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An Evaluation of Trout Passage through Six Highway Culverts in Montana

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Abstract.—Combinations of water velocity and passage length in highway culverts were evaluated to determine conditions that enabled or prevented the passage of nonanadromous rainbow trout *Oncorhynchus mykiss*, brown trout *Salmo trutta*, cutthroat trout *O. clarki*, and brook trout *Salvelinus fontinalis*. Fish passage through six culverts 45–93 m long was determined by trapping and electrofishing. Water velocities were measured 5 cm above the bottom (bottom velocity) and at 0.6 of the water depth at intervals between rest sites throughout the lengths of the culverts. Nonlinear regression lines specific to species and state of sexual maturity were fit to the combinations of mean bottom velocity and passage length representing the most strenuous conditions that allowed the upstream passage of trout. Because of the similarity of the strenuous passage relations among species, the spawning rainbow trout relation could be used as the general criterion for passage of the trout studied. This relation indicated that fish could swim distances of 10, 30, 50, 70, and 90 m with mean bottom velocities up to 0.96, 0.80, 0.74, 0.70, and 0.67 m/s, respectively.

Highway culverts often impede or block fish movements. The steep slopes and low roughness coefficients of culverts frequently cause high water velocities to develop that have prevented the passage of Arctic grayling *Thymallus arcticus*, longnose suckers *Catostomus catostomus*, northern pike *Esox lucius* (Derksen 1980), steelhead (anadromous rainbow trout) *Oncorhynchus mykiss*, coho salmon *O. kisutch*, chinook salmon *O. tshawytscha* (Kay and Lewis 1970), and cutthroat trout *O. clarki* (Huston 1964; Berg 1975).

The study of fish passage through culverts or steeppass fishways has focused on anadromous salmonids (Gauley 1960, 1967; Kay and Lewis 1970; Slatick 1971) and Arctic grayling (MacPhee and Watts 1976; Derksen 1980; Travis and Tilsworth 1986). The passage abilities of other nonanadromous salmonids have been measured in the field only by Huston (1964), to our knowledge, but they have been assumed to be less than those of anadromous salmonids.

Our objective was to measure the combinations of water velocity and distance that could be negotiated by brown trout *Salmo trutta*, brook trout *Salvelinus fontinalis*, rainbow trout, and cutthroat trout. This information would be useful for designing new culverts and for identifying existing culverts that prevent or limit the passage of nonanadromous salmonids.

Study Culverts

The six round, corrugated-metal culverts studied are located at four sites in Montana. The two culverts on Cedar Creek, a tributary to the Yellowstone River, are positioned side by side. These culverts are 45.0 m long and 1.9 m in diameter and are on a 4.4% slope. The north culvert has been improved by fitting it with a ladderlike structure constructed from angle iron and lying about 20 cm above the culvert bottom. The ladder rungs are spaced a mean distance of 1.2 m apart (range, 1.1–1.5 m) and retain bed load that provides rest sites for trout. The improvement structure is about 1.1 m wide and extends the entire length of the culvert. The unimproved south culvert contains no structure and essentially no bed load. Before installation of the structure in the north culvert, both culverts had blocked the migratory movements of cutthroat trout from the Yellowstone River (Berg 1975). Cedar Creek contains small resident populations of brown trout, cutthroat trout, and brook trout.

The two culverts on Sourdough Creek, a tributary to the East Gallatin River, also are located side by side. These culverts are 94.0 m long and 3.0 m in diameter and are on a 1.2% slope. Of the two, the west culvert receives the greater flow, and the east culvert has accumulated more bed load. Neither culvert contains improvement structures.

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Sourdough Creek contains brown trout, rainbow trout, and brook trout.

The culvert outlet at Depuy's Spring Creek was 0–17 cm above the surface level of the Yellowstone River during our study. Distance above surface level depended on the river stage. This culvert, which contains no improvement structures, is 50.5 m long and 1.6 m in diameter and is on a 0.2% slope. The stream supports resident brown trout and rainbow trout and is a spawning site for migrating rainbow trout from the Yellowstone River.

The culvert on Twelvemile Creek, a tributary to the St. Regis River, is 69.5 m long and 5.3 m in diameter and is on a 1.8% slope. The culvert contains 5 of the original 10 plate-metal baffles installed to promote trout passage. The five functional baffles are spaced an average of 6.1 m apart (range, 6.0–6.2 m) and are located in the upstream 30.4 m of the culvert. Each baffle consists of an upright sheet of plate metal 0.65 m high at the center with a single notch adjacent to a culvert wall about 1 m wide by 0.15 m deep. These notches are on alternate sides on consecutive baffles and cause the current to meander. A boulder (about 2.5 m in maximum dimension) that had knocked down several baffles also acts as an additional velocity-reducing structure 49.0 m from the upstream inlet of the culvert. Twelvemile Creek contains brook trout, brown trout, rainbow trout, cutthroat trout, and bull trout *Salvelinus confluentus*.

Methods

Trout passage.—In 1984–1986, the passage of trout through the culverts was determined during their seasonal spawning periods. The trout studied were on natural spawning runs or were those returning upstream through the culverts after being physically displaced downstream. Displaced trout were upstream residents that were captured by electrofishing, marked, and released below the culverts.

Traps and electrofishing were used to capture trout that had swum through the culverts. We placed traps and leads immediately above culverts to capture fish successfully completing passage. Traps were constructed of wood frames covered with 2.5-cm-mesh poultry wire and contained two offset baffles at the mouth. Either nylon netting or poultry wire, each with 2.5-cm mesh, was used for trap leads. When traps were not in use, we electrofished areas above culverts for marked fish that had been displaced below the culverts. A Smith–Root type V or VII electroshocker was used for electrofishing.

The species, length, weight, and sex (if obvious) of each captured trout were recorded. We marked each captured fish about 260 mm long or longer (all lengths measured as total length) with a Floy T-tag and each fish shorter than about 260 mm with a caudal fin clip.

Hydraulic characteristics.—Water velocities were measured at and between rest sites (passage areas) throughout the lengths of the culverts. Velocity measurements between rest sites were taken in the deepest water, usually at 5.0–10.0-m intervals; however, 1.5–3.0-m intervals were usually used in sites where substantial variations in velocities were apparent.

Water velocities were measured about 5 cm above the culvert bottom at all sites. These bottom velocities were measured because they reflected the influence of the bottom materials present and because trout were observed swimming along the bottom or sides of the culverts. In addition to bottom velocities, velocities at 0.6 of the water depth (theoretical vertical means) were measured at many locations so the relation between the two types of measurements could be determined in a regression analysis. This relation was determined to compare the results of this study with other fish-passage studies that used 0.6-depth velocities. All velocities were measured with a Gurley model 622 current meter or, where conditions dictated, a Gurley model 625 or Montedoro–Whitney model PVM 2 current meter.

Water depths were measured at all velocity measurement sites. On June 24, 1985, the water depth in Cedar Creek decreased from 8 to 4 cm in the unimproved culvert. This was the only time when we believed that insufficient water depth blocked trout passage through culverts. In all other situations where trout did not pass through culverts, water depths between rest sites were greater than 26 cm, which would not restrict passage.

Strenuous conditions of trout passage.—Mean bottom velocities for passage areas between rest sites were calculated from velocity measurements made between the slow waters associated with the rest sites. Slow waters usually occurred within 0.3 m upstream and 1.2 m downstream of the structure creating the rest site. The passage length is defined here as the length of culvert between the most distant velocity measurement points included in the mean velocity calculation for a passage area. Thus, the passage length is less than the distance between rest sites and does not include the slow waters near the rest sites.

The observed combinations of mean bottom velocity and passage length were plotted on figures that were specific to species and spawning condition. Unless they were sexually mature, rainbow, brown, and cutthroat trout were assumed to be nonspawning fish during their spawning period if they were less than 250 mm long; similarly, brook trout were considered to be nonspawning if they were less than 200 mm long. Fish captured outside of their spawning period were included with the nonspawning fish. The points found near the upper boundary of a scatter plot were selected as the strenuous combinations of mean bottom velocity and passage length. When a sufficient range of data points was present, we fitted the strenuous combinations that trout swam through with a nonlinear regression line by using the quasi-Newton technique (Wilkinson 1988). These regression lines were compared with the general linear test by using the Bonferroni multiple-comparison technique to control the overall confidence at 0.95 (Neter et al. 1985).

Field tests.—From June 19 to 24, 1985, 17 cutthroat trout were placed in an enclosure that opened into the downstream outlet of the unimproved culvert in Cedar Creek. The position of the enclosure forced the fish trying to move upstream to attempt to pass through the unimproved culvert. Two rocks, each about 33 cm in diameter, were placed in the unimproved culvert to create rest sites at locations 15 and 30 m from the upstream inlet of the culvert from June 20 to 24.

Trout access to the east culvert on Sourdough Creek was blocked with 2.5-cm-mesh poultry wire from March 21 to April 21, 1985, to force fish to attempt passage through the west culvert, which carried most of the streamflow. We placed up to four rocks, about 40–51 cm in diameter, at locations in the west culvert to provide distances between rest sites of 7.0–94.0 m. Rocks 1 and 2, when in place, were located 15.0 and 22.0 m from the upstream inlet of the culvert, respectively. When present, rock 3 was located 41.5 or 35.0 m from the culvert inlet, and rock 4 was 68.7, 64.0, or 55.5 m from the culvert inlet.

Results

Rainbow Trout

Rainbow trout passed through culverts on Sourdough, Depuy's Spring, and Twelvemile creeks during the study (Table 1). All rainbow trout passed through the east culvert in Sourdough Creek until its entrance was blocked during the field test. After the east culvert was blocked, however, rainbow trout passed through the west culvert even after all the rest sites introduced during the field test were removed.

The combinations of mean bottom velocity and passage length that spawning and nonspawning rainbow trout passed through are shown in Figure 1. The nonlinear regression lines fitted to strenuous conditions passed by spawning and nonspawning rainbow trout were not significantly different. These regression lines are characterized as steeply descending for passage lengths of about 0–10 m and gradually descending for passage lengths greater than 10 m.

Brown Trout

Brown trout passed through culverts on Sourdough, Depuy's, and Twelvemile creeks during the study (Table 1). Like rainbow trout, all brown trout passed through the east culvert in Sourdough Creek until its entrance was blocked. After the east culvert was blocked, however, nonspawning brown trout passed through the west culvert even after the introduced rest sites were removed. Because the field test was conducted only in the spring, introduced rest sites were not present in the west culvert in Sourdough Creek for spawning brown trout.

The conditions that spawning and nonspawning brown trout passed and did not pass through are shown in Figure 2. The regression lines fitted to the strenuous passage conditions for spawning and nonspawning brown trout were significantly different. The regression lines, however, do appear to be similar for passage lengths of 25–100 m. The regression line for spawning brown trout was not significantly different from that of spawning rainbow trout, even though spawning brown trout faced fewer strenuous passage conditions. Although the nonlinear regression line for nonspawning brown trout was significantly different from those for spawning and nonspawning rainbow trout, the strenuous passage relation of nonspawning brown trout for passage lengths of 20–94 m was not significantly different from those for spawning or nonspawning rainbow trout ($P > 0.05$).

Brook Trout

Spawning and nonspawning brook trout passed through the culverts on Twelvemile and Sour-

TABLE 1.—Characteristics of spawning and nonspawning rainbow, brown, and brook trout that passed through study culverts in three Montana creeks. Spawning trout were those captured during the spawning season and found to be sexually mature or greater than 250 mm total length (TL) for rainbow and brown trout or greater than 200 mm TL for brook trout.

Creek	Year	Culvert	Trout data: Spawning condition	Trout data: Number of fish passed	Trout data: Total length (mm)
			Rainbow trout		
Twelvemile	1984		Nonspawning	1	161
Sourdough	1985	East	Spawning	14	215–393
		East	Nonspawning	3	192–247
	1986	West	Spawning	36	189–368
		West	Nonspawning	10	185–243
Depuy's Spring	1985		Spawning	39	255–470
			Nonspawning	1	223
			Brown trout		
Twelvemile	1984		Spawning	2	289–341
			Nonspawning	2	225–249
Sourdough	1985	East	Spawning	1	430
		East	Nonspawning	2	222–244
	1986	West	Nonspawning	4	224–350
Depuy's Spring	1985		Spawning	7	330–400
			Nonspawning	2	298–323
			Brook trout		
Twelvemile	1984		Spawning	6	211–255
Sourdough	1985	East	Spawning	2	213–215
		East	Nonspawning	1	229
	1986	West	Nonspawning	20	225–308

dough creeks (Table 1). Nonspawning brook trout also passed through the west culvert in Sourdough Creek after the east culvert was blocked, and they did so even after all the introduced rest sites were removed. As for spawning brown trout, introduced rest sites were not present in the west culvert in Sourdough Creek for spawning brook trout. No brook trout were present in Depuy's Spring Creek to attempt passage through that culvert.

The conditions that spawning and nonspawning brook trout passed and did not pass through are shown in Figure 3. The regression lines for spawning and nonspawning brook trout were significantly different from each other and were significantly different from those of spawning and nonspawning rainbow trout. Spawning brook trout did not face passage conditions as strenuous as those faced by other species in spawning condition. The regression line through the strenuous passage conditions for nonspawning brook trout for passage lengths of about 20–94 m was not significantly different from those for spawning and nonspawning rainbow trout ($P > 0.05$).

Cutthroat Trout

Thirty-nine spawning cutthroat trout (224–426 mm) passed through the Cedar Creek culvert improved with the ladderlike structure during the 1984 and 1985 study periods. Spawning cutthroat trout did not pass through the unimproved culvert on Cedar Creek until the rest sites were introduced during the field test in 1985; however, eight cutthroat trout (294–356 mm) did pass through the unimproved culvert after rest sites were introduced. No cutthroat trout passed through the unimproved culvert containing the introduced rest sites after the water depth decreased from 8 to 4 cm.

Strenuous passage conditions for spawning cutthroat trout were not found over a sufficient range of passage lengths to warrant fitting a nonlinear regression line (Figure 4). However, the strenuous passage conditions found for spawning cutthroat trout corresponded closely to those along the regression line for spawning rainbow trout.

Relation of Bottom Velocities to 0.6-Depth Velocities

The relation of 0.6-depth velocities to bottom velocities in the round, corrugated-metal culverts studied without bed load was determined so we could compare our results with those from other studies that used 0.6-depth velocities. This relation was

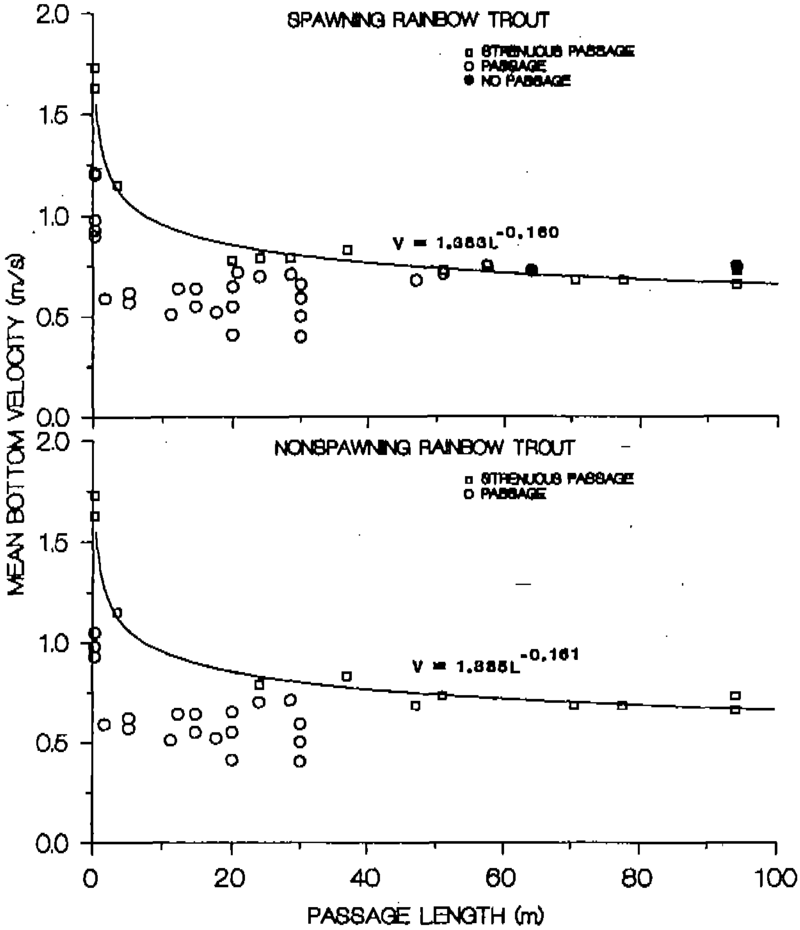

FIGURE 1.—Combinations of mean bottom water velocity (V) and passage length (L) that spawning and nonspawning rainbow trout did and did not pass through. The nonlinear regression lines are fits to the strenuous passage combinations indicated by the open squares. Each passage symbol indicates at least one fish successfully completed passage.

$$A = 0.062 + 1.317B; \quad (1)$$

A is the water velocity (m/s) at 0.6 depth; B is the water velocity (m/s) 5 cm above the bottom. The coefficient of determination (r^2) of equation (1) was 0.76, but it increased to 0.84 when water depth was added as a variable:

$$A = -0.106 + 1.281B + 0.005C; \quad (2)$$

A and B are defined as in equation (1); C is water depth (cm). Culvert slope and diameter did not significantly influence this relation ($P > 0.05$).

Discussion

The bottom-velocity–passage-length relation of strenuous passage for spawning rainbow trout (Figure 1) is probably a fair representation of the general passage abilities of all four species studied, regardless of their state of maturity. The relations for nonspawning rainbow trout and spawning brown trout are not significantly different from that of spawning rainbow trout, nor are the relations of nonspawning brook and brown trout for passage lengths of 20–94 m. Though there is an insufficient range of passage points to determine a relation for spawning cutthroat trout, the individual points of strenuous passage coincided with the spawning rainbow trout relation. Only the relation for spawning brook trout has consistently lower strenuous passage velocities than spawning rainbow trout throughout the range of passage lengths studied. We believe the reason strenuous passage velocities differ among species and between spawning conditions for some passage

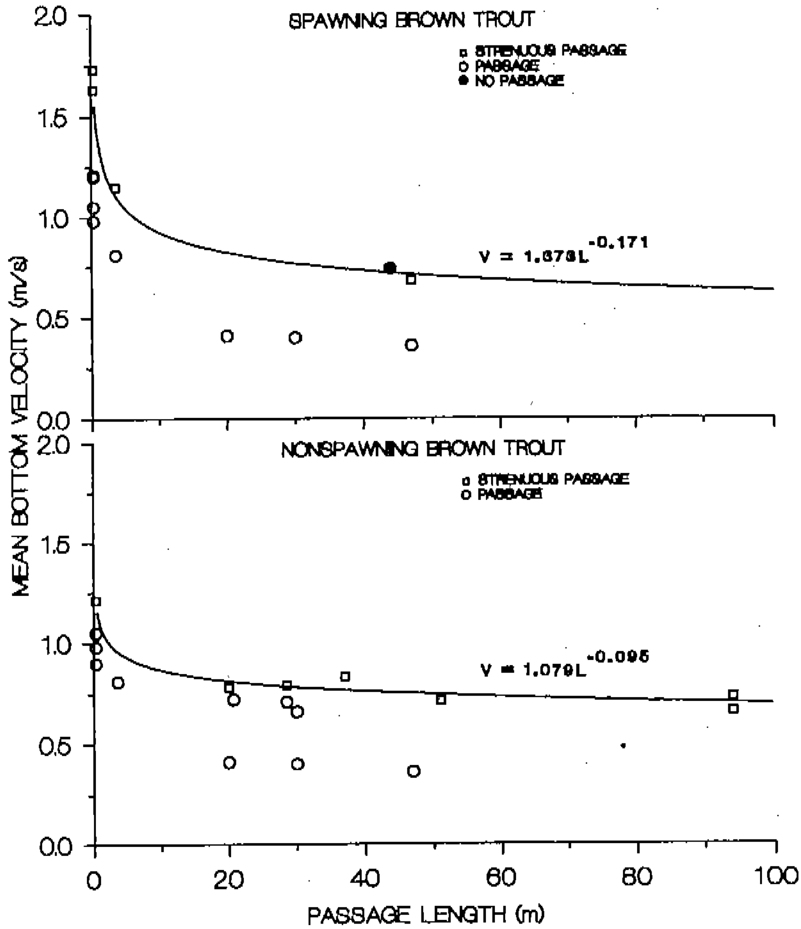

FIGURE 2.—Combinations of mean bottom water velocity (V) and passage length (L) that spawning and nonspawning brown trout did and did not pass through. The nonlinear regression lines are fits to the strenuous passage combinations indicated by the open squares. Each passage symbol indicates at least one fish successfully completed passage.

lengths is that some groups did not face as strenuous passage conditions as spawning rainbow trout and not because these groups have less swimming ability.

In other studies, the swimming abilities of rainbow trout and Arctic grayling increased with total body length when the fish were tested in culverts (MacPhee and Watts 1976) and swimming stamina devices (Fry and Cox 1970; Jones et al. 1974). Because we found trout of different lengths passing through similar hydraulic conditions, there appears to be no relation between total length of trout and passage ability for the lengths of fish studied here. This lack of relation may have been the result of smaller fish being able to use lower-velocity zones near the bottom or sides of the culverts more efficiently than larger fish.

We used equation (1) to convert the relation of strenuous passage for spawning rainbow trout in Figure 1 to 0.6-depth velocities for comparisons with results from other studies (Table 2). The maximum velocities we found are similar to those recommended previously for nonanadromous salmonids for passage lengths of 30 m or less and greater than those values recommended earlier for passage lengths greater than 30 m. In contrast, our maximum velocities for nonanadromous salmonids are about one-half the velocities recommended by Kay and Lewis (1970) for anadromous salmonids throughout the range of passage lengths we studied. This ratio has been previously implied in the recommendations made by Gebhards and Fisher (1972) and Lauman (1976) for maximum allowable velocities in culverts.

After a passage length of about 10 m, our study indicates that the slope of the strenuous-passage

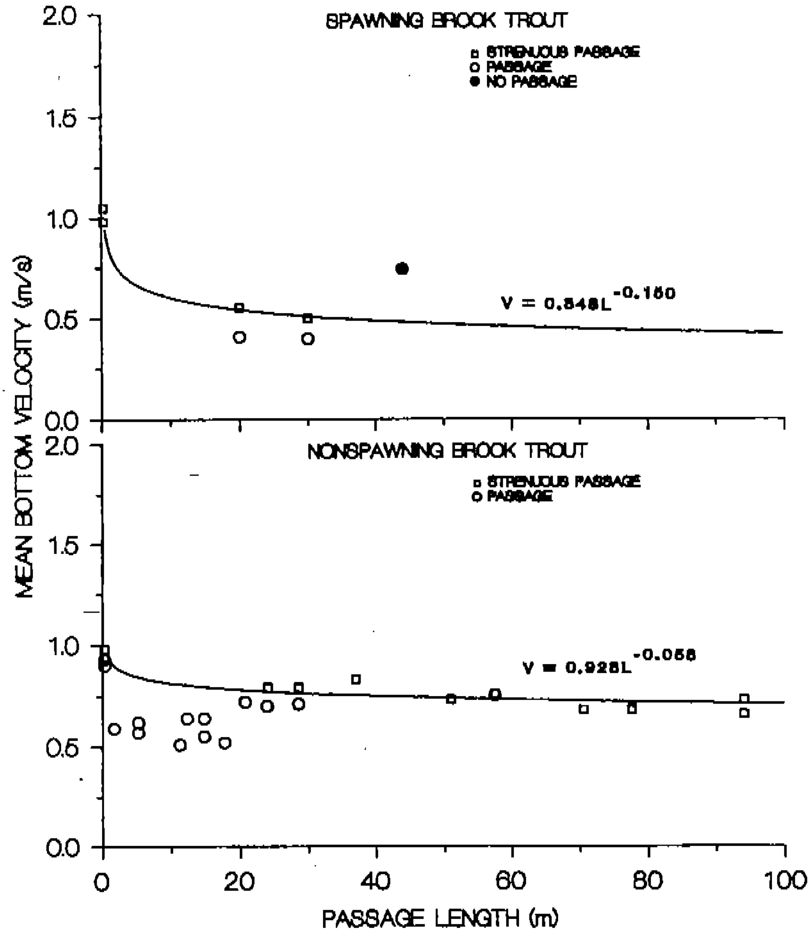

FIGURE 3.—Combinations of mean bottom water velocity (V) and passage length (L) that spawning and nonspawning brook trout did and did not pass through. The nonlinear regression lines are fits to the strenuous passage combinations indicated by the open squares. Each passage symbol indicates at least one fish successfully completed passage.

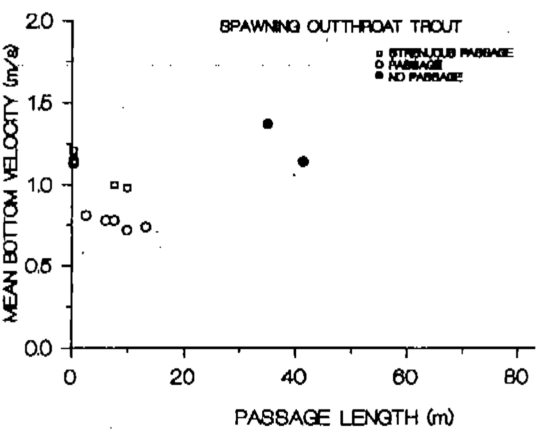

FIGURE 4.—Combinations of mean bottom water velocity and passage length that spawning cutthroat trout did and did not pass through. Each passage symbol indicates at least one fish successfully completed passage.

relation for spawning rainbow trout becomes relatively flat. We hypothesize that for passage lengths greater than about 10 m, trout use prolonged swimming rather than burst swimming to achieve passage and that these velocities should be similar to prolonged swimming speeds found in laboratory swimming stamina tests. Prolonged swimming speeds are defined as speeds maintainable for 20 s to 200 min (Beamish 1978). Beamish (1978) projects, from data collected by Bainbridge (1960, 1962), that the maximum prolonged swimming speed of a rainbow trout 350 mm in length is about 1 m/s. Additionally, Jones et al. (1974) found that wild-caught and hatchery-reared rainbow trout could maintain swimming velocities of 0.67 and 0.96 m/s on the average, respectively, for 10 min. Indeed, the prolonged swimming abilities of rainbow trout in laboratory swimming

TABLE 2.—Maximum water velocities at 0.6 of water depth projected in five studies to permit the passage of nonanadromous and anadromous salmonids through culverts at various passage lengths.

Maximum passage length (m)	Velocities for nonanadromous salmonids: Present study[a]	Saltzman and Koski (1971)	Lauman (1976)	Travis and Tilsworth (1986)[b]	Velocities for anadromous salmonids: Kay and Lewis (1970)
10	1.32	1.22	1.22	1.38	2.51
30	1.12	1.22	1.22	0.90	2.29
50	1.04	0.61	0.61	0.79	2.16
70	0.99	0.61	0.46	0.55	2.02
90	0.95	0.61	0.46	0.55	1.89

[a] The velocities given are from the spawning rainbow trout relation in Figure 1 converted to 0.6-depth velocities by text equation (1).

[b] Maximum water velocities that are recommended at the mean annual flood discharge.

stamina tests do appear to be similar to the strenuous bottom velocities of 0.96–0.66 m/s predicted for passage lengths of 10–100 m from the spawning rainbow trout relation in Figure 1.

Wild, resident salmonid populations are important recreational resources. Habitat alterations have severely depleted many of these populations by reducing the availability of spawning habitat, thus limiting recruitment. Culverts with high-velocity waters continue to impede or depress spawning migrations and thereby recruitment. To reduce the effects of highway culverts, we recommend that the relations describing the most strenuous passage conditions found in this study be used as the maximum allowable bottom velocities for passage lengths in culverts. The relation found for spawning rainbow trout may be used as a general criterion for the proper installation of highway culverts and to suggest locations for placement of velocity-reducing structures in culverts, if necessary. We believe that measuring bottom velocities throughout the lengths of culverts, whenever practical, is the best method of obtaining the most accurate velocity characteristics that trout face when attempting to pass through culverts.

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