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Fish Passage at Road Crossings: An Annotated Bibliography

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Abstract

A report of special interest to fishery biologists, resource managers, hydrologists, and road engineers, this bibliography lists publications pertinent to road crossings of salmon and trout streams. Topics include bridge and culvert installation, design criteria, mechanics, hydraulics, and economics, as well as their biological effects.

Keywords: Bibliographies (fish habitat), fish habitat, forest engineering.

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Fish Passage at Road Crossings: An Annotated Bibliography

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References by Subject

This annotated bibliography was prepared as a guide to the literature available on problems with fish passage at road crossings. Crossings that include bridge ana culvert installations and adaptations of culverts are emphasized. A limited selection of the general literature on fish-passage devices is also included.

We have attempted to review and abstract a broad spectrum of the literature to provide field biologists, engineers, and land managers with a guide to what is available. Additions to the current list would be appreciated.

Some relevant information is in relatively obscure technical reports. We were usually able to obtain copies of the cited papers from the producing agency; most of them are on file at the Forestry Sciences Laboratory, USDA Forest Service, P.O. Box 909, Juneau, Alaska 99802.

References are listed by author and number. A list of general topics and the number corresponding to the source are included.

1. Adamovich, L., R. P. Willington, and D. Lacate.
1973. Bibliography on forest roads and the environment. Fac. For. Univ. B.C., Vancouver. Unpubl. ms., 25 p.

A list is given of published and unpublished material on most aspects and effects of forest roads through 1973. Topics include esthetics, aerial photo interpretation, bridges, construction, cut and fill procedures, and various effects on fisheries.

2. Bell, M. C.
1973. Fisheries handbook of engineering requirements and biological criteria. Fish. Eng. Res. Program. Corps Eng., North Pac. Div., Portland, Oreg.

A wide range of information on fisheries and engineering problems is included. Areas applicable to fish passage are discussed in several chapters. These include passage around dams, fishways and other conduits, swimming speeds, and velocity barriers. Chapter 31 deals specifically with culverts and briefly discusses some of the hydraulic characteristics of culverts. Some general guidelines for culvert installation are provided: Culverts should be installed close to zero gradient; average velocities with a slope of 0.5 percent are 4.8 to 2.6 ft/s, which will allow fish to pass; culvert floor roughness should approximate natural streambed; and a minimum swimming depth of 12 inches should be allowed. Darkness in a culvert is not a block to fish passage.

3. Blahm, T. H.
1963. Passage of salmon fingerlings through small tunnels. Trans. Am. Fish. Soc. 92(1):302-303.

Tests were conducted in an artificial channel to determine the optimum combination of water velocity and light that would be most effective for downstream passage of salmon fingerlings through small tunnels. Higher velocities (3.0 to 3.5 ft/s) in combination with downstream light induced the highest percentage of downstream passage.

4. Clay, C. H.
1961. Design of fishways and other fish facilities. Dep. Fish. Can., Ottawa. 301 p.

This handbook of fish-passage devices primarily deals with artificial and natural obstructions. Design criteria for fishways, vertical slot passages, entrances, baffles, and exits are discussed. Other chapter topics include fish locks, weirs, barrier dams, fish screens, and artificial spawning channels. A brief review of elementary hydraulics is contained in an appendix.

5. Collins, G. B., and C. H. Elling.
1960. Fishway research at the fisheries-engineering research laboratory. U.S. Fish and Wildl. Serv. Circ. 98. 17 p.

Results of 4 years of research on fishway problems, rates of movement of salmonids ascending fishways, and spatial requirements of fish are given. Experiments to measure fishway capacity are described. The effect of fishway slope and length on fish performance and physiology were measured in "endless" fishways. Preference of salmonids for water velocities and light conditions revealed marked differences among species. Effects of light and water velocity on rates of passage through channels and fishways are described. Experiments on fingerling passage and the testing of full-scale prototype fishway designs are discussed.

6. Collins, G. B., J. R. Gauley, and C. H. Elling.
1962. Ability of salmonids to ascend high fishways. Trans. Am. Fish. Soc. 91(1):1-7.

Ability ana persistence of salmonids to ascend pool-and-overfall fishways were measured in experimental "endless" structures in which fishways of any height could be simulated. Rate of ascent of all fish tested increased after an initial period of experience in the fishway. Measurement of blood lactate in the exercised fish showed no evidence of fatigue. Practical significance of the data in relation to fishway design is discussed.

7. Dane, B. G.
1978. A review and resolution of fish passage problems at culvert sites in British Columbia. Fish. and Mar. Serv. Tech. Rep. 810, 126 p.

Report includes guidelines for culvert design and installation, which describe salmonid passage requirements and hydraulic parameters., Five types of culverts are described. Their characteristics are compared with photos and sketches. Author described type, cause, and effect of obstructions in the spawning/rearing area, as well as effects of habitat and hydraulic instability. Recommendations are made for the installation of culverts to avoid conflict with fish use in the stream during construction. For a condensed version of this report, see Dane, Culvert guidelines: recommendations for the design and installation of culverts in British Columbia to avoid conflict with anadromous fish. Fish. and Mar. Serv. Tech. Rep. 811. 57 p.

8. Dass, P.
1970. Analysis of slot orifice fishways. M.S. thesis. Univ. Idaho, Moscow. 101 p.

Criteria for a slot orifice fishway are developea. Size and space of orifices can be designed to create flow conditions satisfactory for fish passage. The slot orifice fishway functioned well in a wide range of discharges and should not have any serious silting problems. Values of drag coeffients for the slot orifice constrictions were evaluated by model studies.

9. Dryden, R. L., and C. S. Jessop.
1974. Impact analysis of the Dempster Highway culvert on the physica'l environment and fish resources of Frog Creek. Fish. and Mar. Serv., Can. Dep. Environ./Fish. Oper. Dir./Cent. Reg./ Tech. Rep. Ser. CEN/T-74-5, 59 p.

Improper culvert design and its effects on hydrology and fish populations of Frog Creek, Northwest Territories, Canada, are discussed. The effects documented are on migration of fish (northern pike, Esox lucius, and broad whitefish, Coregonus nasus) and streambank stability attributable to water velocities in excess of 1.5 m/s (5 ft/s). The causes were high flows through the culvert and energy dissipation at the outfall. Biological measurements made on northern pike and whitefish included age, growth, movement, and gonad development.

10. Dryden, R. L., and J. N. Stein.
1975. Guidelines for the protection of the fish resources of the Northwest Territories during highway construction and operation. Fish. and Mar. Serv., Can. Dep. Environ./Fish. Oper. Dir./ Cent. Reg./Tech. Rep. Ser. CEN/ T-75-1, 32 p.

These guidelines are intended to aid highway designers; they are applicable to all water courses that flow for at least one period each year, as well as all highway-related stream alterations, including both temporary and permanent road crossings, culverts, right-of-way approaches, and gravel removal. The study was confined to Mackenzie Valley, Northwest Territories, streams and species. Statistical conclusions may be site specific; however, the biological and technical guidelines are universal in dealing with highway design and fish-passage problems.

11. Engel, P.
1974. Fish passage facilities for culverts of the Mackenzie Highway. Dep. Environ., Hydraul. Div., Can. Cent. Inland Waters, 33 p. Burlington, Ont.

The stuay evaluated three types of fish-passage facilities for large culverts--spoilers, offset baffles, and side baffles. The relation of hydraulic characteristics to swimming speeds of fish is described and modeled. Effectiveness of each design was proportional to gradient. Maximum recommended slope was 5 percent. Suggestions for application of elliptical ana arch culverts to fish-passage facilities are also made. Recommendations and limitations of each device are given. Problems with debris and sediment may occur. Ice may be more of a problem with side baffles. Data for swimming speed (burst), friction factors, and velocities are given, as are design diagrams.

12. Evans, W. A., and F. B. Johnson.
1974. Fish migration and fish passage: A practical guide to solving fish passage problems. USDA For. Serv. Reg. 5, 43 p.

Practical problems of fish passage through and over natural and artificial structures in streams are discussed. Fish barriers are illustrated, and barriers from road crossings and methods for correcting them are described. The authors provide a useful guide for installation of culverts and stream crossings to provide for fish passage. Figures and tables are given to provide gradient, velocity, and other data for various culvert sizes.

13. Gauley, J. R.
1966. Effects of water velocity on passage of salmonids in a transportation channel. U.S. Dep. Int., Fish. and Wildl. Serv., Bur. Comm. Fish., Fish Bull. 66(1):59-63.

Passage times of chinook salmon, sockeye salmon, and steelheau trout through a test channel were compared at velocities of 1 and 2 ft/s. The test channel was 4 feet wide, 6 feet deep, and 100 feet long. Passage times did not differ significantly with water velocity for any of the three species. The two salmon, species moved faster than steelhead trout at both water velocities. The author concluaed that 1 ft/s is as suitable as 2 ft/s for fish passage.

14. Gauley, J. R., and C. S. Thompson.
1962. Further studies on fishway slope and its effect on rate of passage of salmonids. U.S. Dep. Int., Fish and Wildl. Serv., Bur. Comm.. Fish., Fish. Bull. 63(1): 45-62.

Rates of passage of chinook and sockeye salmon and steelhead trout were studied in 1:16- and 1:8-slope, pool-and-overfall fishways. In general, the passage through the 1:8-slope fishway with a 1-foot rise between pools was as fast as, or faster than, in the 1:16-slope with a 1-foot rise. When the rise between pools was .increased to 1.5 feet in the 1:8-slope fishway, chinook and sockeye passage was slower. The "Dalles-type" weir crests (3.3-m, 4-ft pool

width) in a 1:16-slope fishway appeared to accelerate chinook passage. Chinook and sockeye displayed seasonal differences in passage time.

15. Gauley, J. R., C. R. Weaver, and C. S. Thompson.
1966. Research on fishway problems, May 1960 to April 1965. 3d Prog. Rep. Fish. Eng. Res. Program, Corps Eng., North Pac. Div., p. 29-66. Portland, Oreg.

Research program sponsored by the U.S. Army Corps of Engineers to investigate design criteria for fish-passage facilities for hydroelectric projects is reviewed. The primary objective was to provide basic information on the behavior of fish and what is required for fish passage. Major emphasis was on cost reduction of fish-passage facilities without reduction of efficiency to pass fish. Passage times for various salmonids through several fish-ladder designs and the response of salmonids to vertical and horizontal orifices in fishways are reviewed. Counting and identification studies at fishways are also discussed.

16. Gebhards, S., and J. Fisher.
1972. Fish passage ana culvert installations. Idaho Fish and Game Rep., 12 p.

The authors list fish blocks resulting from improper culvert installation that occur at the outfall, within the culvert, and at the inlet. Criteria for installation, including timing of construction, design, and placement to insure fish passage, are given. Design criteria include gradient, velocity, and depth. Use of baffles, separator walls, and multiple installations are discussed. Velocities and distances impeding fish passage are graphed. A design for culvert baffles is also presented.

17. Gregory, R. W., and J. Trial.
1575. Effect of zinc-coated culverts on vertebrate and invertebrate fauna in selected Maine streams. Completion Rep. Land and Water Resour. Inst., 18 p. Univ. Maine, Orono. Sept. 1975.

Effect of zinc loss from galvanized culverts on vertebrate and invertebrate fauna was investigated. Results indicated that corrosion of galvanized culverts significantly increased zinc concentrations in stream water, particularly in newer culverts, although culverts 5-6 years old also showed significant loss of zinc. Highest zinc concentration was correlated with high temperature and low flow. No adverse effect of increased zinc concentration was documented for either fish distribution or invertebrate diversity or abundance, with the possible exception of Spongilla. Levels of zinc were at times above the avoidance threshold (0.05 ppm) of Atlantic salmon.

18. Harrison, M. B.
1972. Analysis of a skewed slot orifice. M.S. thesis. Univ. Idaho, Moscow. 89 p.

Design criteria for a skewed slot-orifice fishway exit are developed. The fishway exit can be constructed using these criteria in culvert wingwalls. The outlet terminates at a skew angle; it can be designed to create flow conditions necessary for fish passage. Values of slot-orifice contraction ratios ranged from 0.65 to 0.82 of the culvert width; culvert slope varied from 1.5 to 4.5 percent; skew angles ranged from 30 to 75°; and three lateral positions of the fishway channel were tested. Dimensional analysis was used to determine the significant design parameters. Design curves that display the relationship between the backwater ratio (H/h) and the Froude number are presented. The design curves and an equation, based on the momentum principle, are used to design two types of

skewed-orifice exits. One problem uses the same contraction ratio for the skewed-exit and normal-slot orifices placed downstream; the other uses different values of contraction ratio for the skewed-exit and normal-slot orifices downstream. Necessary criteria for suitability of flow for fish passage are also discussed.

19. Katopodis, C., P. R. Robinson, and B. G. Sutherland.
1978. A study of model and prototype culvert baffling for fish passage. Can. Fish. and Mar. Serv. Tech. Rep. 828. 78 p.

A hydraulic-model study tested and developed a set of offset and spoiler baffles to aid fish passage through culverts. Based on the model-study recommendations, they were installed at the Mackenzie Highway crossing of the Redknife River. Field testing showed the effectiveness of both baffle types is inversely proportional to culvert slope. Maximum recommended slope is 5 percent. A method of judging adequacy of baffles is provided. The problems created by ice, debris, and sediment are presented. The list of figures includes design dimensions, installation, and water-surface profiles for offset and spoiler baffles, as well as cross sectional velocity distributions.

20. Kay, A. R., and R. B. Lewis.
1970. Passage of anadromous fish through highway drainage structures. Calif. Div. Highw., Dist. 01 Res. Rep. 629110, 15 p.

Authors discuss factors that impede passage of migrating fish and establish design criteria for fish passage. Graphs and tables are included. A field investigation of 40 existing culverts was conducted and their fish-passage characteristics were evaluated.

21. Lauman, J. E.
1976. Salmonid passage at stream-road crossings: A report with department standards for passage of salmonids. Oreg. Dep. Fish and Wildl., 78 p. Portland.

The author's review provides guidance for bridge and culvert projects. Causes and solutions for fish-passage problems--excessive water velocity, inadequate water depth, excessive entrance jump--are discussed. Structural guidelines for location, type, and size of fishway are included. Recommended velocities for adults and juveniles, as well as comprehensive tables and figures, are presented.

22. Leedy, D. L.
1975. Highway-wildlife relationships, vol. 1. A state-of-the-art report. U.S. Dep. Trans., Fed. Highw. Adm. Tech. Rep. FHWA-RD-76-4, 183 p.

An extensive review of effects of highways, including logging roads and construction, on fish and wildlife is given. Also included is habitat created by highway right-of-way. A discussion of erosion, sedimentation, and loss of wildlife habitat is given through a review of existing literature. Roads are identified as a major source of sediment and responsible for drainage of large areas of wetlands. A set of recommendations for additional research on highway and fish and wildlife topics is listed in addition to general guidelines for management.

23. Leedy, D. L., T. M. Franklin, and E, C. Hekimian.
1975. Highway–wildlife relationships, vol. 2. An annotated bibliography. U.S. Dep. Trans., Fed. Highw. Adm. Tech. Rep. FHWA–RD–76–5, 417 p.

A group of 794 references pertaining to the relation of wildlife and fish to highways and highway construction are abstracted. Major topic areas are: (I) The highway system: effects on and relation to fish and wildlife; (II) Opportunities for enhancing fish and wildlife and mitigating or reducing damage to the resource; and (III) Environmental considerations and evaluations in highway planning, construction, and operation.

24. Long, C. W.
1959. Passage of salmonids through a darkened fishway. Fish and Wildl. Serv. Spec. Sci. Rep.–Fish. 300, 9 p. Washington, D.C.

An experiment to produce specific information on rate of ascent of salmonids through a darkened fishway was conducted in a short, pool–and–overfall fishway without submerged orifices. The fish (98 percent steelhead trout) negotiated the 6–pool fishway significantly faster in near–total darkness than in light conditions approximating a bright, cloudy day.

25. Lowman, B. J.
1974. Investigation of fish passage problems through culverts. USDA For. Serv. Equip. Dev. Cent., Proj. Rec. ED&T 2427, 17 p. Missoula, Mont.

The author reviewed problems related to culvert installation, requirements for fish passage including recommended velocities, and corrective measures. Baffles in culverts are discussed with replies from various agencies to a questionnaire on fish–passage problems and use of baffles in culverts. Economic value of spawning areas is reviewed in an appendix.

26. McClellan, T. J.
1970. Fish passage through highway culverts. U.S. Dep. Trans., Fed. Highw. Adm. and Oreg. State Game Comm., 16 p. Portland.

A review of 62 culverts installed by several agencies in Oregon was made (1) to determine effectiveness of installation to pass fish and (2) to evaluate which types were most effective, simplest to install, and least expensive to install and maintain. Review included round pipe, single and double culverts with baffles or other special devices, plated arches (with both open and closed bottoms), and a few nonculvert installations. The author concluded that stream condition at inlet and outlet may override design in importance. Controlling factors for fish passage were velocity, length, slope, and headwater and tailwater conditions. Description of culverts reviewed, problems, and comments on fish passage are given. Evaluation forms with photographs are provided in the appendix.

27. McKinley, W. R., and R. D. Webb.
1956. A proposed correction of migratory fish problems at box culverts. Wash. Dep. Fish. Fish Res. Pap. 1(4):33-45.

The authors discuss culvert standards and methods of culvert correction. Model culvert studies, fishway criteria, and an experiment on grading of baffles are included. Baffle arrangements--types, sizes, dimensions, and so on--are discussed at length.

28. Mavis, F. T.
1943. The hydraulics of culverts. Pa. State Coll. Bull. 56, 34 p.

Two hypotheses are tested: (1) When the culvert flows partly full and the inlet serves as a control section, the discharge is a function of the elevation of the headwater pond above the invert of the culvert at the inlet for a given culvert; and (2) The culvert flows entirely full, and for a given culvert the discharge is a function only of the difference between headwater and tail-water levels. The report includes extensive tests of culvert hydraulics: discharge of culverts flowing partly full, or flowing full and submerged; calculations for free discharge with outlet flowing full; and transitions between categories of flow. The paper includes sketches and tables.

29. Metsker, H. E.
1970. Fish versus culverts. USDA For. Serv. Eng. Tech. Rep. ETR-7700-5, 19 p. Washington, D.C.

This report, directed toward resource managers, illustrates some fishery problems associated with culverts and gives some solutions to them. The author suggests use of multiple culverts, stacked culverts, outlet control, downstream barriers, and baffles to facilitate fish passage.

30. Otis, M. B., and D. G. Pasko.
1964. Suggested measures for minimi'zing damage to fishing streams from highway projects. N.Y. State Conserv. Dep., Div. Fish and Game, Bur. Fish., 4 p. Albany.

The authors include a series of recommendations for streambank stabilization, bridge and culvert installation, gravel removal (generally not recommended), and streambank cover and shelter improvements.

31. Sheridan, W. L.
1969. Benefit/cost aspects of salmon habitat improvement in the Alaska region. USDA For. Serv., Reg. 10, 47 p. Juneau.

A method is presented for benefit/cost analysis of projects to improve habitat, whereby funds can be allotted to obtain the highest dollar return on the investment. The Shrode Creek fishway is evaluated.

32. Shoemaker, R. H.
1956. Hydraulics of box culverts with fish-ladder baffles. Natl. Res. Counc., Highw. Res. Board Proc. 35:196-209.

Placement of transverse baffles in box culverts to provide fish passage has become increasingly necessary in recent years. Model studies were made to determine design factors for baffled culverts related to baffle height and spacing, and to develop hydraulically efficient baffle shapes for use in culverts. The results of the studies, based on the treatment of baffles as roughness in a rectangular conduit, were obtained in the form of velocity-head coefficients--one dependent on and the other independen of friction effects.

33. Skeesick, D. G.
1970. The fall immigration of juvenile. coho salmon into a small tributary. Oreg. Fish Comm. Res. Rep. 2(1):90-95.

An upstream-downstream trap was monitored for 10 years; each fall, an upstream migration of large juvenile coho occurred. An average of 62.6 percent survived and 'returned downstream in the spring as smolts; they avera'ged 14 mm longer than native stock. The recapture rate of adults that had been upstream-migrant juveniles was 0.3 percent and for the native stock it was 0.8 percent. The author theorized that (1) the immigrant juveniles had spent the summer in the main stream where they grew rapidly; (2) they entered the tributary in the fall to escape high water in the main stream; and (3) as adults, they returned to their natal stream rather than to the study stream. Observations from two other river systems appear to substantiate the behavior pattern and suggest that other species may have similar habits.

34. Slatick, E.
1970. Passage of adult salmon and trout through pipes. U.S. Fish and Wildl. Serv. Spec. Sci. Rep.-Fish. 592, 18 p.

This study determined (1) if adult salmon and trout would use a pipe as a passageway, and (2) how the conditions at the entrance and within the pipe--such as diameter and length, illumination, and flow would influence passage. The pipes were 0.3, 0.6, and 0.9 m in diameter and 27.4 to 82.3 m long. Chinook salmon, sockeye salmon, coho salmon, and steelhead trout passed through uniiluminated pipes up to 82.3 m long. Only steelhead appeared to benefit from illumination. For distances up to 82.3 m, a 0.6-m diameter pipe was large enough to pass all salmon and trout. The fish would not readily enter a 0.3-m pipe until special conditions of water velocity and transition from pool to pipe were provided.

35. Slatick, E.
1971. Passage of adult salmon and trout through an inclined pipe. Trans. Am. Fish. Soc. 100(3):448-455.

The author examined a passageway at Bonneville Dam on the Columbia River, which required a descent and ascent by migrating adult salmon and trout. The influence of water velocities on fish passage was measured with velocities of 0.30, 0.76, and 1.22 m/s, and the relation between performance and length of fish was aetermined by comparing median passage times of large and small fish. From 64 to 100 percent of the fish passed through the pipe in 45 minutes. Median passage times ranged from 3-23 minutes. Chinook salmon passed through the pipe most rapidly at the 0.76-m/s flow; coho salmon and steelhead trout passed through at 1.22 m/s. Sockeye salmon passed through equally well at flows of 0.76 and 1.22 m/s. No significant differences were demonstrated between median passage times of small and large chinook salmon, sockeye salmon, coho salmon, or summer steelhead trout. Results of this experiment indicated that if proper flow conditions are provided, a large percentage of migrating, adult salmon and steelhead will pass through an inclined pipe requiring a descent and ascent of about 5.2 m.

36. Tollefson, T. C.
1966. Facilities at culvert installations. Wash. Dep. Fish. 8 p.

Report includes basic recommendations for placement of culverts, use of baffles, downstream controls, separator walls, and multiple installations, plus drawings of these facilities.

37. I'refethen, P. S.
1968. Fish passage research, review of progress, 1961-66. U.S. Dep. Int., Fish and Wildl. Serv., Bur. Commer. Fish., Circ. 254, 24 p. Washington, D.C.

Results of laboratory and field experiments to investigate problems of anadromous fish passage at high dams are summarized. Studies were made on: passage of adult and juvenile fish through large, medium, and small impoundments; design and operation of facilities for passage of adult fish at dams; mortalities of juvenile fish passing through turbines and methods of reducing losses; collection of juvenile fish from rivers, streams, and reservoirs: transportation of juvenile fish: and the effect of the changing environment on passage and survival.

38. U.S. Department of Agriculture, Forest Service.
1975. Making culverts good fish passages. Equip. Dev. Cent. 4 p. Missoula, Mont.

The report covers factors influencing fish passage--velocity, length, resting pools, and water depth. Information is summarized on each topic, with some brief recommendations.

39. U.S. Department of Agriculture, Forest Service.
1978. Fish/culvert roadway, drainage guide. Eng. and Aviat. Manage. Div., Alaska Reg., Juneau. Ser. R 10-42, 125 p.

A guide for engineers, biologists, and hydrologists to aid in solving fish-passage problems, especially for juvenile salmon, trout, and char. Performance ratings of various culvert types, procedures for site selection, methods of determination of the design flow, and hydraulic charts and nomographs are included.

40. U.S. Department of Agriculture, Forest Service, Alaska Department of Fish and Game, and Department of Natural Resources.
1976. Logging and fish habitat. USDA For. Serv., Reg. 10, 21 p. Juneau, Alaska.

This public information pamphlet is directed mainly to specialists in timber-sale layout, sale administrators, and loggers. Some of the major habitat requirements of salmon and trout are described. Basic practices that will help to protect the habitat are listed. Photos of proper and improper methods and examples of good and poor habitats are included.

41. Watts, F. J.
1974. Design of culvert fishways. Water Resour. Res. Inst., 62 p. Univ. Idaho, MOSCOW.

Types of fish migration and typical fish-blockage problems associated with culverts are reviewed. Swimming capabilities of fish as a function of species, fish length, and water temperature are discussed. Also reviewed are: (1) hydrologic characteristics of streams and the importance of the timing of fish runs and peak discharge; (2) a procedure for analyzing culverts of corrugated metal pipe and pipe arches for recommended swimming velocities; (3) slot-orifice fishways for box culverts (slot orifice placed perpendicular to the flow and skewed wingwall slot orifice); (4) design aids developed for hydraulic analysis; and (5) instream construction in or near prime fish habitat.

42. Watts, F. J., P. Dass, C. P. Liou, and M. Harrison.
1972. Investigation of culverts and hydraulic structures used for fishways and the enhancement of fish habitat. Water Resour. Res. Inst., Tech. Rep., 7 p. Univ. Idaho, Moscow.

A method for the design of slot-orifice fishways for box culverts was developed. Characteristics for a satisfactory fishway are identified. Graphs for sizing slot-orifice fishways for a given performance capability of a fish are presented. The hydraulics of slot orifices constructed in the face of skewed wingwalls are explained. A table compiled from existing literature lists the swimming capability of various species of fish.

43. Wightman, J. C., and G. D. Taylor.
1976. Salmonid swimming performance in relation to passage through culverts. Fish Habitat Improv. Sect., Fish and Wildl. Branch, Minist. Recreation and Conserv., 50 p. Victoria, B.C.

The authors review literature on swimming performance of fish in culverts to establish standards for culvert design and installation to insure fish passage. Measured swimming abilities of game and nongame fish are explored, as well as factors affecting swimming performance--such as water temperature, dissolved oxygen, and previous exertion. The authors discuss baffles, downstream controls, and multiple installations. Appendixes include recommendations for proper culvert installation, graphs of swimming performances of anadromous fish, and methods for culvert modification.

44. Ziemer, G. L.
1961. Fish transport in waterways. Alaska Dep. Fish and Game, 12 p.

The mechanics of fish passage at and in pipe culvert waterways under highways are given. Illustrations of stylized models demonstrate stress-level patterns of a migrating fish through time compared with normal performance--for example, the work required of a fish to navigate through a culvert where the upstream end head is less than one pipe-diameter. Hydrodynamics are examined for the following: total opposing force on swimming fish; gradient vector; drag force on the fish; weight of fish; angle of inclination of hydraulic gradient; length of fish; mass density of fluid; velocity of fish relative to the water; rate at which fish expends energy; transit time through culvert; length of culvert; and velocity of fish relative to the channel. The report gives a checklist of controlling factors to consider when designing the culvert.

45. Ziemer, G. L.
1965. Culvert design. Alaska Dep. Fish and Game, 2 p.

Standards for design and placement of culverts in salmon streams are presented; a graph shows swimming capability of migrating salmon related to the horizontal distance between resting pools and the velocity of the water in the culvert.

Anderson, Lynette, and Mason Bryant.
1980. Fish passage at road crossings: An annotated bibliography. USDA For. Serv. Gen. Tech. Rep. PNW-117, 10 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A report of special interest to fishery biologists, resource managers, hydrologists, and road engineers, this bibliography lists publications pertinent to road crossings of salmon and trout streams. Topics include bridge and culvert installation, design criteria, mechanics, hydraulics, and economics, as well as their biological effects.

Keywords: Bibliographies (fish habitat), fish habitat, forest engineering.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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