MEMORANDUM OF AGREEMENT

BETWEEN

ALASKA DEPARTMENT OF FISH AND GAME

AND

ALASKA DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES

FOR THE

DESIGN, PERMITTING, AND CONSTRUCTION OF CULVERTS FOR FISH PASSAGE

This MEMORANDUM OF AGREEMENT (MOA) is made and entered into between the Alaska Department of Fish and Game, P.O. Box 25526, Juneau, AK, 99802-5526, hereafter referred to as the ADF&G, and the Alaska Department of Transportation and Public Facilities, 3132 Channel Drive, Juneau, AK, 99801-7898, hereafter referred to as ADOT&PF. ADF&G enters into this agreement under the authority of AS 16.05.050(13), 16.05.840 – 16.05.860, 16.05.870 – 16.05.900, 16.20.050 –16.20.060, 16.20.094, 16.20.150(c), 16.20.162(e), 16.20.530 and 5 AAC 95. ADOT&PF enters into this agreement under the authority of AS 19.05.010 – AS 19.05.125.

I. BACKGROUND AND PURPOSE OF THE MEMORANDUM OF AGREEMENT

Anadromous and resident fish populations depend on reliable passage through drainage structures when migrating to spawning, rearing and over-wintering grounds. Barriers to fish passage can be a significant factor in fish population decline.

The federal-aid funding received by Alaska for highway, transit and airport projects has grown and continues to grow. This has increased the number of Fish Habitat permits processed annually by ADF&G for culvert-related work by ADOT&PF in fish-bearing waters. This underscores the need for a statewide MOA to provide uniform and consistent guidance to project design and permitting staff.

The State of Alaska is committed both to the maintenance and conservation of its fisheries resources and development of its transportation infrastructure in a safe and economic manner. Therefore, ADF&G and ADOT&PF agree to use the guidelines and procedures identified in this MOA to ensure that, where ADOT&PF and ADF&G have determined that culverts are the appropriate stream crossing structure and are utilized in fish-bearing waters, they are designed and installed to provide efficient fish passage and to ensure statewide consistency in Title 16 permitting of culvert related work. These review procedures and design criteria clarify and make certain that individual project review and permit requirements under AS 16.05.840, AS 16.05.870, and 5 AAC 95.400 – 5 AAC 95.990 with respect to fish passage requirements through culverts are met.

This agreement extends solely to the design, permitting, and installation of culverts in fish-bearing waters. This includes both new culvert installation and reinstallation of culverts during maintenance activities. To the maximum extent feasible and practicable, retrofits of existing culverts shall comply with the relevant portions of this agreement. Non-complying retrofits will be authorized by ADF&G on a case-by-case basis. The agreement does not address any other statutory or regulatory responsibilities of ADF&G or ADOT&PF. Additional factors unrelated to fish passage (such as unique environmental considerations, locating culverts in anadromous fish spawning or high-value rearing habitat, or other public safety, engineering, or economic issues) will be addressed on a project specific basis during preparation of the ADOT&PF environmental document.

II. APPLICATION

This agreement applies to each agency as a whole and specifically to all headquarters, regional, and area personnel within ADF&G Division of Habitat and Restoration, and all personnel within the ADOT&PF Division of Design and Engineering Services, and regional Construction and Maintenance sections.

III. ADF&G and ADOT&PF mutually agree:

A. To apply the interim procedures, design criteria, and guidelines set forth in Exhibit A statewide for the design, permitting, and construction of culverts in fish-bearing waters. In agreeing to this covenant, ADF&G and ADOT&PF recognize that ongoing research is providing new tools and insight into fish passage design. Therefore, both agencies agree to annually review the interim procedures, design criteria, and guidelines as set forth in Part VI.D and to amend this agreement as necessary to accommodate new information and proven fish passage techniques.

B. That ADOT&PF is responsible for the selection, project engineering and technical design of fish passage structures consistent with the guidelines and criteria contained in Exhibit A. ADOT&PF will request assistance from ADF&G as needed to interpret and apply fish passage criteria.

C. That ADF&G is responsible for identifying fish-bearing waters, design fish species and fish length(s), the time of year fish passage is required, type of stream (840 or 870), and anadromous spawning and high-value rearing sites.

D. That permit disagreements involving interpretation or whether the provisions of this MOA have been fully complied with may be elevated first to ADF&G and ADOT&PF's regional supervisors, and secondarily to ADF&G's Director of

Habitat and Restoration and ADOT&PF's Director of Design and Engineering Services, for timely and final resolution. Both agencies recognize the value of this process. Staff in both agencies is encouraged to make use of this process rather than allowing a disagreement to remain unresolved. Nothing in this MOA prevents either agency from resolving permit disagreements in accordance with the provisions of AS 16.05.840—16.05.860, AS 44.62.330—44.62.630, 5 AAC 95.710(c), and 5 AAC 95.920.

IV. ADOT&PF agrees:

A. To coordinate with ADF&G during the earliest possible project phase, but not later than the project's environmental phase, on all projects potentially affecting fish-bearing waters.

B. To have all proposed fish passage structures, including those proposed by Maintenance and Operations, reviewed by the Regional Hydraulic Engineer or other qualified technical experts for compliance with the design criteria contained in Exhibit A.

C. To provide ADF&G reasonable opportunity to field inspect culverts or as-built plans prior to project shutdown, demobilization, and/or release of the contractor(s), in order to ensure that all culverts are installed in accordance with permit terms and conditions.

V. ADF&G agrees:

A. To timely identify of all fish-bearing waters that require fish passage and to provide a list of species present and habitat type present (i.e. spawning, rearing, etc.)

B. To timely provide ADOT&PF with all available information listed in III.C of this MOA early in the design process.

C. To request additional information, if needed, in a timely manner and in a consolidated form. Multiple, unconsolidated requests for information are discouraged.

D. To timely approval of permit applications for culvert installations that comply with this MOA. This covenant is limited to fish passage considerations and does not extend to other components of a project review that are unrelated to fish passage, nor does it preclude ADF&G from requiring compliance with other applicable laws or regulations.

VI. MUTUAL AGREEMENT AND UNDERSTANDINGS.

It is mutually agreed that:

A. Nothing in this agreement obligates any party in the expenditure of funds, or for future payments of money, in excess of appropriations authorized by law and administratively allocated for these purposes.

B. Nothing in this agreement is intended to conflict with federal, state, or local laws or regulations. If there are conflicts, this agreement will be amended at the first opportunity to bring it into conformance.

C. External policy and position announcements relating specifically to this agreement may be made only by mutual consent of the agencies.

D. Both agencies shall meet jointly on at least an annual basis to discuss matters relating to this agreement. Many of the criteria and assumptions contained in this agreement are interim assumptions and subject to further refinement. Either agency may request an earlier review. No revision shall be binding to either agency without the written consent of both agencies.

E. The effective date of this agreement shall be from the date of the final signature.

F. Either party may terminate its participation in this agreement by providing to the other party notice in writing 30 days in advance of the date on which its termination becomes effective.

G. Any material published or data acquired as a result of this agreement may be reproduced with credit given to the agencies or organizations responsible for the development of the material.

SIGNATURES

Michael Downing, Chief Engineer
Statewide Design and Engineering Services
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and Public Facilities

Ken Taylor, Director
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EXHIBITS

EXHIBIT A. Design, Construction, and Maintenance of Culverts in Fish-Bearing Waters. Pg. 7.

EXHIBIT B. FISHPASS.EXE Culvert Fish Passage Program and Technical Advisory. Pg. 19.

EXHIBIT C. ADF&G AS 16.05.840 and 16.05.870 Permit Application Information Requirements for Culvert Installation or Maintenance in Fish Streams. Pg. 25.

EXHIBIT D. Definitions. Pg. 27.

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EXHIBIT A
Design, Construction and Maintenance of Culverts in Fish-Bearing Waters

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Section 1. Background and Purpose

Most water bodies in Alaska contain one or more species of resident or anadromous fish. Fish migrations in these water bodies involve completing one or more cycles of upstream and downstream movements. Fish migrations may occur during all or just part of the year depending on the fish species, life stage, its location, and the type of migration. Fish migrate to spawn, to feed, and to seek refuge from predators or adverse environmental conditions, such as the complete winter freeze-up of a stream, slough, or pond.

To maintain viable and healthy fish populations, all life stages of fish must be able to freely migrate up and down these water bodies. Mature adult fish must be able to reach spawning grounds with minimal delay, especially anadromous fish species. Since anadromous fish species typically cease feeding when they enter freshwaters to spawn, migration delays at culverts can seriously deplete stored energy reserves and impact reproductive success. For juvenile fish, delays in reaching feeding areas, over-wintering habitat, or predator relief areas may affect survival. No data exist that define how much delay is too much. Some of the most productive rearing habitats are in tributaries of major rivers - the very locations most culverts are installed. Inadequately sized and constructed culverts at these locations can significantly reduce fish access to the watershed, potentially reducing the amount of habitat and the number of fish produced. Partial barriers to fish passage may block segments of the fish population. The cumulative impacts of structures that block or impede fish passage to spawning and rearing habitats can threaten populations on a watershed level. Conversely, properly designed culvert and associated in-stream work may mitigate naturally occurring barriers and augment populations of fish by making more habitat available.

Exhibit A describes the procedures, criteria and guidelines that will be used by ADF&G and ADOT&PF for permitting culvert related work in fish-bearing waters. The guidelines are adopted under the FY01 MOA between ADF&G and ADOT&PF. Users of these guidelines are encouraged to read the MOA and enabling statutes and regulations.

The guidelines represent the best available methodology at this time for Alaska. However, some of the fish passage principals and guidelines are based on limited research and field observations. Others are extrapolations from different fish species studies. Ongoing research is providing new tools and insight into fish passage design. Future changes to the culvert guidelines are anticipated as new information becomes available.

Section 2. General Planning

Fish passage structures can have significant bearing on project costs and on the significance of the environmental impacts of a transportation project. Many fish passage problems associated with road crossings of streams can be avoided by considering hydraulic and environmental factors as early as possible in project development. Guidelines for siting culverts and alignment criteria are discussed in the Alaska Highway Drainage Manual and the Pre-Construction Manual. In addition to engineering considerations, siting considerations can include the location of spawning habitat, location of drainage divides or proximity to natural slope breaks, stream widths versus floodplain widths, icing problems, future access needs, vehicle design speed and vehicle sight distance.

Section 3. Fish Passage Design Discharge

- **ADOT&PF's Regional Hydraulic Engineer** is responsible for developing the hydrologic estimates for the fish passage design flow. For ungaged watersheds, ADF&G biologists or others may have local site knowledge that would assist ADOT&PF in making this determination.

- **ADF&G Habitat and Restoration Division** is responsible for identifying the design fish species, size and the time of year fish passage is required.

Current formulas and models for estimating flood flows are based on statistical analysis of rainfall, runoff records, and/or other basin parameters. These estimates are ADOT&PF's best statistical estimate of flood flows and have varying degrees of error. The true value of the flow may be greater or smaller than the predicted value. The expected magnitude of this variation can be determined, if necessary, for some formulas or models as part of the hydrologic design procedure.

Federal, state, and municipal policies directing ADOT&PF's hydrologic analysis are outlined in the *Alaska Highway Drainage Manual* (ADOT&PF 1995).

I. Fish Passage Design Flow

The interim fish passage design high flow (Q_{fish}) corresponds to the 2-year flood truncated for a two-day duration (Figure A-1). In the future, estimates for fish passage design discharge will account for the specified time of year that the design fish is migrating upstream. Multiple design discharges may be needed if different fish species of concern migrate upstream at different times of the year. ADF&G Habitat and Restoration Division staff should be consulted to verify the appropriate timing windows for fish passage.

A. Mainland Alaska (excluding Southeast). The 2-year, two-day duration flood in mainland Alaska generally can be estimated by interpolation using (1) either a Log Pearson Type III analysis (as defined in Water Resources Bulletin 17B, 1981, "Guidelines for Determining Flood Flow Frequencies,") or Jones and Fahl's (1994) regional regressions for the Q_2 instantaneous flood, and (2) Ashton and Carlson's (1984) regressions for the Q_2 three-day duration floods. Linearity is assumed. In some cases, interpolation using Ashton and Carlson's 1 and 3 day delay discharges may be appropriate. On a case –by-case basis other methods may be used if it is determined that neither of the above methods is appropriate for the region or the specific basin characteristics.

B. Southeast and Coastal Alaska (Jones and Fahl, 1994, Flood Frequency Area 1). The interim value for the fish passage design discharge is 40% of the instantaneous 2-year flood (Q_2). In southeast and southern coastal Alaska, the Q_2 may be determined using either a Log Pearson Type III analysis or Jones and Fahl's (1994) regional regressions for the Q_2 instantaneous flood. Preliminary flow duration evaluation of limited gaged watershed hydrology records in SE Alaska suggest that the 40% Q2 fish passage design flow corresponds to a mean daily discharge that is exceeded one to five percent of the time for the record evaluated. The interim fish passage design flow is subject to future revision based on ADOT&PF and ADF&G's evaluation of flow regimes for a variety of channel types and watershed characteristics.

Field-testing in Southeast Alaska uncovered significant variability associated with different methods of estimating the fish passage design flow. Application of regional regressions and Manning's equation produced higher discharge estimates relative to stream gaging and unit discharge/area estimates. This variability has the potential to incorrectly identify culverts as problems that actually do pass fish at design flows. The following specific factors affecting this variability should be recognized (Gubernick and Levesque, July 1999):

1. Use of the USGS regression equations to extrapolate for watersheds less than 1.35 square miles should be used with care. Many culvert crossings in Southeast Alaska have watershed areas much smaller than this, requiring extrapolation outside the regression equations' original data set.

2. Characteristics of small basins are extremely difficult to determine due to limitations associated with aerial photography, topographic maps, and forested terrain.

3. Estimation of Manning's "n" is often understated. Channels in mountainous-forested terrain are considerably rougher due to woody debris, irregular channel

sections, and water depth to grain (substrate) size (small and shallow channels versus large and deep).

4. Wetted perimeter may be under-estimated due to (3) above.

5. Over-estimate of design discharge may result from the redundant conservatism built into current methods for flow estimation.

6. Tail-water depth estimation can be difficult because the estimate must be made in areas of non-uniform flow.

Note: The Q_2, two-day duration flood is the interim fish passage design flow. At present, it applies to all fish species, anadromous and resident alike, juvenile and adult migrants. This standard probably overestimates fish passage design discharges for juvenile salmon; however, it will remain the standard until additional hydraulic and biological studies are completed. If the fish passage discharge estimate based on these methods is unreasonably high, a site-specific hydrologic analysis may be necessary.

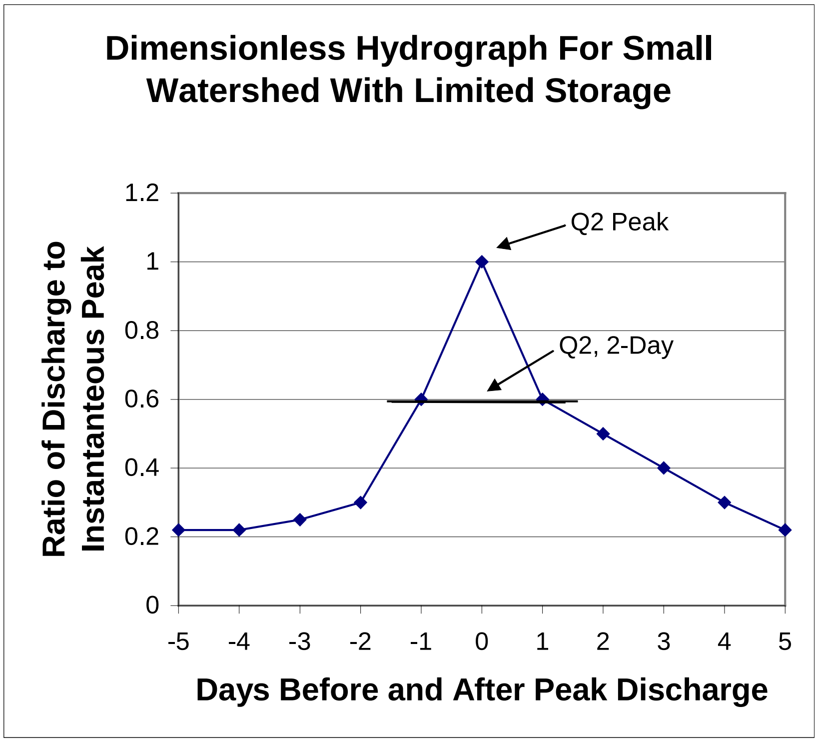

Figure A-1. Median dimensionless hydrograph depicting a two-day duration discharge.

II. Low Flow Evaluation

A low flow design discharge has not been specified. Many streams used by fish are ephemeral or may cease flowing during drought conditions. A written assessment should be prepared evaluating the low flow characteristics during the time of year passage is required.

Water depths during low flow fish passage periods should be concentrated within the culvert barrel to maintain a minimum flow depth that is two and one half times the height of the design fish's caudal (tail) fin (Figure A-2). Interior Alaska Arctic grayling typically have caudal fin heights about 32% of the fish's fork length (McLean, 2000). Thus, a 240-mm Arctic grayling has a caudal fin height of about 77 mm and requires a minimum flow depth of about 192 mm (7.6 inches). Using a similar percentage for juvenile salmonids, a 60-mm coho salmon juvenile requires a minimum flow depth of about 48 mm (1.9 inches).

These minimum flow depths are necessary because fish forced to swim near the water surface or only partially submerged generate surface waves that deplete energy that would otherwise be available to the fish to propel itself through a culvert. These wave-generated forces can consume as much as 2-1/3 times as much energy as the energy required to swim against the same velocity (profile drag) in water depths greater than the minimums (Behlke, 1998, personal communication). Wave induced forces are generally not as significant for adult fish (as a result of their significantly greater power/energy capabilities) and are insignificant for juvenile fish if the submergence depth is more than two times the caudal fin height (measured from the water surface to the midline of the fish (Behlke, 1998). Assuming that the caudal fin is symmetrical (generally true for Alaskan freshwater fish species), the minimum water depth necessary to minimize wave-induced swimming forces is two and one half times the height of the caudal fin.

Note: If resting areas are available within the culvert barrel, the additional wave induced forces may pose less of a barrier to fish.

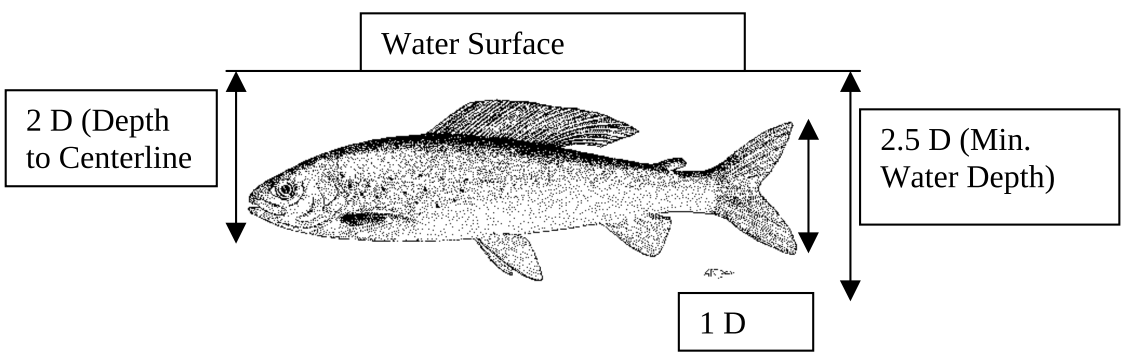

Figure A-2. Minimum water depths for fish passage (D = height of caudal fin).

Section 4. Culvert Guidelines

Culverts in fish-bearing streams will be designed and permitted using one of the following design approaches. The design approaches are presented in a tiered manner, which encourages use of the stream simulation approach by (1) decreasing the level of detailed engineering required for fish passage consideration and (2) increasing assurances that the structure will receive ADF&G authorization. It is the engineer's responsibility to determine which design method best fulfills all facets of design, including site conditions, alignment, and project schedule.   Tier 1 design most closely replicates natural stream conditions. Each succeeding tier further deviates from natural stream conditions and consequently will require progressively more detailed engineering and analysis to ensure that fish passage is provided.

Tier 1. Stream Simulation Design. (*New or replacement installations, particularly in narrow valleys with entrenched flood flows. The stream simulation method is applicable in gradients up to six percent. Additional hydraulic analysis is needed for gradients over six percent*).

Stream simulation, as the name suggests, is a culvert design technique that attempts to replicate natural stream channel conditions within a culvert. Sediment transport, flood and debris conveyance, and fish passage are designed to function as they would in a natural channel. The design methodology is a derivative of Canadian research (McKinnon and Hyntka, 1979, 1985), Washington State's fish passage culvert criteria (Bates, et al., 1999), and The Oregon Plan's Road/Stream Crossing Restoration Guide (Robison, 1998 and Robison, et al. 1999).

Culverts designed using the stream simulation method are sized larger than culverts sized hydraulically for floodwater conveyance alone. The culvert width at the Ordinary High Water (OHW) stage waterline must be greater than the 0.9 * OHW width. The culvert grade should approximate the channel slope, but in no instance should it deviate more than 1% from the natural grade (e.g. a 4% channel with an installed 3% culvert). In stream channels with slopes less than 1% (typically palustrine, estuarine, and flood plain channels), culverts may be installed at slopes less than 0.5% with culvert widths greater than 0.75 * OHW.

Within the culvert barrel, substrate material should remain dynamically stable at all flood discharges up to and including a fifty-year flood. This requires either placement of oversized material that can resist predicted critical shear forces or substrate retention baffles that allow bed load to continuously recruit within the culvert barrel. If gravel retention baffles are used, they should have a weir height of 0.5 times the culvert invert burial depth.   The need for outlet aprons and inlet protection should be investigated and designed as necessary. If needed, outlet aprons should extend about 3 culvert widths downstream or as required based on site conditions.

Invert burial depths for Tier 1 circular culverts should be at least 40% of the culvert diameter. Invert burial depths for arch pipes should be at least 20% of the rise.

If the above criteria are followed, it is assumed that fish passage is met. Further hydraulic analysis to support fish passage is not required. Without question, the initial cost for installing oversized culverts under the stream simulation approach will be higher than the cost of pipes sized strictly for hydraulic capacity. However, higher initial costs may be offset by lower life cycle costs and a simpler, more streamlined permitting process.

Tier 2. FISHPASS Program Design. (*For retrofit of existing installations or new installations where Tier 1 is not preferred. This method requires hydrologic and hydraulic analysis and evaluation of biological parameters based on field documented power / energy capabilities of some Alaskan fish species.)*

Culverts are designed using a combination of traditional hydraulic engineering methods (e.g., HY-8) and the Alaska Interagency Fish Passage Task Force's 1991 "FISHPASS" computer modeling program. The fish passage computer modeling program and background documentation are published in:

Behlke C., Kane D., McLean R., and Travis M. 1991. Fundamentals of culvert design for passage of weak-swimming fish. Alaska Dept. Trans. & Pub. Facil. Rpt. No. FHWA-AK-RD-90-10. Fairbanks, AK.

Subsequent updates of the FISHPASS computer-modeling program are expected to refine the equations for additional fish species and to enhance the modeling capabilities of the program. Current collaborative efforts include merging the FISHPASS program with the U.S. Forest Service's FISHXING computer modeling program. Adoption of this computer software or any other alternative becomes effective under the MOA only upon joint approval of ADOT&PF and ADF&G.

Culverts designed using the FISHPASS computer program must be evaluated for the design discharge for the fish, the design flood hydraulic capacity and effects on the upstream and downstream channel. Appropriate treatments will be investigated if needed to address outlet perching or upstream effects (e.g. headcutting if slope not matched).

Tier 3. Hydraulic Engineering Design. (*For use where site-specific conditions preclude use of Tier 1 or Tier 2.)*

Professionally recognized hydraulic engineering methods will be used to ensure appropriate fish passage characteristics in the culvert. This type of design requires more detailed evaluation of hydrologic, hydraulic and biological parameters. ADF&G's permit review is proportionately more complex.

Table A-1. Summary of Fish Passage Culvert Design Options

DESIGN OPTION	**BENEFITS / LIMITATIONS**
Stream Simulation (Tier 1)	• Minimal design requirements, simplified permitting. • New and replacement culverts. • Passage provides for all fish species and life stages. • Culvert slope generally equals slope of natural

	channel. • Culvert gradients are less than 6%; or if >6%, they are supported by hydraulic analysis of the stability of streambed material within the culvert. • Stream widths are relatively narrow and incised (less than 20 feet at OHW).
Fish Pass / Fish Crossing Model (Tier 2)	• Moderate design and permit review process. • Use for culverts narrower than those required for Tier 1. • Use for new, replacement and retrofit culverts when gradient and virtual mass forces are significant and must be considered at culvert inlet and outlet. • Low to moderate gradient slopes without baffles. • Baffled culverts up to 10% slope. • Target fish species identified for passage. • Suitable for any size watershed or length of pipe.
Other Hydraulic Methods (Tier 3)	• Detailed design and review process. • Must be used for all baffled culverts when installation slope is greater than 10%. • Appropriate for use when installation includes downstream weirs or other tail water control structures. • Use with Tier 1 design to evaluate bed stability when slopes are greater than 6%.
Applied Research	• Experimental structures. Joint ADOT&PF/ADF&G decision. • Detailed engineering and permitting requirements. • Must include post-monitoring and remediation guarantees.

Technical Notes

A. Except as otherwise noted for culverts designed using the Tier 1 – Stream Simulation approach, at least one-fifth of the diameter or 18 inches, whichever is less, of each circular culvert or at least 12 inches of the height of each elliptical or arch type culvert should be buried, at both the inlet and outlet of the culvert, below the natural channel thalweg. This guideline is not applicable to bottomless culverts.

(*NOTE: This is a guideline that may not be able to be met in all cases. The FISHPASS.EXE program does not require depression of the culvert invert. However, routinely depressing the culvert invert increases barrel roughness, Increases the tail water depth, and provides greater assurance that, over time, downstream channel degradation will not result in a perched culvert.*

B. Generally speaking, culvert boundary roughness is a necessity for successful fish passage. Corrugated structural steel plate pipes with corrugations 6 inch by 2 inch or 9 inch by 2.5 inch are recommended. Boundary zone velocities in these rougher culverts typically range between 10 – 40% of the average water velocity (Q/A). In contrast, boundary zone velocities in culverts with shallower corrugations (3 inch by 1 inch) are reduced only about 20% over average water velocity (Q/A). Spiral (helical) and smooth-wall culverts are particularly discouraged, except in low gradient drainages (<0.5%) due to their low Manning's n values. Turbulence in the fish-swimming zone near culvert walls with shallow depth corrugations has been observed to negatively impact passage of juvenile salmonids. Larger depth corrugations also create turbulence; however, field observations suggest the width of the low velocity zone immediately adjacent to the culvert wall is adequate to provide a free passage zone outside the negative influence of turbulence.

For design purposes, circular culverts with 2 inch or greater depth corrugations are conservatively assumed to have boundary water velocities 0.4 Q/A. If a mild water surface profile (M-1 or M-2) exists in the culvert, water velocities near the outlet are assumed to be 0.8 Q/A, gradually decreasing to 0.4 Q/A in the culvert barrel upstream from the outlet acceleration zone (Figure A-3).

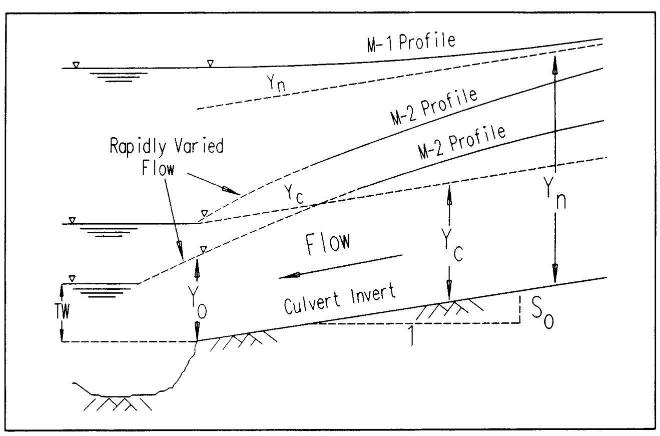

Figure A-3. Water surface profiles in the outlet zone. Y_n, Y_o, and Y_c are hydraulic normal, outlet and critical depths, respectively. M-surface profiles occur because normal depth is greater than critical depth.

C. In general, culverts in fish-bearing waters should be designed for outlet control for discharges ranging up to the design fish passage flow. Field analysis of many culverts shows that most of an Arctic grayling's energy is expended in the white muscle (anaerobic) mode in passing through the culvert outlet. Because of this, culvert tail water depths generally need to be high enough so the outlet flow is sub-critical (Behlke et. al, 1991). This normally precludes inlet control in culverts at the design fish passage flows. In practice, many culverts can be designed to function under outlet control at the fish passage design flow and under inlet control at the fifty-year or other maximum design flood.

   Data have not yet been gathered to evaluate whether this also holds true for stronger-swimming fish. Stronger-swimming fish species such as adult chinook salmon, coho salmon, sockeye salmon, and steelhead may be capable of sustaining burst (white muscle mode) speed for longer time periods (perhaps as long as 7 to 10 seconds) and reaches of the culvert than Arctic grayling and other weak-swimming fish species (Bell, 1986). Juvenile coho have been observed moving past a hydraulic jump within the barrel of a culvert and again past the supercritical flow at the inlet (Kane, 1999).

D. Maximum culvert slopes have not been specified. However, modified (stream simulation, buried invert) or baffled culverts generally are necessary to successfully pass fish at gradients in excess of 3.0 %.

E. If culvert baffles are used, the recommended weir baffle spacing is 0.6 times the culvert diameter with a maximum baffle height of 0.15 times culvert diameter. Weirs should be sharp-crested. Broad crested weirs create a longer, high velocity, distance that fish have to negotiate or leap. Individual weirs may need to be notched, slotted, offset, or slanted to concentrate low flow.

   For juvenile salmonids, Powers (1993) recommends that the maximum hydraulic drop at each weir should not exceed 21.3 cm (8.4 inches) or 30.5 cm (12 inches) for 45 to 65 mm and 80 to 100 mm fish, respectively. Powers (1993) further recommends that the hydraulic drop at the entrance and exit to the baffled culvert should not exceed 4 cm (1.6 inches) or 10 cm (4 inches) for 45 to 65 mm and 80 to 100 mm fish, respectively. Finally, Powers (1993) suggests that the baffled culvert inlet should be submerged 15 cm (6 inches) or more below the pond water surface. (Note: compliance with the invert burial guideline (Note B) meets this standard.)

   In contrast, the U.S. Forest Service interim guidelines for fish passage in the Tongass National Forest suggest use of a more conservative 7.6 cm (3 inch) maximum drop between weir baffles. Until additional field analysis is completed, the designed drop between weir baffles should range somewhere between the U.S. Forest Service Tongass and Powers (1993) recommendations, with designers encouraged to "error" on the conservative side until further clarification is obtained. The above baffle criteria are general recommendations. A hydraulic engineer should check baffle designs for adequacy.

F. Although rapid or fluttering lighting transitions may evoke negative response, most field research indicates that lighting per se within culverts is not a significant factor affecting fish passage (Bell, 1986).

G. The erodibility of channel-bed material at culvert outlets should be evaluated. Appropriate treatments such as a rip-rap apron, energy dissipation pool, or other suitable materials may be necessary to avoid outlet perching. Minimum tail water elevations necessary to achieve fish passage or to maintain minimum culvert water depths should be maintained at all discharges up to and including the maximum fish passage design flow. Impact-type energy dissipation structures generally are not conducive to fish passage and should not be used unless they can be designed to provide fish passage.

H. Whenever possible, culverts should be aligned in a direction as nearly parallel to the direction of water flow as possible. If the culvert is significantly skewed, hydraulic analysis of the inlet hydraulic conditions and barrel boundary layer velocity distributions may need to be conducted to ensure that fish passage conditions are provided.

I. To minimize upstream and downstream channel changes (e.g., head cutting), and the need for additional treatments, culverts generally should be aligned with the gradient of the natural stream. (*See specific limitations for culverts designed using the Tier 1 – Stream Simulation approach.*)

J. The need for normally dry flood relief culverts or roadway sags should be evaluated with regard to culvert bed stability and scour issues at flood flows. These structures would normally be located away from the stream channel but within the flood plain. For example, a site with a narrow deep channel and a wide floodplain may be a candidate for this type of treatment.

K. Culverts should be installed during low flow periods whenever possible. Where significant flow is present, generally acceptable techniques to isolate the construction site from stream flow include but are not limited to channel bypasses, temporary flumes, sheet pile or sandbag walls, water filled cofferdams, or pumping the stream flow around the work site.

L. Installation of trash racks or debris interceptors should be avoided unless they can be designed and maintained to have minimum effect on culvert inlet hydraulics.

M. These fish passage design criteria augment, but do not replace or supercede, ADOT&PF's standard design criteria presented in the A*laska Highway Drainage Manual* (ADOT&PF, 1995) or the American Association of State Highway and Transportation Officials (AASHTO) guidelines. Both hydraulic design requirements and fish passage criteria must be satisfied.

N. Potential changes in watershed land use that could increase the flood discharge flows within the design life of the structure should be considered when initially sizing a culvert.

Section 5. Permit Application Procedures

Application for an ADF&G Fish Habitat Permit for a culvert structure will describe the proposed culvert installation, time periods requested for in-water activity, and for Tier 2 and Tier 3 designs (See Section 4) will include a fish passage analysis for the fish design discharge (Q_{fish}) and an evaluation of low flow fish passage characteristics.

A standard application form is not required for ADOT&PF installations. However, a written description from ADOT&PF is required and should contain the information identified in Exhibit C. The amount of information required is directly linked to the specific design tier used. Tier 1 designs require less site-specific information than Tier 2 or 3.

There will be pre-application coordination between ADF&G and ADOT&PF staff prior to a formal application being submitted. It is easier and less costly for ADOT&PF to revise and modify plans while they are still in preliminary design. Optimally, all disagreements should be resolved before a permit application is submitted to ADF&G.

EXHIBIT B
FISHPASS Culvert Fish Passage Program
And Technical Advisory

FISHPASS.EXE Computer Program

The **Tier 2** evaluation of culverts for fish passage is based on a microcomputer-supported analysis of the combined profile drag (velocity), virtual mass forces, and non-Archimedean buoyant (gradient) forces acting on a swimming fish in a culvert. The component forces are described in the "Fundamentals of Culvert Design for Passage of Weak Swimming Fish" (Behlke et al., 1991). This design is not based on acceptable cross-section culvert velocities. Rather, the design method evaluates the component hydraulic forces within a culvert against a fish's available power and energy capabilities. The analysis further differentiates between the red muscle (aerobic) propulsive mode typically used by fish within the culvert barrel and the white muscle (anaerobic) propulsive mode used under most flow regimes at the culvert inlet and outlet. Power and energy evaluations are particularly useful in steep culverts, perched culverts and culverts with significant inlet contraction where virtual mass and gradient forces become significant relative to profile drag (velocity).

ADF&G, in cooperation with the University of Alaska Fairbanks, currently is funded by ADOT&PF to collect fish swimming performance data for juvenile chinook, coho, Dolly Varden, and cutthroat trout. This information will be used to modify the power and energy equations for non-grayling fish species and will be included in a combined FISHPASS.EXE / Fish Xing program currently under development by the U.S. Forest Service (USFS), Six Rivers National Forest Watershed Interactions Team.[1] A future version of FishXing will include computer simulations of other culvert types, including box, elliptical, squash, and bottomless arches.[2]

ADOT&PF and ADF&G will use the FISHPASS.EXE program and the power/energy equivalents specified in Table B-1 as the primary tool for determining if a proposed **circular** culvert designed using **Tier 2** procedures provides acceptable fish passage. The power/energy equivalents are derived from velocity / time-decay curves prepared by Hunter and Mayor, 1986, and are benchmarked to the observed performance of adult Arctic grayling. Because the power/energy equivalents are based strictly on a comparison of the relative swimming velocities (profile drag) of various fish species, the power/energy equivalents should be used with caution for hydraulic gradients greater than 3%. Culverts with slopes greater than 3% or with significant drops in the water surface elevation (e.g. steep inlet drawdown greater than a 3%) at any point within the culvert will have significant virtual mass and gradient forces in addition to profile drag.

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[1] Under sponsorship from the U.S. Forest Service T&D Program, U.S.Forest Service Rocky Mountain Research Station, Federal Highways Administration, U.S. Forest Service Soil, Water and Air T&D Program, Humboldt State University and Humboldt State University Foundation, and the National Marine Fisheries Service.

[2] A future release of FishXing (Ver. 3) is expected in the near future and will include a separate module using FishPass equations to evaluate fish power/energy requirements.

These additional forces are not included in calculation of the interim power/energy equivalents. Because there is a substantial size difference between adult Arctic grayling and juvenile salmonids, using an equivalent length in FISHPASS.EXE will result in excessive calculation of gradient forces for the much smaller juvenile salmonids. This will over-estimate the actual power / energy required. Hand calculation of forces using actual design fish size and not the equivalent grayling size may be necessary. Until comparative field data become available, the equivalents should be used with some caution. A combination of best professional judgement, FISHPASS.EXE, and other available hydraulic models should be used in these situations.

FOR EXAMPLE, an acceptable evaluation of juvenile coho salmon performance may be obtained for low gradient installation using a fish length 1.57 times the design juvenile coho salmon length (e.g., input 96 mm in the Fish Length field if the design coho is 60 mm). This adjustment reflects the greater power and energy capabilities of coho salmon in the red muscle swimming mode (sustained) for a given length relative to the power and energy capabilities of Arctic grayling. The equivalents are based on the average differential swimming performance of cold-water fish species presented in Hunter and Mayor, 1986 (Tables B-2). Performance values are used only if the reported water temperatures during the test were equivalent to those typically found in Alaskan waters. The interim equivalent values do not include an adjustment for the scale effects of fish length on power capability versus power required (e.g., capability increases by $\text{Length}^{2.34}$ whereas power required only increases by $\text{Length}^{1.8}$). The interim values are set at the lowest differential value where considerable variability exists between studies.

Field observation suggests that the modeling inputs for Arctic grayling may be similar for other adult Alaskan fish species (i.e., relative transit times under red and white muscle modes). Data are not available to confirm their applicability to juvenile salmonids. Although juvenile salmonids have been observed swimming in the same general area adjacent to the culvert wall as adult Arctic grayling, they do so much closer to the culvert wall, where the relative velocities are considerably less than the value used in FISHPASS. Hence, while FISHPASS can be used to model the performance of juvenile salmonids, it should be recognized that the modeled performance is probably a conservative estimate. As additional juvenile fish swimming performance and culvert wall boundary water velocity data become available, these assumptions will be revised and updated.

In some instances it is possible to use the FISHPASS.EXE program to evaluate culverts with non-circular shapes by approximating the actual wetted section with an equivalent partial circular section. Figure B-1 illustrates this concept with an elliptical culvert. Flood discharge capacity (Q_{50}) should be evaluated using other methods that account for the actual culvert section.

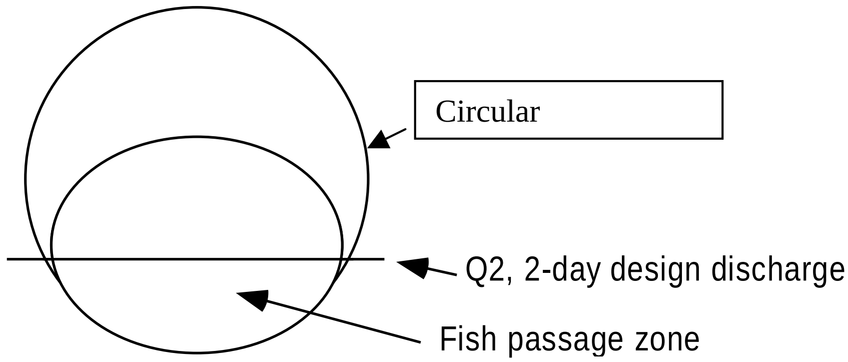

Figure B-1. Circular approximation of an elliptical culvert within the fish passage zone at the design discharge. The equivalent circular culvert diameter is used in the FISHPASS.EXE program..

Table B-1. Equivalent Conversions To Be Used in FISHPASS (< 3% slope) To Evaluate The Performance Of Other Fish Species.[1] (Based on Hunter and Mayor, 1986, velocity-time decay equations.)

Fish Species	**Design Length**	**Equivalent Length To Input In FISHPASS**	**Conversion Factor**
<u>Upstream Migrant Adults</u>			
Arctic Grayling	240 mm	240 mm	1.00
Long-nose Suckers	350 mm	225 mm	0.64
Northern Pike	450 mm	107 mm	0.24
Sheefish	450 mm	175 mm	0.39
Humpback Whitefish	120 mm	120 mm	0.99
Dolly Varden (Arctic char)	450 mm	350 mm	0.78
Steelhead / Rainbow	600 mm	1200 mm	3.03
(*No sustained velocity-time decay curves are available for adult steelhead. The 60-200 mm equation for rainbow trout is applied to adults. This is a conservative estimate. Available power goes up by Length* $^{2.34}$ *whereas required power goes up by Length* $^{1.8}$.)			
Cutthroat Trout	250 mm	*No velocity-time decay curves available; assume equivalent to Arctic grayling (Bell, 1986).*	
Chinook Salmon	600 mm	*No velocity-time decay curves available for this size class; assume equivalent to Arctic grayling 1.57 times as long.*	
Sockeye Salmon	400 mm		
Coho Salmon	600 mm		
Pink Salmon	400 mm	503	1.26
Chum Salmon	500 mm	*No velocity-time decay curves available; assume equivalent to pink salmon.*	
<u>Upstream Migrant Fry/Fingerlings</u>			
Chinook Salmon	60 mm	*No velocity-time decay curves available; assume equivalent to coho salmon (Bell, 1986).*	
Coho Salmon	60 mm	96 mm	1.60
Sockeye Salmon	40 mm	61 mm	1.53
Steelhead / Rainbow	60 mm	182 mm	3.03
Dolly Varden	70 mm	85 mm	1.21
Cutthroat Trout	100 mm	*assume equivalent to Dolly Varden until Alaskan field data is evaluated*	

[1] *To use the equivalent conversion factors, multiply the length of the design fish by the conversion factor and input that product in "Length Field" of the FISHPASS.EXE Program.*

Based on Hunter et al., 1986, velocity-time decay equations. The conversion factors ONLY consider profile drag (velocity).

Table B-2. Swimming performance of Alaskan fish species (from Hunter and Mayor, 1986).

Species	Length Range (mm)	Water Temp. (C)	Burst (m/s)	Sustained (m/s)	Source of Field Data
Northern Pike	100 to 800	12 to 13		1.17*L^0.55*t^-0.1	Jones et al. (1973)
Longnose Sucker	30 to 700			2.39*L^0.529*t^-0.1	Jones et al. (1973)
Humback Whitefish	60 to 600	7 to 20		1.73*L^0.35*t^-0.1	Jones et al. (1973)
Broad Whitefish	50 to 400	12 to 13		1.46*L^0.45*t^-0.1	Jones et al. (1973)
Burbot	100 to 700	7 to 10		2.23*L^0.07*t^-0.26	Jones et al. (1973)
Pink Salmon	494 to 607	20		4.08*L^0.55*t^-0.08	Brett (1982)
Coho Salmon	356 to 510	10 to 19	13.3*L^0.52*t^-0.65		Weaver (1963) and Beamish (1978)
Coho Salmon	40 to 178	8 to 12		3.02*L^0.52*t^-0.1	Glova and McInerney (1977); Davis et al. (1963); Flagg et al. (1983); and Howard (1975)
Coho Salmon	40 to 133	13 to 15		5.67*L^0.7*t^-0.1	Glova and McInerney (1977); Davis et al. (1963); Flagg et al. (1983); and Howard (1975)
Coho Salmon	40 to 120	18 to 20		5.87*L^0.7*t^-0.1	Glova and McInerney (1977); Davis et al. (1963); Beamish (1978); and Dahlberg et al. (1968)
Sockeye Salmon	N/A	2		3.31*L^0.6294*t^-0.1	Brett and Glass (1973)
Sockeye Salmon	N/A	5		3.63*L^0.6243*t^-0.1	Brett and Glass (1973)
Sockeye Salmon	N/A	10		4.46*L^0.6294*t^-0.1	Brett and Glass (1973)
Sockeye Salmon	N/A	18 to 20		4.99*L^0.6293*t^-0.07	Brett and Glass (1973) and Brett (1982)
Sockeye Salmon	N/A	15 to 18		5.21*L^0.06345*t^-0.09	Brett and Glass (1973) and Brett (1982)
Sockeye Salmon	77 to 539	15		4.42*L^0.5*t^-0.1	Brett (1965a)
Sockeye Salmon	126 to 611	10 to 15		5.47*L^0.89*t^-0.07	Brett (1964, 1967, and 1982)
Chinook Salmon	508 to 965	19	11.49*L^0.32*t^-0.5		Weaver (1963)
Rainbow Trout	103 to 280	N/A	7.16*L^0.77*t^-0.46		Bainbridge (1960)
Rainbow Trout	103 to 813	7 to 19	12.8*L^1.07*t^-0.48		Bainbridge (1960); Weaver (1963); and Beamish (1978)

Table B-2 (Continued). Swimming performance of Alaskan fish species (from Hunter and Mayor, 1986).

Species	Length Range (mm)	Water Temp. (C)	Burst (m/s)	Sustained (m/s)	Source of Field Data
Rainbow Trout	610 to 813	7 to 19	12.3*L^0.52*t^-0.51		Weaver (1963) and Beamish (1978)
Rainbow Trout	60 to 200	10		3.28*L^0.37*t^-0.1	Fry and Cox (1970)
Arctic Char	70 to 420	9 to 10		3.74*L^0.606*t^-0.13	Welch (1979) and Beamish (1980)
Arctic Char	70 to 420	9 to 10		2.69*L^0.606*t^-0.08	Welch (1979) and Beamish (1980)
Brook Trout	40 to 270	15		1.99*L^0.43*t^-0.1	Beamish (1980)
Brook Trout	42 to 260	15		2.71*L^0.52*t^-0.1	Beamish (1978 and 1980) and Peterson (1974)
Sheefish	70 to 800	12 to 20		1.29*L^0.175*t^-0.1	Jones et al. (1973)
Arctic Grayling	60 to 400	12 to 20		1.67*L^0.193*t^-0.1	Jones et al. (1973)
Arctic Grayling		1 to 7.1	7.2*L^0.799*t^-0.05		Behlke et al. (1988 and 1989)
Arctic Grayling		1 to 7.1		4.348*L^0.797*t^-0.087	Behlke et al. (1988 and 1989)
Arctic Grayling		1 to 7.1	14.18*L^0.854*t^-0.1		Behlke et al. (1988 and 1989) using Hunter et al. (1986) partial equation methodology

L = total length of the fish in meters (not fork length)
t = duration of swimming effort in seconds
Note: Substitute Arctic char for Dolly Varden char.

EXHIBIT C

ADF&G AS 16.05.840 and 16.05.870 Permit Application Information Requirements For Culvert Installations in Fish Streams

The following permit application information requirements are adopted under the 2001 Memorandum of Agreement (MOA) between ADF&G and ADOT&PF. The information requirements vary depending on which design tier (Exhibit A of the MOA) is used by ADOT&PF.

Tier I Permit.

- Name of waterbody
- Project location, construction timing and plan
- ADF&G Anadromous Catalog Number (if applicable)
- Ordinary High Water channel width
- Channel slope
- Culvert type and dimensions
- Culvert invert burial depth
- Culvert invert slope
- Fish passage design discharge (Q_{fish})
- Assessment/analysis of culvert substrate stability
- Assessment of need for normally dry lateral flood relief.

Tier II Permit.

- Name of waterbody
- Project location, construction timing and plan
- ADF&G Anadromous Catalog Number (if applicable)
- Fish species, size, and time of year (supplied by ADF&G)
- Fish passage design discharge (Q_{fish})
- Stream channel substrate size (or alternately the culvert invert substrate size if an alternative backfill is specified)
- Ordinary High Water channel width
- Channel slope
- Culvert type and dimensions
- Culvert invert burial depth (if buried)
- Culvert invert slope
- Corrugation width and depth
- Low flow analysis (discharge and depth of flow)
- Description of bank armoring or inlet and outlet scour protection (if used)
- Tailwater elevation at Qfish
- Jumping height (if any) if tailwater control is required
- Baffle details if used (type, spacing, height, top angle, slots, etc.)
- Assessment of need for normally dry lateral flood relief.

Tier III Permit.

- Information required for Tier 2
- Summary of analysis supporting fish passage

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EXHIBIT D
Definitions

840-Stream defines fish passage for resident fish streams (AS 16.05.840); is also applied to uncataloged anadromous fish streams.

870-Stream is a cataloged anadromous fish stream specified under AS 16.05.870(a) and adopted by reference under 5 AAC 95.010(a).

Aufeis is an ice feature formed by water overflowing onto a surface such as river ice or gravel deposits, and freezing, with subsequent layers formed by water overflowing onto the ice surface itself and freezing.

Bankfull discharge is the discharge corresponding to the stage at which the floodplain of a particular stream reach begins to be flooded. The bankfull discharge is a morphological indicator that is related to the formation, maintenance, and dimensions of a stream channel as it exists under modern climatic conditions. The bankfull discharge, on average, has a flood frequency of approximately 1.5-years on the annual series. However, this frequency can vary widely depending on the particular watershed and stream reach characteristics. Bankfull discharge in one reach of a stream is rarely the same in adjacent reaches.

Bed roughness is a measure of the irregularity of streambed materials as they contribute to resistance to flow. Commonly measured in terms of Manning's roughness coefficient.

Bedwidth is the distance from the bottom of the left bank to the bottom of the right bank. The distinction between bed and bank are determined by examining channel geometry and the presence/absence of vegetation.

Channel is a natural or artificial waterway of perceptible extent that periodically or continuously contains moving water. It has a definite bank and bed that serves to confine the water.

Critical depth is the depth at which the specific energy of a given flow rate is at a minimum. For a given discharge and cross-section geometry there is only one critical depth. This occurs roughly where $Q^2B / gA^3 = 1.0$ (Q = discharge; B = width of water surface across culvert; g = acceleration due to gravity; A = cross-section area of water flow). However, the relationship changes with different cross-sectional shapes and depths of flow. Hydraulic analysis by a knowledgeable engineer can determine this value.

Design Flood is the probabilistic estimate of a flood whose magnitude is equaled or exceeded within a given frequency.

Grade control structure is a structure placed in a stream channel (generally with its central axis perpendicular to flow) to control bed elevation. Grade control structures can be used to control tailwater elevation and to prevent head-cutting.

Head-cutting is channel bottom erosion moving upstream through a basin and may indicate that a readjustment of the stream's flow regime (slope, hydraulic control, and/or sediment load characteristics) is taking place.

Hydraulic jump is a hydraulic phenomenon, in open channel flow, where supercritical flow changes to sub-critical flow. This can result in an abrupt rise in the water surface.

Invert is the flow line of the culvert (inside bottom).

Manning's n is an empirical coefficient for computing stream bottom roughness used in determining water velocity in stream discharge calculations.

Mean annual flood discharge is the arithmetic mean of all the annual peak floods at a given site and should not be confused with the flood having a recurrence interval of one year. The mean annual flood has a recurrence interval of 2.33-years according to the theory of extreme values as applied to floods by Gumbel (1945).

Migration is the deliberate movement of fish from one habitat to another. Includes the downstream movement of young anadromous fish from streams to sea; the upstream movement of adult anadromous fish from sea to freshwater spawning streams; the movement (upstream and downstream) of juvenile anadromous fish to rearing and over-winter habitats; and the movement (upstream and downstream) of resident fish to spawning, rearing and over-wintering habitats.

Normal depth of flow is the depth at which uniform flow will occur in an open channel, and is determined where $Q = A R^{2/3} S_o^{1/2} /n$ (Q = discharge (m^3/sec); A = cross sectional area of water flow; R = hydraulic radius; So = slope of the energy grade line, n = Manning's roughness coefficient), and requires a trial and error solution. Conversion of the equation to English units (cubic feet per second) multiplies the right side of the equation by a factor of 1.486.
Sub-critical flow occurs when the normal depth is greater than the critical depth.

Super-critical flow occurs when the normal depth is less than the critical depth.

Swimming speeds of fish vary from essentially zero to over six meters per second, depending upon species, size, and activity. Three categories of performance are generally recognized:

> **Cruising speed** is the speed a fish can maintain for an extended period of travel without fatigue. Metabolic activity in this mode is strictly aerobic and utilizes only red muscle tissues.

Sustained (prolonged) speed is the speed that a fish can maintain for a prolonged period, but which ultimately results in fatigue. Metabolic activity in this mode is mixed anaerobic and aerobic and utilizes some white muscle tissue and possibly red muscle tissues.

Burst (darting) speed is the speed a fish can maintain for a very short period, generally 5 to 7 seconds, without gross variation in performance. Burst speed is employed for feeding, escape, and negotiating difficult hydraulic situations, and represents maximum swimming speed. Metabolic activity in this mode is strictly anaerobic and utilizes all of the white muscle tissues.

Thalweg is the line connecting the lowest or deepest points along a streambed.

Velocity is the time rate of motion; the distance traveled divided by the time required to travel that distance.

Mean culvert cross-sectional velocity ($V_{Q/A}$) is the discharge divided by the cross-sectional area of the flow in a culvert. Usually termed "average velocity".

Mean column culvert velocity is the average velocity measured on an imaginary vertical line at any point within a culvert. A measurement at 60% of the depth, measured from the surface, closely approximates the average velocity for the water column. In water greater than 76 cm in depth, the average of measurements made at 20% and 80% of the depth approximates the mean column velocity.

Maximum culvert velocity (V_{max}) is the highest velocity encountered in all cross-sectional profiles in a culvert.

V-occupied culvert velocity (V_{occ}) is the water velocity in the locations within a culvert where fish are actually swimming as opposed to a mean cross-sectional velocity or the maximum velocity.

Fish swimming velocity (V_{fw}) is the velocity of a swimming fish with respect to the ground. It is the summation of the V-occupied velocity and the forward rate of movement of the fish through the water.

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EXHIBIT E
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