Fish Passage Behavior through Baffled and Nonbaffled Culvert

M. A. Khodier
Utah State University, m.khodier@aggiemail.usu.edu

Blake P. Tullis
Utah State University, blake.tullis@usu.edu

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M.A. Khodier¹ and B.P. Tullis²
¹Dept. of Civil & Environmental Engineering
Utah State University
Logan, UT 84322
USA
²Dept. of Civil & Environmental Engineering
Utah State University
Logan, UT 84322
USA
E-mail: m.khodier@aggiemail.usu.edu

ABSTRACT

Culverts can have a negative impact on fish passage. Installing baffles inside culverts can potentially improve culvert fish passage by decreasing the flow velocity and increasing the flow depth. Fish passage behaviors of wild brown trout through a small prototype-scale (0.6 m diameter, 18.3 m in length) baffled, and non-baffled culverts were observed in the laboratory for a variety of discharges and pipe slopes (up to 6%). The baffle height and spacing was 0.15 and 0.9 times the culvert diameter, respectively. The correlation between successful fish passage, sample fish population, and the fish length was evaluated. The influence of baffles installed inside the culvert on fish passage compared to the non-baffled culvert was reported. Resting and staging zones for the fish passing the culvert upstream were observed and reported. A threshold velocity (calculated based on above-baffle flow area) for the fish passage was found to be 1.5 m/s.

Keywords: Fish passage; baffle; culvert; fish length.

1. INTRODUCTION

Maintaining the ability for free movement of many aquatic species, including fish, throughout a river drainage system can be critical with respect to the pursuit of foods or spawning. Some hydraulic structures, including culverts, may create a barrier for these species. Many studies have investigated the influence of culverts on the fish passage as a function of flow condition (Bell 1986; Clay 1995; Pearson et al. 2006). Fish passage through culverts can be improved by installing baffles along the culvert invert at a regular spacing. Baffles have many different designs, but some common ones include weir baffles, slotted-weir baffles, spoiler baffles, and offset baffles. The flow characteristics through different baffle designs were studied by Rajaratnam et al. (1988), Rajaratnam et al. (1989), Rajaratnam and Katopodis (1990), and Rajaratnam et al. (1991). They derived a flow equation that correlates discharge (Q), flow depth (y), culvert slope (S), and gravity acceleration (g). Feurich et al. (2011) investigated numerically the effect of the spoiler baffles on the flow field, and they compared the velocity fields for both baffled and non-baffled culverts. They found a reduction in flow velocities due to baffle installation. No biological tests were conducted in Feurich’s study. Morrison et al. (2009) conducted laboratory fish passage tests on juvenile salmon through a spiral-corrugated baffled-culvert of 1.83 m inside diameter at a single culvert slope of 1.14% and different flow rates (Q=43 to 198 L/s). They investigated the correlation between the flow turbulence characteristics and juvenile salmon passage, but no significant relationship was found.

Liao et al. (2003) studied the influence of vortices on Rainbow trout swimming behavior in a small test section. They observed that fish used the vortices to reduce the amount of energy they expended while swimming. Liao’s experiment was limited to a small test section. A study by Trítico and Cotel (2010) was conducted to investigate the influence of turbulent eddy diameter and vorticity on the stability and swimming speed of creek chub (Semotilus atromaculatus). They found that the turbulent eddies have significant effects on fish behavior and swimming stability. Their study was concise for a small test section of 2.5 m length, 0.6 m width, and 0.55 m height. The influence of flow velocity and turbulence on the fish behavior of juvenile salmonids was studied by Smith et al. (2005). They observed that a flow region of high velocity and low turbulence was a more preferred swimming
environment for fish than a flow region of low velocity and high turbulence. Pearson et al. (2005) conducted fish passage tests on juvenile coho salmon through corrugated, non-baffled culverts with slopes of 1.14% and 4.33% and a variety of flow rates. They observed that juvenile coho preferred to swim in areas of low velocity, which were near the culvert wall. Tillinger and Stein (1996) studied the influence of fish length on the swimming strength. They found that larger fish are typically considered stronger swimmers. Watts (1974) studied the effects of fork length of the fish tail and fish total length on the swimming speed of juvenile fish. They concluded that there is a proportional relationship between the swimming speed and fish total length. Behlke et al. (1991) concluded from their study that larger fish were more likely to pass through culverts than smaller ones. Belford and Gould (1989), however, observed little relationship between fish swimming ability and fish size. Olsen and Tullis (2013) investigated the influence of installing baffles in a culvert on wild brown trout fish passage under a variety of culvert slopes (0% ≤ S ≤ 3.5%) and flow rates (28.3–85 L/s). They observed that fish passage through culverts was improved significantly by installing baffles.

The goal of this study was to evaluate the ability of wild brown trout to pass through a weir-baffled culvert at steeper culvert slopes, ranging from 3.0% ≤ S ≤ 6.0%. The preferable swimming zone for the fish is described, and the influence of the fish sample size on the fish passage is reported.

2. EXPERIMENTAL SETUP

A laboratory fish passage was conducted on wild brown trout through a weir-baffled culvert 18.3 m long and 610 mm in diameter. All experiments were carried out at Utah Water Research Laboratory (UWRL) at Utah State University. The culvert and the baffle were made from high-density polyethylene (HDPE). The baffle spacing and height were 0.9D and 0.15D, respectively, where D is the culvert inside diameter. As shown in Figure 1, the upstream end of the culvert was connected to the head tank that supplies flow to the culvert. The downstream end of the culvert was connected to a tail tank where the fish were placed to pass upstream. The weir-baffled culvert was supported by a steel I-beam and adjustable pipe section. In order to provide instrumentation access and a clear visual observation, small rectangular windows were cut into the top of the culvert (Figure 2).

Another observation window was installed in the sidewall near mid-span of the culvert between two adjacent baffles. A flexible sheet of clear Lexan (355-mm-wide and 406-mm-tall) replaced the curved section that was removed from the culvert. In order to eliminate the optical distortion for the video images through the curved windows, an acrylic box of 584×685×635 mm was attached to the observation window, as shown in Figure 2. This box was filled with water. The flow rates were measured using calibrated venturi flow meters with ±0.2% accuracy. The tested flow rates were 28.3, 56.5, and 85 L/s. The corresponding average velocity through the baffled culvert was calculated by dividing the flow rate by the flow area above the baffle (V = Q/A). A tank of 350-gallon capacity was used to hold the fish. In an effort to maintain some level of consistency between the fish storage tank and the river environment, the tank was continuously supplied with fresh water from Logan River via a hose/nozzle assembly. The hose-induced jet was used to oxygenate the water in the tank through turbulent mixing at the water surface. A drain was attached to tank to keep the water level constant in the tank. Fish were fed with night crawlers (worms) daily (one per fish). The fish were allowed a minimum of 1 day of rest between tests.

![Figure 1. Schematic of baffled culvert fish passage test facility.](image-url)
Figure 2. Overviews of baffled culvert observation ports and windows for fish viewing (a) elevation; (b) perspective; (c) photographic

Figure 3. Fish holding tank

3. RESULTS AND DISCUSSION

Wild brown trout passage was evaluated through a non-baffled and baffled culvert of 0.61 m diameter at culvert slopes ranging from 0% to 6% and flow rates of 28.3, 56.5, and 85 L/s. Figure 4 shows the number of fish, percentage of fish passing, and the average flow velocity at each culvert slope and flow rate. The data in Figure 4 shows that the fish percentage passing increased with baffles relative to the non-baffled culverts. In general, the data in Figure 4 show that percentage fish passage decreased as the culvert slope and flow rates increased. Also, Figure 4 shows that for $S=3.0$ and 4.0%, the percentage of fish passage at small and mild discharge ($Q=28.3$ and $Q=56.5$ L/s, respectively) was consistent and the data were not significantly dependent on the culvert slope. However, at larger flow rates ($Q=85$ L/s), the fish percentage passing was significantly affected by the culvert slope. At culvert slopes $S>5.0\%$, the fish percentage passing significantly decreased for all flow rates. Note that there is a threshold velocity for the fish passing at $V>1.5$ m/s. The cruising speed, sustained speed, and bursting speed for brown trout fish are...
0.674 m/s, 1.884 m/s, and 3.875 m/s, respectively (Bell, 1986). Note that the threshold velocity is between the cruising speed and sustained speed. The influence of the fish sample size on the fish passage results was evaluated at three different sample sizes: 9, 17, and 25. Figure 5 shows the fish percentage passing for three different samples at different culvert slopes and discharges. For $S=3.0\%$, there is a deviation of approximately $\pm 4.0\%$ from the mean and less than $\pm 7.0\%$ for slopes of 5.0 and 6.0%. This indicates that the fish sample size has significant influence on the fish passage at high culvert slopes specifically at $S\geq 5.0\%$.

Figure 4. Summary of baffled and non-baffled-culvert fish passage data as a function of $S$ and $Q$

Figure 5. Summary of baffled-culvert fish passage versus fish sample size
Another factor that may influence fish passage is the physical characteristics of the individual fish, such as fish length. Figure 6 shows the ratio of successful total number of passing to the total attempts as a function of the individual fish length. The total number of attempts was fifteen times for all fish. In general, the data in Figure 6 reveal a linear relationship between the ratio of total number of fish passing and the fish length. This observation is consistent with Tillinger and Stein (1996) who found that the swimming ability increases with the size of the fish. Every 5 minutes, the head tank was observed for any successful fish passage, and the number of the fish in the head tank was reported until the end of the experiment. The duration of the experiment was 120 minutes. Figure 7 shows the timeline for the number of fish in the head tank as a function of the elapsed time counted from the last fish entering the culvert. The data in Figure 7 show that at low culvert slope ($S=3.0\%$), more time was required to pass through the culvert and the rate of fish passage success was higher. At the steeper culvert slopes ($S=5.0\%$), the culvert transit time reduced, as did the overall success rate. These results are partly due to the fact that with the more turbulent, higher velocity flow conditions corresponding to the steeper culvert tests, the effectiveness of the fish-resting zones was diminished. Without the ability to rest during transit, fish had to traverse the culvert more quickly before fatiguing.

![Figure 6. Total number of successful culvert passages to the total number of attempts ratio as a function of fish length (each column represents an individual fish, each fish participated in 15 trials)](image)

![Figure 7. Number of fish in the head tank as a function of elapsed time](image)

In an effort to observe the behavior of the fish passing upstream, a high-definition video camera was used to record the motion of the fish through the observation window located at the mid-span of the culvert. Two zones were preferred by the fish; Zone 1 was located on the downstream side of the baffles, and Zone 2 was located along either
sidewall in between baffles. Figure 8 shows these Zones. Zone 1 was used as resting place for the fish, and Zone 2 was used as a staging area before swimming upstream. Swimming between the two Zones was also observed. Zone 1 and Zone 2 are observed along the whole culvert through the observation rectangular windows cut into the crown of the culvert. In Zone 1, the fish either aligned their bodies parallel to the baffle (Figure 9 a) or aligned themselves with the culvert axis facing the local flow downstream direction (Figure 9b). This illustrates how installing baffles helps to improve the fish passage percentage.

![Figure 8. Illustrations of fish zones in the baffled culvert](image1)

**CONCLUSION**

Wild brown trout passage was evaluated through baffled prototype-scale culvert (18.3 m long and 0.60 m in diameter) under a variety of culvert slopes and discharge conditions. One can conclude the following:

- The percentage of fish passage is inversely proportional to culvert slope ($S$) and flow rate ($Q$), and no successful fish passage was reported for $S$=5 and 6% at flow rates of 85 L/s.
- For less severe hydraulic conditions, fish sample size showed variation $< \pm 4.0 \%$ from the mean and $< \pm 7.0 \%$ for severe flow condition.
- The swimming ability of the brown trout increased as the length of the fish increased.
- The duration of the overall fish passage process increased as the severity of the hydraulic conditions lessened. Fish that were able to pass with the more severe hydraulic conditions utilized less time.
- Two different Zones were observed for the fish while swimming upstream. Zone 1 was used as a resting area for the fish and Zone 2 was used as a staging area.

![Figure 9. Photographic examples of fish resting](image2)
5. ACKNOWLEDGMENTS

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6. REFERENCES


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