MODIFICATIONS OF A TURBULENT FOUNTAIN FOR USE AS A FISH SCREEN IN SMALL HIGH-GRADIENT STREAMS

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ABSTRACT

We tested the efficacy of a modified turbulent fountain for its ability to screen fish from an irrigation diversion in McCabe Creek, Montana. We released westslope cutthroat trout (Onchorynchus clarki lewisi) into the intake of a prototype fountain in order to field-test screening capability and impingement rates. We then corrected observed flaws in the screen and repeated the test to compare efficacy of the prototype to the modified, more "fish-friendly" design. Fish lengths were similar between the two tests. Following modification of the prototype screen, the number of impinged fish declined from 37 to 6 percent. The duration of impingement declined by 93 percent, from a median of 30 to 2 sec. This evaluation indicated that turbulent fountain screens, when designed and constructed with proper fisheries considerations, can be effective at screening fish and providing a low-maintenance, more practical alternative to traditional fish irrigation screening devices on small streams.

Key Words: fish screen, impingement, irrigation diversion, native fish recovery, turbulent fountain

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INTRODUCTION

Populations of many native fishes in the western United States have declined in part because of entrainment in irrigation ditches (Schill 1984, Fleming et al. 1987, Der Hovanisian and Megargle 1998). In the Blackfoot drainage of Montana, unscreened irrigation ditches are common within the range of bull trout (*Salvelinus confluentus*), which is *threatened* (63 FR 31647) under the ESA (USDI Fish and Wildlife Service 2002), and westslope cutthroat trout (*Onchorynchus clarki lewisi)* a *species of special concern* in Montana (Pierce et al. 2002a). Blackfoot tributary assessments have identified irrigation ditches on 47 of 89 inventoried streams (Montana Fish, Wildlife and Parks files). As a tool to assist recovery of native fish populations, resource agencies, conservation groups, and irrigators are screening irrigation diversions to minimize population losses due to ditch entrainment. Screening irrigation ditches in the Blackfoot River drainage has contributed to increased fish densities in tributary populations as well as the overall densities of imperiled native fish in the Blackfoot River (Pierce et al. 2002b).

Although some states require irrigators to screen ditches, Montana relies on voluntary compliance. For voluntary screening programs to be effective, fish screening devices must meet fish screening objectives and provide adequate water supply for agricultural needs, operate effectively with little or no maintenance, and must be cost effective (Black 1998, personal observation). Although there are many options for screening irrigation ditches (Odeh 1999, Nordlum 1996), barrier screens are often expensive and require higher maintenance than many irrigators are willing to accept (Mefford and Kubitschek 1997, Fleming et al. 1987, Black 1998; personal observation).

Here, we discuss potential for a turbulent fountain, originally designed as a self-cleaning trash remover (Bondurant 1983) and then modified as an effective fish screen. A turbulent fountain screen consists of a circular, horizontal screen with a vertical riser pipe in the center. Water flows up through the center pipe and spreads laterally over the screen pushing fish and any entrained debris outward towards the edge of the screen surface (Kemper and Bondurant 1985). Turbulent fountain screens operate entirely with hydraulic pressure as a single integrated diversion structure and contain no moving parts, require no external power and only minimal maintenance (*See* Bondurant and Kemper [1985] and Kincaid [2002] for original descriptions and diagrams of turbulent fountain screens).

As with other types of barrier screens used for fish protection, suitability of a turbulent fountain screen varies with site conditions. A turbulent fountain is most appropriate for small irrigation diversions with flows ranging from 0.03 to 0.15 m^3/sec, and a moderate level of hydraulic differential between the intake and the fountain riser, e.g. higher gradient streams, Kincaid (2002). Although turbulent fountain screens offer an effective, low-maintenance option for screening debris from small stream irrigation diversions (Bondurant and Kemper 1985), the efficacy of turbulent fountains is untested for screening fish.

To assess efficacy for screening fish, we designed and installed a prototype turbulent fountain fish screen on McCabe Creek, Montana. Our objectives for evaluating the turbulent fountain fish screen were to 1) determine the potential of a turbulent fountain system for screening fish, 2) assess impingement, i.e., fish contact with the face of the screen, and 3) provide guidance to irrigators regarding efficacy and design criteria of this alternative fish screen.

METHODS

In addition to hydraulic design criteria defined by Bondurant and Kemper (1985), our prototype "fish screen" design incorporated a circular outer wall with an attached fish bypass pipe (Fig. 1), along with inflow and outflow capacity designed to maintain constant flow through the bypass pipe. The screen was designed for a maximum inflow of 0.14 m^3/sec, of which a maximum 0.085 m^3/sec was available for outflow, with the remainder available for the bypass. The screen incorporated a 1.25-mm mesh over a 1.68-m^2 circular stainless screen set at a 1-percent slope, with a maximum mean approach velocity of 0.122 m/sec over the surface of the screen. We also reduced the screen diameter from the recommended original criteria of 213 cm to 152 cm to more effectively wash fish and debris off the screen. Following construction, we evaluated the fish screening capability in 2000 and again in 2002 following correction of observed construction flaws.

In 2000 we captured 48 westslope cutthroat trout using a backpack-mounted, battery-powered DC electrofishing unit (Smith-Root). Fish were anesthetized with tricaine methanesulfonate, counted, and measured for total length. After fish recovered from the anesthetic, we released individual fish through the fountain intake. As fish exited the intake riser, we counted by size category (Table 1) and timed the duration of all fish impinged on the screen for ≥ 2 sec. After all fish passed, we walked up- and downstream of the bypass exit to visibly detect signs of related mortality or signs of injury.

During this impingement evaluation of our initial fish screen design, we identified two construction flaws that appeared to contribute to unnecessary impingement: 1) the close proximity of inner chamber to a portion of outer wall of the structure, and 2) a lower screen angle than specified in our prototype design (Fig. 2). Due to the first construction flaw, the fountain was unable to completely wash debris from the edge of the screen. At this location, fish were unable to wash free of the screen and were impinged on the screen against the debris. Based on this observation, we modified our original screen by adding a flow deflector shield to the fountain riser in order to direct water, debris and fish away from this area of screen. We also modified the shape of the screen from a low-angle flat screen to a rounded cone-shaped screen with a mean 1-percent slope (Fig. 1).

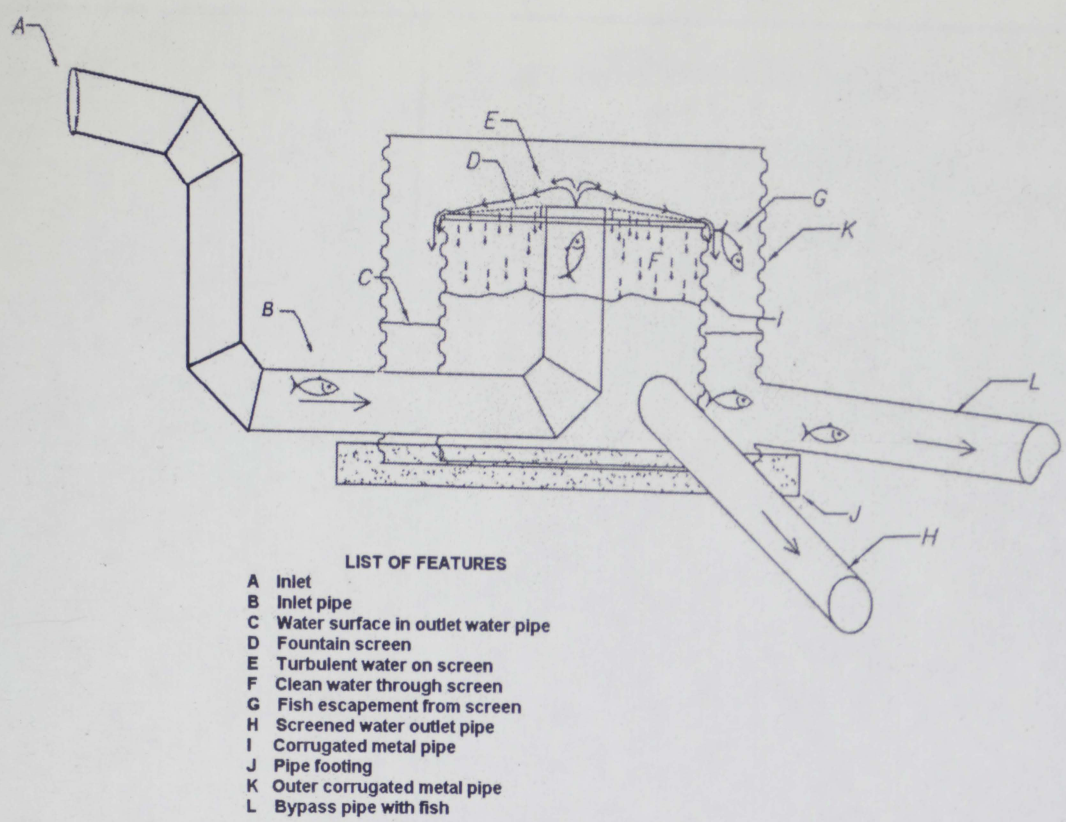

Figure 1. Conceptual design of a turbulent fountain fish screen with bypass to stream.

Following these screen modifications, in 2002 we repeated the impingement trial with 66 westslope cutthroat trout entrained through the fountain intake. Capture, handling, and observation of these fish were similar to the previous trial. During both experiments, the fountain intake was operating at full (0.14 m^3/sec) capacity.

We used Mann-Whitney nonparametric tests to compare lengths of fish in the initial trial to fish lengths in the second trial as well as duration of impingement between the prototype and modified design. A chi-square analysis was used to test whether the number of impinged fish varied by size class (50-110, 111-150, and >151 mm) between trials, where the number of impinged fish from the original design trial was used as the expected values of impingement in the modified design trial. In all cases, differences were considered significant at P-values ≤ 0.05.

Results

Prior to screen modification, 31 westslope cutthroat trout (65%) passed through the fountain with no impingement (< 2 seconds) on the screen. Seventeen fish (35%) were impinged for ≥ 2 seconds, of which 14 managed to work free of the

Table 1. Numbers and sizes of impinged fish before (2000) and after (2002) modification of the original screen

Year	N	Total lengths (mm) mean (SD), range	Number fish impinged	Size class of impinged fish (mm) (50-110)	(111-150)	(>151)
2000	48	134(45), 61-241	17	9	3	5
2002	66	121(38), 61-216	4	2	1	1

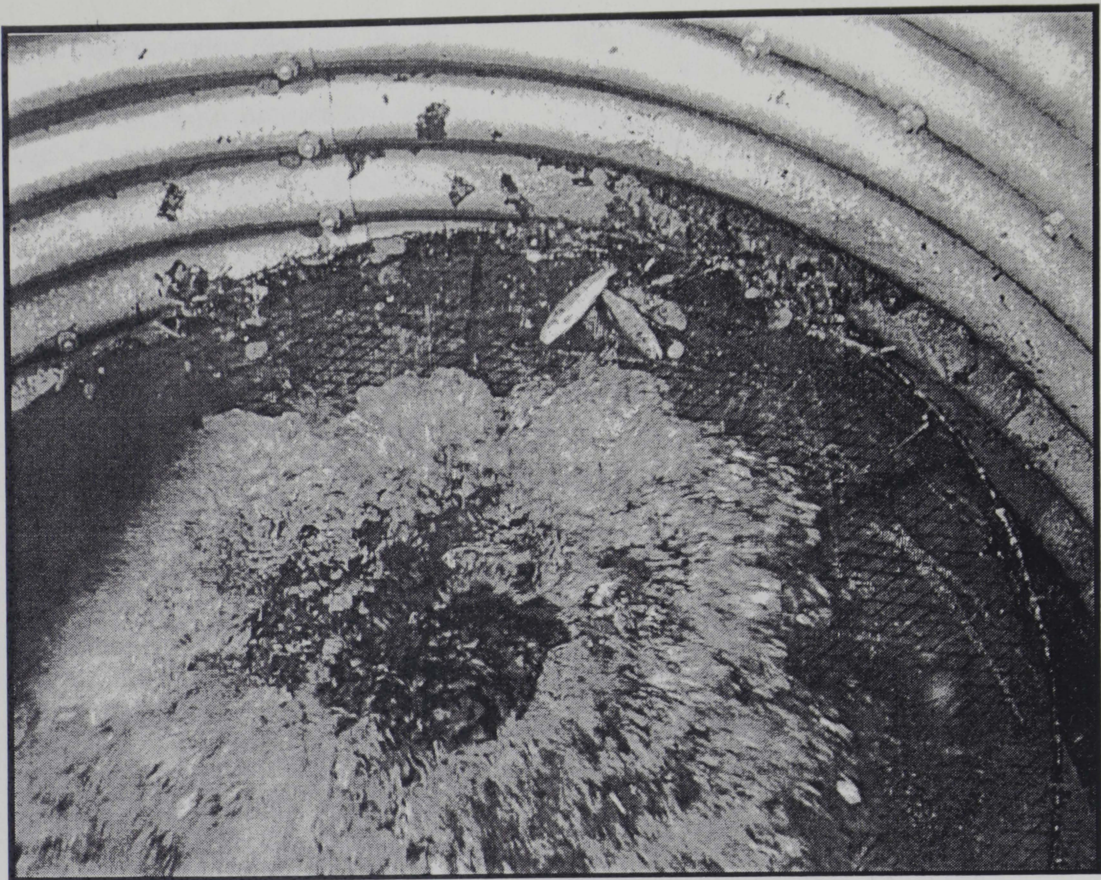

Figure 2. Fish impinged on the outer portion of the screen against the screen in area of debris collects.

screen (median impingement time = 30, range = 2-1560 sec). Three (6%) of the sampled fish remained in the fish screen after 26 min when we ended the experiment (Table 1).

Following screen modifications, all but four (6%) of the 66 fish immediately passed through the fountain and screen with no impingement (< 2 seconds). Of the four impinged fish, all washed over the screen within four seconds (median = 2, range = 2-3 sec). For these four fish, all impingement occurred in a localized boundary area between the main flow and the shielded portion of the screen.

We detected no difference in total length of fish between the first and second tests (Mann-Whitney, $P = 0.081$, Table 1), nor did the proportion of impinged fish vary among the three size classes between the first and second trial ($x^2 = 3.0$, 2 df, $P = 0.223$). The number of impinged fish declined from 37 percent in the first test to 6 percent in the second test (Table 1). The duration of impingement between the first and second test also declined significantly (Mann-Whitney, $P = 0.006$).

Upon completion of both experiments, we walked up-and downstream of the bypass and found no evidence of injury or mortality resulting from impingement from either test.

Discussion

Our modifications and evaluations of turbulent fountain screens suggest that this device can provide an effective, low-cost, low-maintenance fish screening system. Our field trials further outline the importance of constructing screens to exact design specifications.

Based on our design, evaluate, and modify approach, the following observations will help ensure effective application of this screen in the future. Fabricators and installers should ensure sufficient distance between the inner and outer chamber to facilitate movement of fish and entrained debris off the screen, plus include a sloped (or crowned) screen with a minimum 1-percent slope. Not only do lower angle screens increase impingement, but also several fish, once on the original more horizontal screen, attempted to swim towards the main flow (center) of the fountain. These fish remained on the screen for an extended time before escaping. A smaller-diameter inner chamber with minimal screen surface would also clean the screen more efficiently and reduce fish contact with the screen on its outer portion. A larger intake with excessive volume would serve a similar purpose by washing fish more quickly from the screen. Similarly, a smaller diameter out-flow pipe relative to intake pipe diameter forces upwelling on the outer portion of a sloped screen and assists in washing fish from the screen with less screen contact. Another possibility that was not tested might be to elevate the bypass pipe or otherwise submerge the screen in order to minimize fish contact with the screen and enhance fish passage over the screen.

Proper operation and maintenance of a fish screen is equally important to quality screen design (Nordlum 1996) to assure long-term effectiveness and function. In the Blackfoot River drainage, inadequate maintenance has reduced the effectiveness of many mechanical fish screens (paddlewheel and rotating drum). Because it has no mechanical parts, the turbulent fountain screen requires less maintenance than conventional fish screens and is cheaper to install and use. The total cost of the entire modified turbulent fountain system including the head gate was $9900, approximately 75 percent of the cost of self-powered paddlewheel driven fish screen and head gate of comparable flow capacity (Montana Fish, Wildlife and Parks data). While comparable in cost to electrically powered rotating drums of similar capacity, a turbulent fountain required lower maintenance at less expense. Throughout the three summers of use, the turbulent fountain required less manual cleaning than either traditional paddlewheel driven flat-plate screens or electrically powered rotating drums.

With proper design and construction, a turbulent fountain fish screen, as an integrated diversion structure, can meet multiple objectives. These include 1) volume control to an irrigation system and automatic removal of debris from a pipeline, 2) the elimination of entrainment into diversion ditches and the return of fish directly back to the stream immediately below the diversion point, 3) reduced impingement, 4) minimal screen maintenance, and 5) a cost-effective screening device. Unfortunately turbulent fountains have not been designed for volumes > 0.15 m^3/sec although Bondurant and Kemper (1985) suggest designs for higher flows are possible. Required hydraulic differential for larger diversions should also be evaluated in order to identify specific site requirements. Although turbulent fountain screens appear to minimize entrainment and impingement on small diversions, we did not fully measure all aspects of screen velocities (approach or sweeping), or all aspects of physical contact of fish with the screen. Future studies should also evaluate screen-injury potential such as scale loss, as well as other design improvements to expand this technology to areas where formal fish screening criteria currently preclude use of turbulent fountain fish screens.

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