, $p < 0.0001$).

5 mm TL fish.--Fathead minnows in the nominal 5 mm TL group (actual mean TL = 5.9; 95% CI, 5.8 to 6.0 mm) were excluded at relatively higher rates in all high release treatments and in low releases in the 60° 0.5 mm slot width screen compared to fish in low release treatments with 1 mm slot width screens (Fig. 4). Exclusion rates in high release treatments averaged 95% for the 0.5 mm screen, but were significantly lower and similar at 56 and 68% for tests conducted with 1 mm screens inclined 45° and 60°, respectively (F =16.2, df = 2, 17, $p < 0.0001$). Similar to high release tests, average exclusion rates for 5 mm TL fish in low release tests were high at 88% for the 0.5 mm screen, but significantly lower at 2 and 22% for fish in tests with 1 mm screens inclined at 45 and 60°, respectively (F =119.8, df = 2, 17, $p < 0.0001$). Exclusion rates were significantly higher (79%) in high than in low (50%) releases when trials were pooled across screen types (F = 7.55, df = 1, 38, p = 0.009). Survival rate of fish 5 mm TL in 0.5 mm screen trials averaged 28%, which was the only survival data collected for fish of that size.

Post-screening mortality patterns were consistent across trials and fish sizes. Most fish succumbed to presumptive effects of screening within 1-2 d after tests were conducted. Although the cause of mortality was not evident in all trials, mortalities in low release treatments sometimes had missing eyes, disrupted abdominal regions, or craniums that were distended or broken.

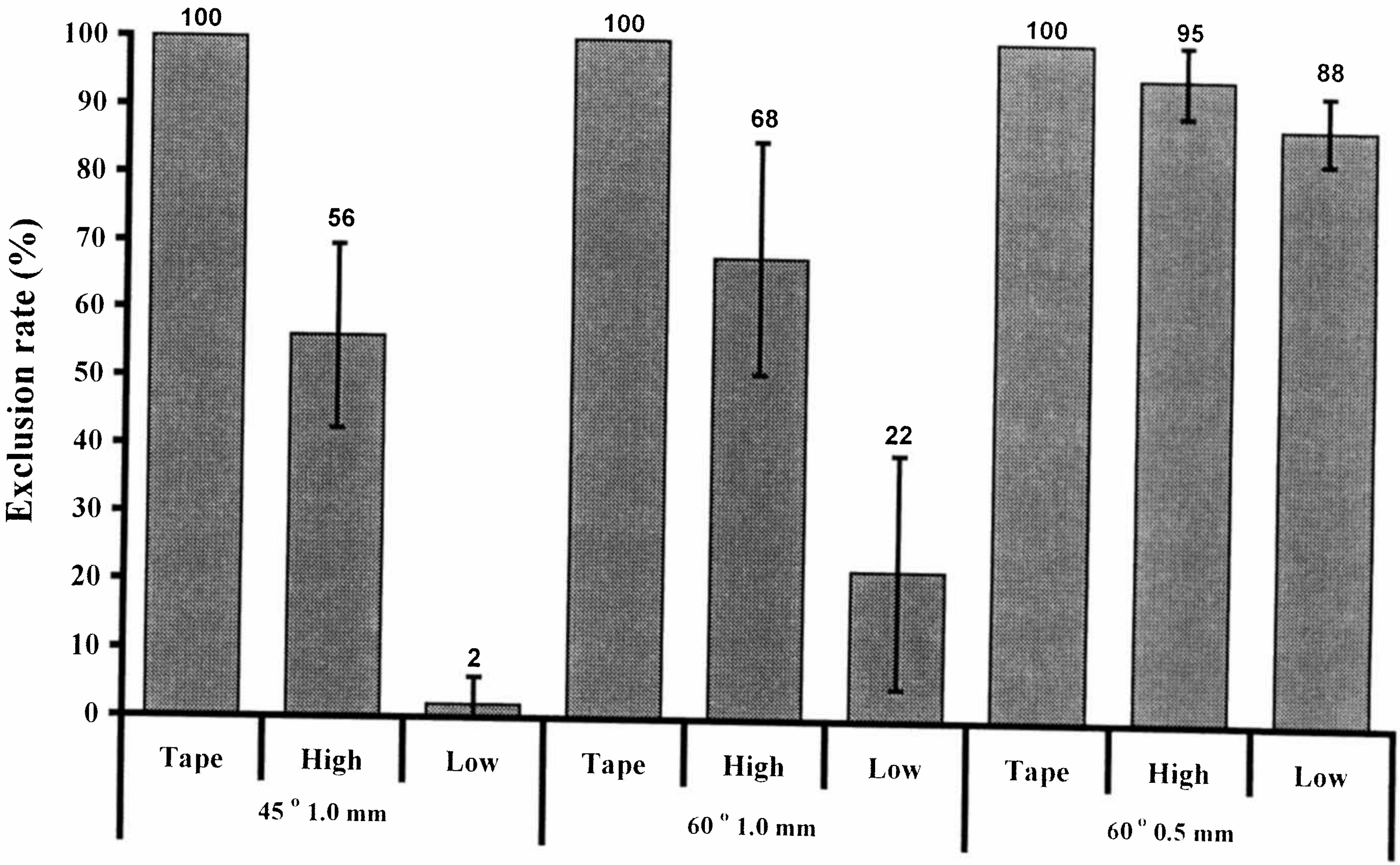


Figure 4.-- Exclusion rates (%) of fathead minnows 5.0 mm TL in tape, high, and low release treatments in three configurations of an inclined horizontal wedge-wire fish screen. Screens were inclined either 45 or 60 °, had 0.5 or 1.0 mm slot widths, and low (10%) overflow rates.

DISCUSSION

Fathead minnows in 22.5 mm TL and 45 mm TL size-classes were effectively screened by the inclined wedge-wire screen. Fish in the 12.5 mm TL size class were nearly completely excluded and generally survived at relatively high rates of 60 to 86%. The relatively low survival of low release, 12.5 mm TL fish in trials with the 60° 0.5 mm screen may be due to more frequent contact with more closely-spaced screen wedge-wires or their slightly smaller size (average TL = 10.7 mm) compared to fish used in other screen configuration trials (average TL = 12.2 mm). Collectively, these data suggested that the relatively large catostomid larvae (about 12 mm TL) that occur in the South Platte River would be effectively excluded and survive at relatively high rates if a 1 mm screen were installed.

Fish 7.5 mm TL in high release treatments were excluded at a relatively high rate but fewer were excluded in 1 mm screens in low release treatments. Survival of those fish was moderate in high release treatments but declined in all low release treatments. The 5 mm TL fish were best excluded by the 0.5 mm screen and about one-fourth of those fish survived. Fish were excluded at moderate rates by 1 mm screens, but survival was not assessed because most were dead after capture. Thus, to maximize exclusion and survival of recently hatched cyprinid larvae (e.g., 5 to 6 mm TL) in the South Platte River, a screen with 0.5 mm slot width is recommended.

Exclusion rates of fish by the 60° screens were higher than those for 45° screens, especially when the high overflow rate data was included (Appendix I). However, fish survival rates were not consistently higher for screens inclined at either angle. Effects of different overflow rates were confounded by high net impingement mortality in high overflow tests. In a natural setting, survival rates of fish subjected to high screen overflow rates should be comparable to fish subjected to lower overflow rates, as long as fish are not exposed to excessive turbulence or physical abrasion upon entering the receiving water.

Stream fish community structure is affected by a host of natural and human-caused factors, but relative importance of each is often difficult to ascertain, especially in highly modified systems. A better understanding of factors that affect stream fish community structure may assist both the agencies responsible for enforcing water quality standards and the entities that they regulate to prioritize and implement the most urgent remediation activities for the South

Platte River. Additional information should be gathered prior to modifying the Fulton Ditch headworks to determine relative benefits of screen installation for South Platte River fishes compared to a no-screen alternative. Such an analysis could be accomplished with simple model simulations and would require determination of reproductive phenology of fish species of interest over a variety of seasonally variable flows in a variety of water years. This would allow prediction of the percentage of entrained fish actually saved by installation of the screen types tested in this study.

Criteria for selection of a particular screen type should also consider the species and life history stage (length) targeted for exclusion. For example, a screen with 1 mm slot width may optimize survival of relatively large catostomid larvae in the South Platte River, but a screen with a smaller 0.5 mm slot width may optimize survival of smaller cyprinids. Screen selection criteria should also consider the hydraulic capacity and self-cleaning capability of each screen (Wahl 2000). Entrainment rate data for a simulation model study are already available from a previous South Platte River study at Fulton Ditch (Bestgen et al. 1999). Other necessary information should be available from the general fishery literature. Once that assessment is completed, relative merits and costs of a fish screen could be weighed against other management actions which may also improve health of the fish community in the South Platte River.

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LITERATURE CITED

Bestgen, K. R., K. A. Zelasko, and J. M. Bundy. 1999. Entrainment of fishes from the South Platte River into Fulton Ditch, 1998. Unpublished final report to Metro Wastewater Reclamation District, Denver, Colorado. Larval Fish Laboratory Contribution 108. Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, Colorado.

Buell, J. W. 1996. Biological performance and evaluation of an overflow weir profile bar fish screen for East Fork Irrigation District. Unpublished report by Buell and Associates, Inc. Portland, Oregon.

Newman, M. C. 1995. Quantitative methods in aquatic ecotoxicology. Advances in trace substances research series. Lewis Publishers, CRC Press. 426 pp.

Propst, D.L., and C.A. Carlson. 1986. The distribution and status of warmwater fishes in the Platte River drainage, Colorado. Southwestern Naturalist 31:149-168.

SAS Institute, Inc. 1988. SAS/STAT Users Guide, Release 6.03 Edition. Cary, North Carolina. 1028 pp.

Wahl, T. L. 2000. Hydraulic tests of proposed Coanda-effect screens for Fulton Ditch: Phase I test results. Unpublished final report to Metro Wastewater Reclamation District, Denver, Colorado. U. S. Bureau of Reclamation, Water Resources Research Laboratory Group, Denver, CO.

Wahl, T. L. 2001. Hydraulic performance of Coanda-effect screens. Journal of Hydraulic Engineering 127 (6):480-488.

Appendix I. Capture (Tape) or exclusion rates (%) of fathead minnows released over inclined horizontal wedge-wire screens. The 95% confidence limits and sample size for each mean are in parentheses.

			Fish TL			
		5.0	7.5	12.5	22.5	45
Screen Configuration	**Test/ Trial**	Mean (CI, N)	Mean (CI, N)	Mean (CI, N)	Mean (CI, N)	Mean (CI, N)
45 ° 1.0 mm low flow	**Tape**	N/A	98 (96 - 100. 5)	100 5	100 5	100 5
	Hi	56 (42 - 70. 5)	90 (83 - 97, 5)	100 5	100 5	100 5
	Low	2 (0 - 4, 5)	34 (16 - 53, 5)	100 5		
45 ° 1.0 mm high flow	**Tape**	N/A	100 5	100 5		
	Hi	48 (13 - 84, 5)	76 (71 - 80, 5)	100 5		
	Low	2 (0 - 4, 5)	16 (12 - 20, 5)	98 (96 - 100, 5)		
60 ° 1.0 mm low flow	**Tape**	N/A	100 5	100 5		
	Hi	68 (51 - 85, 5)	76 (71 - 81, 5)	98 (96 - 100, 5)		
	Low	22 (5 - 39, 5)	68 (51 - 85, 5)	96 (91 - 100, 5)		
60 ° 0.5 mm low flow	**Tape**	100 5	100 5	100 5		
	Hi	95 (90 - 100, 10)	98 (96 - 100, 5)	100 5		
	Low	88 (83 - 93,10)	98 (96 - 100, 5)	100 5		

Appendix II. Survival rates (%) of fathead minnows released over inclined horizontal wedge-wire screens. The 95% confidence limits and sample size for each mean are in parentheses.

		Fish TL				
Screen Configuration	Test/Trial	5.0 Mean (CI, N)	7.5 Mean (CI, N)	12.5 Mean (CI, N)	22.5 Mean (CI, N)	45 Mean (CI, N)
45 ° 1.0 mm low flow	**Control**	N/A	83 (66 - 100, 3)	100 3		
	Net recovery	N/A	60 (43 - 77, 5)	97 (90 - 100, 3)	100 3	100 3
	Tape	N/A	37 (19 - 54, 5)	100 5	100 5	78 (59 - 97, 5)
	Hi	N/A	13 (6 - 20, 5)	86 (68 - 100, 5)	100 5	88 (76 - 100, 5)
	Low	N/A	3 (0 - 10, 5)	62 (43 - 81, 5)		
45 ° 1.0 mm high flow	**Control**	N/A	97 (90 - 100, 3)	100 3		
	Net recovery	N/A	40 (30 - 50, 3)	90 (79 - 100, 3)		
	Tape	N/A	2 (0 - 4, 5)	56 (38 - 75, 5)		
	Hi	N/A	0 5	20 (3 - 37, 5)		
	Low	N/A	0 5	2 (0 - 4, 5)		
60 ° 1.0 mm low flow	**Control**	N/A	97 (90 - 100, 3)	100 3		
	Net recovery	N/A	60 (37 - 83, 3)	93 (78 - 100, 3)		
	Tape	N/A	52 (22 - 82, 5)	100 5		
	Hi	N/A	14 (2 - 26, 5)	62 (40 - 84, 4)		
	Low	N/A	2 (0 - 7, 5)	71 (54 - 88, 5)		
60 ° 0.5 mm low flow	**Control**	N/A	93 (79 - 100, 3)			
	Net recovery	47 (29 - 64, 3)	87 (73 - 100, 3)	87 (80 - 93, 3)		
	Tape	56 (48 - 64, 5)	62 (46 - 78, 5)	80 (66 - 94, 5)		
	Hi	16 (0 - 35, 5)	35 (31 - 39, 5)	53 (44 - 61, 5)		
	Low	0 5	0 5	12 (5 - 20, 5)		