TFW Monitoring Program

MONITORING APPROACH AND PROCEDURES
TO EVALUATE EFFECTIVENESS OF CULVERTS
IN PROVIDING UPSTREAM PASSAGE OF SALMONIDS

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Abstract

Culverts at forest road stream crossings may create seasonal or year-round barriers to upstream fish movement. Washington State forest practice rules require that new and replacement culverts be installed to ensure free and unimpeded passage for fish, and that road maintenance and abandonment plans specifically address removing artificial barriers to passage of fish by adhering to specific culvert design guidelines. A watershed-scale culvert inventory procedure is provided herein to evaluate the status of stream crossing structures with respect to Washington State culvert design criteria. It also provides an accounting technique to describe the distribution of culverts throughout the fish-bearing stream network and the significance of these culverts with respect to habitat fragmentation. A passage validation monitoring approach is also described and includes monitoring hypotheses to evaluate the influence of various culvert designs on fish movement under a variety of watershed situations.

1 Introduction

Structures associated with forest road crossings of streams are potential barriers to movement of fish. Culvert installations used for stream crossings may create partial or seasonal barriers to fish movement while others may preclude movement of fishes year-round. Culverts may also delay or deny access to seasonally critical habitats, fragment populations, and suppress the recovery of populations following disturbance. While bridges and fords may constrict the stream channel and inhibit fish migration during high flows, culverts create the vast majority of passage barriers associated with forest roads and are, therefore, the focus of this monitoring plan

The Washington Administrative Code 220-l IO-770 (Water Crossing Structures) provides specific guidelines for water crossing structures to ensure free and unimpeded passage for adult and juvenile fishes in order to preserve access to spawning and rearing habitat. It includes fish passage design criteria consisting of maximum water velocity, maximum hydraulic drop, and minimum flow depths, for all crossing structures. These criteria are used as the technical definition of a fish passage barrier in the forest practice regulatory arena and they form the basis for fish passage design. Some type of barrier is assumed to be present when these criteria are not achieved.

It is recognized that fish passage through artificial structures cannot practically be provided at all flows. In many situations, assumptions are made to define the period of year during which fish passage is required, based upon the species that are expected to inhabit the stream (i.e. spawning runs of adult coho in the late fall or upstream redistribution ofjuvenile salmon from overwintering mainstem habitat). A high flow design discharge is selected to be the upper limit of the range through which upstream fish passage criteria are satisfied. WAC 220-l 10-770 requires that the high flow design discharge be the flow that is not exceeded more than 10 percent of the time during the

months of migration. If at high flow design discharge, the culvert velocities are less than or equal to the allowable velocity 90 percent of the time, the WAC criteria is met. If not, the culvert is considered a barrier.

The WDFW is moving away from designing culverts on the basis of velocity. The stream simulation and the default options of culvert design described in the WDFW culvert design manual (WDFW 1998b) assume that by creating natural bed features inside the culvert, fish passage is assured. This method uses channel width as the main design parameter and is the preferred design option in new culvert placement or retrofit of existing culverts.

1.1   Recognition of the Problem

Inventories of culverts in forested watersheds in Washington conducted by state and federal agencies, the tribes, and private organizations have determined that a majority of culverts situated along forest road networks are technically considered barriers. Almost all culverts on streams with a moderate to steep gradient will technically fail WAC passage criteria (WDFW 1998a). Any culvert with a slope of 1 percent or higher, and water depth of 1-2 feet or more during "high flow" will have an average water velocity greater than 4 feet per second and exceed the WAC criteria (although fish can still sometimes swim upstream). This includes many culverts that present only a temporary, or "flow-dependent", barrier to fish passage or are barriers to juvenile and resident fish only. These temporary and partial barriers are omnipresent because of the preponderance of culverts that exceed WDFW maximum velocity criteria at the high flow design discharge. However, it is recognized that some studies indicate that under certain conditions, fish are capable of swimming through higher velocities and jumping greater heights than those indicated by culvert design guidelines (summarized by Kahler and Quinn 1998).

Restoration of fish passage through culverts is becoming a key component of road maintenance plans required of forest landowners. The Forests and Fish Report (USFWS et al. 1999) is the basis for changes in the states forest practice rules to address salmonid Endangered Species Act issues. The report states that one policy objective for the management of forest roads will be "- to maintain or provide passage for fish in all life stages.. .". To achieve these policy objectives, "..the rules and Forest Practice Board Manual will be amended to provide for.. .removing artificial barriers to passage of fish at all life stages." Landowners will be required to develop and implement road maintenance and abandonment plans for all state and private forest roads. Repair or maintenance work to improve fish passage is listed as a priority action for implementation of the plans.

1.2 Need for Monitoring

Considering the high costs of culvert retrofits and the preponderance of culverts that are technically defined as barriers based on WAC criteria, forest managers and landowners recognize the need to know the effectiveness of various culvert designs in maintaining and restoring fish movement. Although the culvert installation requirements have been in place for several years and fish passage improvement projects have recently been emphasized, there has been little systematic effort to monitor the effectiveness of these efforts in maintaining or restoring fish passage. Moreover, the cl-iteria on which barrier determinations are made have not been investigated for their wide application. For

instance, there has not been a systematic analysis to test the assumption that stream crossing structures installed according to the design criteria in the WAC allow unimpeded passage for all species/life history stages in all situations. Likewise, no investigations have attempted to test the assumption that stream structures <u>not</u> installed according to the design criteria in the WAC <u>do not provide</u> passage for species/life history stages that are actually attempting to move upstream

The adaptive management section of the Forests and Fish Report identifies monitoring to determine the effectiveness of culverts in passing fish as a high priority adaptive management project. Understanding the relative impact that any particular culvert has on fish movement, habitat connectivity, and population fragmentation is crucial to effectively incorporate monitoring findings towards adaptive management.

1.3   Goals and Objectives of the Monitoring Program

The TFW Monitoring Advisory Group has requested the development of monitoring procedures to evaluate the effectiveness of culverts associated with forest practices in providing for the upstream passage of salmonids. We have designed a monitoring plan that combines an inventory of culverts and associated habitats with a supporting component of passage validation study that attempts to describe the relationships among fish movement, site situations, and culvert features.

The goals of this monitoring plan are two-fold

- To determine the effect of multiple crossing structures on the habitat availability and fragmentation of salmonid populations.
- To determine the effectiveness of various culvert designs in providing passage for salmonids attempting to move upstream in actual field situations.

Specific objectives of the monitor-ing plan include:

- Conduct an inventory of road crossing structures to determine their compliance with WAC passage criteria;
- Conduct a habitat assessment to evaluate the influence of road crossings identified as bar-riers on habitat availability and connectivity;
- Investigate how stream crossing structures affect the volitional upstream movement of fish; and
- Evaluate the correspondence between structural and hydraulic features of culverts, barrier status, and fish movement.

The components of the monitoring plan are presented in two sections. The watershed-scale culvert inventory procedure is designed to evaluate the status of stream crossing structures with respect to WAC hydraulic design criteria. It also provides an accounting technique to describe the distribution of culverts throughout the fish-bearing stream network and the significance of these culverts with respect to habitat fragmentation.

The second part, passage validation monitoring, has been designed to identify and account for the variability in volitional fish movement under a range of watershed settings and culvert designs. We realize this work is expensive and technically challenging, requires multi-year commitment, and is not feasible to apply to a broad-scale monitoring program

that includes inventory of all culverts in a watershed. Consequently, this more intensive fish passage study would likely be applied to a limited group of study sites.

2 Watershed-Scale Culvert Inventory

2.1 Monitoring Questions

The inventory phase is structured around collection of information to determine barrier status according to hydraulic criteria of WAC 220-1 1 O-770 (which is included as Appendix A) and to describe the extent of accessible habitat associated with each stream crossing structure. The inventory phase of culvert monitoring is designed to address the following questions:

a) Is a particular structure considered a barrier to upstream passage of fish based on WAC criteria?

b) How do stream crossing structures affect habitat availability for the variety of salmonid life history forms that utilize a watershed?

c) How does the barrier status of stream crossing structures and associated habitat fragmentation change over time?

2.2 Inventory Procedures

The WDFW *Fish Passage Barrier Assessment and Prioritization Manual* (WDFW 1998a) describes methods for collecting detailed physical measurements of the culvert and stream channel to allow for barrier analysis, and these methods are incorporated into this monitoring program. However, the habitat assessment procedures proposed herein deviate markedly from the WDFW methods for habitat evaluation.

The habitat assessment will be combined with the barrier assessment to evaluate the cumulative effect of blockages in a watershed and document changes in habitat availability and fragmentation over time as the status of blockages change. The habitat assessment will also provide information that can be used to test for associations among fish movement, fish passage, and habitat characteristics as part of the passage validation phase.

2.2.1 Preliminary Information Gathering and Mapping

The inventory procedure begins with preparation of a map that identifies the entire channel network and road system. Ideally, these map products will include stream name, WRIA and stream numbers, road names / numbers, and water type maps. A unique identifier code should be assigned to each stream crossing structure at this phase. Fish-bearing waters should be indicated, and include information regarding species distribution.

Two sources of information include current DNR water type maps for the region and the Washington Department of Fish and Wildlife Washington Rivers Information System (WARIS). Neither of these sources are consistently accurate; that is they typically underestimate the range of fish-bearing waters in a basin, and these errors are most commonly associated with small, higher gradient headwater and valley wall tributaries.

According to the WDFW, satisfaction of one or more of the following criteria qualifies a water as fish-bearing. If none of the criteria are met, the water is considered non-fish-bearing.

Fish-Bearing Criteria

- Water course having ordinary high water widths in excess of 2 feet in Western Washington and 3 feet in Eastern Washington, provided the stream gradient is less than 20 percent.
- Water courses listed as Type 1,2,3, or 4 on the DNR Water Type Maps
- Water courses listed as fish-bearing in "A Catalog of Washington Streams and Salmon Utilization
- Water courses listed as fish-bearing on StreamNet (http://www.streamnet.org)
- Stream reaches (less than 20 percent gradient) that are found to be flowing during the summer months regardless of their size
- Roadside ditches/streams that are accessible to fish and have flow characteristics that provide useable fish habitat
- Water courses with documented salmonid use determined by visual observation, electrofishing, or verification by local biologists

The barrier assessment will be conducted only on culverts that are situated on fish-bearing waters as determined above.

2.2.2 Barrier Assessment

A limited amount of detailed physical measurements will be taken for each culvert in the inventory phase to allow for barrier analysis. Culverts that substantially violate WAC criteria can be readily identified in the inventory phase with a small sub-set of information required to conduct a comprehensive hydraulic analysis as described in the WDFW barrier assessment **manual.**

2.2.2.1 Physical Measurements of Culverts Associated with Fish-bearing-

Physical measurements will be made for each stream crossing structure associated with a fish-bearing stream following general methods described by the WDFW (1998a). Table 1 denotes information that shall be collected as part of the inventory phase. This information is generally consistent with the information required for the Level A barrier analysis described by the WDFW. The information in Table 1 can be analyzed in the field to identify the majority of culverts associated with forest roads that are barriers according to WAC, without collecting additional data for a more detailed hydraulic barrier analysis.

Table 1. Stream crossing structure information obtained during the inventory phase of the TFW stream crossing structure monitoring program. The variables will be input into the crossing structure database.

Attribute	Description
Stream Crossing Structure ID	Unique identifier for each stream crossing
WAU #	Watershed Administrative Unit
Road Number	Unique identifier for each forest road
Stream Name	Name of stream if available
WRIA Number	Water Resource Inventory Area number of stream
Tributary to	WRIA and stream number of the water body to which stream is connected.
Associated Stream Segment	The segment ID number, should be consistent with stream ID number used in stream segment database (Table 2)
Species use	The species expected or known to use the stream where the culvert is located. Multiple entries allowed.
Crossing structure type	Specifies the type of structure using one of the following codes; br = bridge, c = culvert, f = ford
Following information collected for culverts only	
Shape	Specify the shape of culvert using one of the following codes; rnd = round, box = rectangular, arch=bottomless arch, sqsh= squash (pipe arch), ell=ellipse, oth = other
Material	Specify the material of which the culvert is constructed using one of the following codes; pcc=precast concrete, cpc=cast in place concrete, cst=corrugated steel, sst=smooth steel, cal = corrugated aluminum, sps = structural plate steel, spa = structural plate aluminum, pvc = plastic, tmb=timber, mry=masonry, oth=other
Span	The horizontal dimension of the culvert.
Rise	The vertical dimension of the culvert.
Length	The length of the culvert. Includes apron if present.
Streambed material in culvert	Specifies the presence of streambed material throughout the entire length of the culvert. Values are; yes and no
Outfall drop	Distance from the water surface at the downstream end of culvert to the water surface of the plunge pool.
Culvert slope	Slope of culvert, reported in percent determined with a standard level and tripod or a hand level in association with a staff of pre-established height; both are used in conjunction with a stadia rod. For reasons of accuracy, the use of a clinometer is not recommended.
Barrier status	Results of Level A culvert evaluation - barrier determination. Values are: no = not a barrier; yes = barrier according to WDFW culvert slope and hydraulic drop criteria; flow = flow dependent barrier requiring hydraulic analysis
Culvert condition	Indicator of condition using one of the following codes; c = clear, b = bent, cd= crushed, debris, r=rusted through

2.2.2.2 Barrier Analysis

Although there has not been a comprehensive evaluation of whether the criteria in the WAC or the assumptions used to assign "design flows" are broadly applicable, the WDFW Barrier Assessment method provides a consistent technique for comparing hydraulic conditions of culverts and is widely used in permitting and culvert design. The criteria in WAC 220-I IO-070 provide a technical definition of a fish passage barrier as well as the basis for fish passage design. Some level of barrier is assumed to be present when the criteria are not achieved. Although detailed field measurements and data analysis is needed to determine the barrier status on some crossing structures, culverts that substantially violate WDFW criteria (WAC 220-l 10-70) can be readily identified. After collecting descriptive information and physical measurements outlined in Table 1, each stream crossing structure will be classified into one of three provisional barrier classifications by the following steps:

a) Is there natural streambed material throughout the culvert?

    i) If yes; is the culvert width (span) at least 75% of the average bankfull channel width at the second riffle downstream of the culvert?

- If yes, the culvert shall be classified as *not a barrier*
- If no, the culvert shall be classified as a *flow-dependent barrier*, and a hydraulic analysis would be needed to determine if WAC criteria are exceeded

    ii) If no; is there an outfall drop greater than 0.8 feet?

- If yes, the culvert shall be classified as *complete barrier*
- If no, is the culvert slope greater than or equal to 1%
  - 3 If yes, the culvert shall be classified as a *complete barrier*
  - ➢ If no, the culvert shall be classified as a *flow-dependent barrier*, and a hydraulic analysis would be needed to determine if WAC criteria are exceeded.

Additional information will be gathered on culverts identified as flow-dependent barriers that are selected for the passage validation study described in Section 3. The end product of the barrier analysis conducted during the inventory phase will be a map and associated crossing structure database as described in section 2.2.4.

2.2.3 Habitat Assessment

The habitat assessment procedures conducted as part of the inventory phase have been designed to evaluate the significance of any one particular culvert in restricting access to seasonally important habitats or in fragmenting populations. The habitat assessment will be combined with the barrier assessment to address the cumulative effect of blockages to species-specific life stages in a watershed, as well as to document changes in habitat availability and fragmentation over time as the status of blockages change.

The habitat assessment shall consist primarily of three stages: mapping and channel segmentation; field collection of channel and habitat data; and identification of artificial or natural passage barriers upstream or downstream of the culvert

2.2.3.1 Mapping and channel segmentation

Working from topographic maps and aerial photographs, the channel network will be partitioned into channel segments. A segment will be defined as a portion of stream with similar gradient, confinement, and morphologic conditions such that all portions of the segment are similar to one another. A segment will be delineated based on seven classes of channel gradient and three classes of valley bottom confinement as indicated in Table 2. Partitioning will be initially done using topographic maps and aerial photos, then verified in the field on segments that are associated with culvert crossings. Each stream segment will be labeled with a unique identification number. Segments will extend a minimum of 1000 feet. If a culvert is situated within a segment and not at a segment break, the segment will be partitioned accordingly and assigned a unique segment subdivision identification   code.

2.2.3.2 Channel and habitat surveys

Additional data will be collected to support initial channel segment partitioning, as well as to provide information on general habitat characteristics. Field efforts expended as part of the inventory phase will be limited to 500 feet upstream and downstream of each culvert (although the entire channel network will be partitioned into segments). If a barrier to upstream migration is encountered within 500 feet of the culvert, then field investigation is terminated at this point. Field efforts during the inventory phase will include verification of gradient and confinement calls, estimates of average bankfull channel width, categorical measures of channel morphology and habitat characteristics, and identification of other natural or man-made impediments to upstream fish passage (Table 2).

2.2.4 Data Management and Analysis

The inventory methods described above will result in information pertaining to fish distribution, stream habitat, and stream crossing features. These information bases are combined to determine the effect of multiple crossing structures on the availability and fragmentation of salmonid habitat in a watershed as described below.

2.2.4.1 Inventory Mao and Database Structure

Data collected in the procedures described above shall be input into a relational database file linked to either a GIS coverage or 7.5 minute topographic maps if GIS is not available. Each row of the database is a data record that contains data items specific to a particular stream segment (in the stream database) or to a stream crossing structure (in the crossing structure database), Each column, or data field, contains a single data item with a data record.

Each segment of the entire stream network will be assigned a unique segment identification number. All fish, channel, and habitat data gathered in the preceding steps will be compiled with the segment number with which it is associated. Similarly, each road crossing structure data record will be assigned a unique identifier under which all associated culvert feature data will be compiled with the structure identifier.

Table 2. Channel and habitat attribute descriptions investigated during the TFW stream crossing structure monitoring program.

Attribute	Description
Segment ID	Unique segment ID number
Sub-segment ID	Alpha code to depict location within a given segment relative to all stream crossing structures or to natural barriers
Date and time	Date and time surveyed
Water Type	Determine limit of fish distribution per the DNR emergency rule protocol
Stream Order	What is stream order based on the DNR Hydrology layer
Channel Slope	Measured in %
Channel Slope Class	As determined from topographic maps and defined as <1, 1-2, 2-4, 4-8, 8-12, 12-20, 20+
Channel Confinement	Rated as tight, moderate, or unconfined as described by watershed analysis standard methods (WFPB 1998)
Bankfull Channel Width	Bankfull channel width as estimated by a representative portion of the natural channel reach width near culvert
Dominant/Subdominant Substrate	What is the dominant and subdominant or codominant channel particle size (e.g. gravel/small cobble, large cobble/boulder, etc.) following modified Wentworth classification
Barriers	Identify location of potential natural and man-made barriers based on existing information. A waterfall greater than 4 m high will be considered a natural point barrier, and if the stream gradient exceeds 20% for 160 m, it will be considered a gradient barrier.
Accessible Habitat	Length of accessible stream by gradient class within either direction from the study site as obtained from map and based on barrier identification described above.
Elevation	Approximate elevation of the downstream-most extent of segment, determined from topographic map

Tables 1 and 2 provide details of the data items stored in each data record included in the road crossing structure and stream channel relational databases. These tables provide descriptions of each field in a data record, including field name and kind of data field. These relational databases linked to GIS coverages provide an effective means for maintaining, analyzing, and querying a large amount of information. Data items in each of the databases can be effectively linked by the GIS coverages as well by using the stream segment number as a data field in both the stream and crossing structure databases.

2.2.4.2 Inventory Synthesis to Gain Watershed-Scale Perspective

Information regarding salmonid species distribution among the fish-bearing stream network, characteristics of habitat in relation to stream segments and road crossing structures, location and barrier status of stream crossing structures, and distribution of segment-scale habitats (as defined by channel gradient and confinement class) has been gathered to this point. This information has been compiled in databases linked to GIS coverage of the stream channel and road network for each studied watershed. 'These

relational databases will be used to monitor the extent of habitat fragmentation created by the road as follows:

- All fish-bearing streams will be partitioned into channel segments.
- Stream segment numbers will be the unique identifier around which a database is built.
- Species distribution maps will be overlaid to determine the species associated with each segment.
- GIS will provide the linkage among specific stream segments and crossing structures.
- In the stream crossing structure database, each structure will be identified as to the segment in which it occurs.
- The amount and relative percentage of stream segment types situated upstream and downstream of each culvert will be calculated and entered in the stream crossing structure database

For a given watershed, the amount of habitat fragmentation caused by stream crossing structures is determined by summing the total lineal distance of stream by gradient class, confinement, and stream order (a surrogate for stream size) situated upstream of stream crossing barriers that would otherwise be accessible. The percent of habitat where access has been precluded (assuming a barrier designation as defined by WAC criteria creates a block to upstream movement) can be determined by dividing the amount of habitat upstream of barriers by the total amount of habitat in that particular drainage basin or in the entire watershed. The impacts can be sorted by any combination of species, barrier status, and segment type. Using the GIS, the information can be visually portrayed by producing a map displaying, for example, the distribution and barrier status of culverts and the associated length of contiguous accessible habitat they potentially fragment.

Changes in a culvert's barrier status and how it affects habitat availability can be examined by the using the relational database. For example, the increase in available habitat resulting from providing passage through certain barriers can be calculated, providing an effective tool to compare the significance of each culvert in terms of habitat fragmentation. The inventory products will provide a means of tracking the barrier status of stream crossing structures and attendant degree of habitat fragmentation through time.

3   Culvert Passage Validation

Barrier determinations made by physical and hydraulic measurements as described in Section 2 may not accurately represent the influence a culvert has on fish movement in all situations. In order to document the actual effect of a culvert on fish movement and to determine if the culvert is effective in providing passage in a given situation, it is necessary to collect information on the behavior of the fish in response to the culvert

Many culverts that are determined as barriers based on WAC criteria are not barriers to upstream movement during some flows. In some situations, culverts are expected to be impassable for only brief periods based on hydraulic conditions. The significance of such barriers on fish movement in field situations has not been thoroughly investigated, especially where the occurrence and timing of fish movement is poorly understood. Also, there are gaps in knowledge about the movement patterns of various salmonid species and life history stages (particularly of resident and juvenile salmonids) in small stream channels, It is known that the volitional movement of fish can vary greatly among species, lifestages, habitats, seasons, and years (Gowan et al. 1994, Kahler and Quinn 1998).

The passage validation monitoring component described below proposes an approach and methods to investigate to what extent fish movement occurs in different types of stream channels and how culverts actually affect fish movement in a variety of situations. This component will provide information needed to test the effectiveness of fish passage prescriptions at restoring and maintaining fish passage, a priority monitoring and research project in Appendix L-l of the Forests and Fish Report Procedures to investigate the influence of culverts on movement of both adult and juvenile resident and anadromous fish are   provided.

3.1   Monitoring Questions and Hypotheses

We formulate monitoring questions and hypotheses on I) volitional upstream movement of fish, 2) culvert effects on upstream movement, and the 3) the correspondence between hydraulic conditions and fish movement.

Volitional Movement

> **Monitoring Questions:** In what stream settings does upstream movement of the various salmonid species and life history stages most often occur? Does site situations affect overall, directional, or seasonal movement of fish?

> Null Hypothesis: Overall, directional, or seasonal movement is independent of site situation category and season.

Culverts Influence on Fish Movement

> Monitoring Questions: Does a stream crossing structure provide equal fish passage to the adjacent natural stream reach? In what stream types and locations in a basin are culverts likely to block fish movement?

> Null Hypothesis: Culvert structures have no effect on overall, directional, or seasonal fish movement regardless of the site situation and season

*Correspondence **of** Fish Movement and Culvert Barrier Status*

Monitoring Questions: Are barrier status determinations (complete barrier, flow-dependent barrier, not a barrier) and culvert compliance ratings (percent of time passage design criteria exceeded) accurate in portraying the influence of culverts on fish movement? Does a culvert that is considered a barrier for only a short duration affect fish movement as much as one that is considered a barrier under all flows?

Null Hypothesis: Culvert structures have no effect on overall, direction, or seasonal fish movement regardless of the culvert barrier status and compliance rating.

Culvert Structural and Hydraulic Features

Monitoring Questions: Is there a relationship between fish movement and physical and hydraulic features of culverts? What features and hydraulic conditions of stream crossing structures are most related to fish passage problems? Are some culvert designs more effective at providing for upstream fish movement? How can crossing structures be improved for fish passage?

Null Hypothesis: Fish movement through culverts is not related to the physical and hydraulic design features.

Evaluation of each hypotheses will be discussed in greater detail in Section 3.3. Measures of fish movement that will be tested in the hypothesis evaluation, such as proportional daily movement (PDM) and fish passage efficiency (FPE) are described in section 3.2.3.

3.2 Methods

A wide variety of stream conditions that may influence fish movement in different ways occur throughout forested watersheds of Washington. This study incorporates comparison of fish movement measures across natural reaches with movement through culverts. In order to effectively investigate the influence of culverts on fish movement, this study attempts to control for several key factors that may influence fish movement independent of the culvert. A basic principle of sampling design states that if an area to be sampled has a large-scale environmental pattern, break the area up into relatively homogenous subareas in order to control for extraneous factors that may affect the response variable, in this case, fish movement.

3.2.1 Study Design

A stratified sampling design will be used to group the factors that are predicted to influence fish movement. These groupings enable effective sample site selection to ensure sampling a wide range of conditions of interest and provide a framework for extrapolation of findings to similar situations. These groupings should greatly reduce the among replicate sample (error) variation in movement and passage estimates, thus allowing evaluation of passage effectiveness under a variety of watershed situations. This grouping would facilitate site selection for monitoring in order to evaluate specific problems encountered with stream crossing structures.

3.2.1.1 Site Situation Categories

The basic unit for grouping sites (referred to as site situations hereafter) will be based on a combination of position in the drainage network, channel gradient class, ecoregion, and life-history forms present in the watershed. Position in drainage network accounts for species and potential for certain life history forms to inhabit a given site. Channel gradient class serves to control for the variety of habitat conditions that may influence fish movement during certain seasons and flow conditions. Climatic region classification effectively separate the forest lands into climatic zones which influence stream temperature regimes and run-off patterns, which in turn may influence fish movement. These groups will be further categorized based on the presence of stream crossing structures and their barrier status.

Working from the map and database products described under the inventory phase, each stream crossing structure will be assigned to a site situation category based on channel morphology, position in the drainage network, dominant run-off pattern, and species/life history forms that inhabit the local drainage basin (Table 3).

Table 3. Variables used to define site situation categories for TFW stream crossing structure effectiveness monitoring.

Watershed Position (5 categories)	Channel Gradient (%) (5 categories)	Region / Run-off Pattern (5 categories)	Life History Forms (4 categories)
Mainstem	< 2	Southwest Washington Lowlands	Anadromous fish use by pink and chum salmon only
Valley Floor Tributary	2-J	Olympic Mountains and west-slope Cascades	Anadromous fish use includes coho, chinook, sockeye, and/or steelhead
Valley Wall Tributary	J-8	East slopes Cascades	No anadromous use, but potential use by resident fluvial or adfluvial populations
Primary Tributary	8-12	North central east Washington	stream resident trout or char only
Headwater Tributary	12+	Spring creek any region	

Note: While it appears that there are 100 possible site situation based on physical characteristics alone, many combinations of position and gradient rarely occur. For instance, low-order tributary channels that flow across the valley floor of a mainstem river will rarely exceed 4% gradient, whereas channels situated on the valley wall of mainstem river valley generally exceed at least 4% gradient. Moreover, spring creek run-off patterns dominated by groundwater upwellings (i.e fairly consistent flows throughout year) are infrequent in forest lands of Washington.

3.2.1.2 Study Sites

Study sites should be selected, and effort distributed, among the array of strata defined by the site situation categories. Study sites will include streams with and without culverts present. Suggested attributes of study sites include:

. No natural barriers to upstream movement of adult salmonids occurs within 300 m of study culverts.

. They should contain populations of one or more target species (salmonids) and lifestages.

• Sites where substantial numbers of fish exist will yield the most useful information, and reduce the potential bias associated with studying individual fish at sites with low fish abundance,

. As a group, study sites represent a broad range of actual field situations.

. They are accessible during the course of the study.

Equal sample size per situation category is desirable, but we recognize that few or no actual field situations exist for some categories. We also recognize that some site situation categories may be of more interest to the resource managers responsible for allocation of restoration and monitoring efforts. For instance, culverts situated on moderate to high gradient headwater tributary channels represent the vast majority of culvert barriers, whereas culverts situated on valley floor primary tributaries may represent the greatest potential influence on species of special management concern.

An important aspect of this study design is the comparison of movement of fish through a reach "treated" with a structure with the movement of fish through a "control" reach situated just downstream. In order to validate such an approach, study sites should also include streams without culverts to determine if control reaches situated immediately downstream of fish passage structures adequately describe the upstream movement of fish in natural channels.

3.2. I .3 Sample Reaches within Study Sites

In study sites that include a stream crossing structure, one sample reach will be located just upstream of the stream crossing structure (Reach C), while one is situated just downstream of the crossing (Reach B). The third sample reach (Reach A) will be will be located downstream of Reach B and separated from it by a natural stream reach equal to the distance between Sample reach B and Sample reach C (Figure 1). In study sites with no stream crossing structure, three sample reaches will also be established, each situated 35 m apart (roughly equivalent to the length of a culvert under a double lane forest road).

3.2.1.4 Sampling Periods

Sampling should be scheduled for at least 3 visits during at least 3 sampling periods (seasons) at each study site, generally durin g low, medium, and high flow periods, and ideally such that: 1) the low flow produces water depths less than the design depth WAC criteria (e.g., structure is rated a barrier); 2) the high flow produces water velocity greater than design velocity WAC criteria (i.e., structure is rated a barrier); and 3) the medium flow produces water depth and velocity within the WAC criteria (i.e.. structure is rated passable). Some culverts may be considered barriers at all flows, yet sampling should still target 3 different sampling periods. Besides achieving these flow conditions, sampling should occur during periods when upstream migration of target fish is expected. These dates vary among species, life history forms, flow regimes, and region of the state and should be determined in consultation with local agency, tribal, and industry biologists.

Length of natural control and the treated culvert reach should be the same and approximately the same length of the stream crossing structure

Flow

Sample Reach C

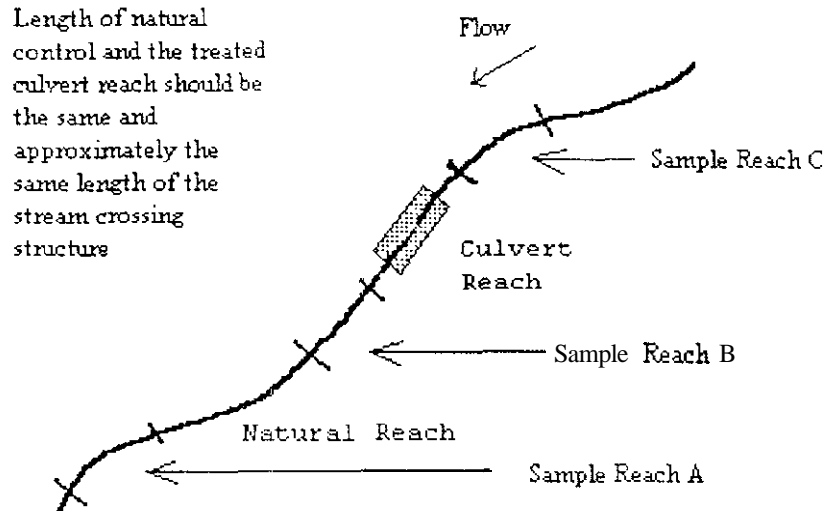Culvert Reach

Sample Reach B

Natural Reach

Sample Reach A

Figure 1. Illustration of study site design, showing the 3 reaches where fish sampling will occur.

3.2.2 Fish Sampling Techniques

Determination of fish movement across natural and culvert reaches relies on observing fish over time and space and allowing them to move on their own accord. There are many methods available for this and they vary considerably in both cost and effort The ability to detect movement also varies among methods, and comparisons of study results must consider the chance of not detecting movement when it actually occurs.

Most efforts at monitoring and validating fish passage through stream crossing structures in Washington have relied on spawning surveys of adult fish (especially anadromous species) to ascertain the ability of fish to move upstream of potential barriers. Direct observation of spawning adult fish is a practical method to determine movement of large-bodied anadromous and adfluvial salmonids. The motivation and timing of upstream migration by adult spawning fish is generally well understood and sampling can be conducted during appropriate periods to assess movement of adult fish through culverts in the field. However, spawning surveys are not suitable for evaluating the effect of stream crossing structures on movement ofjuveniles salmonids or on most smaller-bodied resident fish that may exhibit deliberate upstream movement during some phase of their life history.

While resident trout and juvenile anadromous fish do sometimes move substantial distances in small streams, the motivation for such movements is not well understood

Consequently movement cannot be assumed to occur everywhere or at all times and sampling effort is not as easily allocated. Mark-recapture methods are proposed for evaluating the movement of resident trout and juvenile anadromous fish across natural and culvert reaches.

X.2.2.1 Anadromous and Adfluvial Adults Sampling Procedure

Evaluating movement across natural versus treatment reaches of spawning adult fish would best be accomplished through mark and recapture using the fish traps as described below. However, this requires capturing and handling (and thus, stressing) the fish during a critical period. Fortunately, such fish can be assumed to have an innate propensity for upstream movement, and this can be verified by direct observation, redd counts, or the presence of juvenile fish in areas otherwise inaccessible to them. Consequently, if fish traps are not acceptable, adult spawners or redds upstream and downstream of the culvert can be counted to verify that upstream passage occurred (if redds are found upstream). If spawner surveys and redd counts are conducted, sample reaches may need to be lengthened to ensure comparable amounts of available spawning habitat are inventoried. An alternative method for verifying adult passage through a structure is direct visual observation of fish swimming through or spawning upstream of the structure.

If a specific culvert blocks adult anadromous fish for several days, and a stream has a reasonable number of fish in it, this type of delay should be evidenced by fish congregating in the nearest plunge pool or suitable holding habitat downstream of the culvert, and will be noted during field studies. In streams where turbulence or glare inhibit observations, snorkeling (and/or remote underwater video cameras) will be used to search for adult anadromous fish. Where fish are merely passing through culverts, but are not expected to hold or spawn in the vicinity, field studies should target the time of migration and use remote underwater video cameras or optical movement detectors.

3.2.2.2 Resident and Juvenile Salmonid Salmonid Sampling Procedures

This procedure entails fish being captured and marked in the sampling reaches. Sample reaches would then be sampled after an appropriate interval to see if marked fish had moved into them. Fish capture will be conducted either by electrofishing or trapping methods as follows.

Electrofishing - First place block nets at the upstream and downstream end of each 75 m long sample reach and conduct two-pass electrofishing. Care should be taken to ensure that all habitat is electrofished and that effort remains constant on each pass. All sample reaches within a study site should be electrofished on the same day, or at the very least on consecutive days. All fish captured will be anesthetized, species recorded, measured (total length to nearest mm), weighed (nearest 1 g), batched marked of a color unique to that stream reach and sample period, and released near the point of capture after processing. We propose marking fish by using a subcutaneous injection of acrylic paint.

After the initial marking, resample each site by blocknetting the sites and conducting two-pass electrofishing to determine if marked fish stayed in the reach or moved to an upstream or downstream sample reach All sites will be sampled for recaptures one or

more times after a one-week interval. Captured fish will be examined for marks to determine if movement of the sample population occurred. As with initial capture, all new captures and recaptured fish will be measured for total length and weighed. During each subsequent resample, unmarked fish will be marked, and fishes that move will be re-marked with a color unique to the sample reach in which recapture occurs.

Fish movement measures collected by electrofishing will be useful to investigate the influence of culverts on movement of resident fish and anadromous juveniles. However, detecting movement by this method requires that if fish move from one reach to the next, they must stay there to be detected. We realize that the likelihood of detecting upstream movement by marked fish during a few electrofrshing visits may be low if fish are rapidly moving to spawning or seasonal rearing areas situated well above the study site. We also realize that there may be other fishes inhabiting areas downstream of the sample reaches that could move into and beyond the sample reaches without being detected. Large piscivourous fish marked within the sample reaches may forage widely at night, and have a low likelihood of being encountered in upstream reaches at the time of electrofishing. We believe that the electrofrshing methods will provide movement measures for valid comparisons, as suggested by findings using similar methods reported by Riley et al. (1992) and Warren and Pardew (1998). Although electrofishing methods may not be suitable to detect all movement that occurs through the study site, it will provide a practical measure of fish movement for valid comparisons as described in section 3.2.3 below.

Fish Traps – To increase the likelihood of detecting movement and the accuracy of fish movement measures, fish capture techniques could involve deployment and operation of two fish traps situated upstream and downstream of culvert structures following the initial electrofishing capture and marking at selected study sites. Fish traps would be installed and continuously operated throughout each sampling period at the downstream end of sample reach B and sample reach C to collect both juvenile and adult fish swimming in either an upstream or downstream direction. Traps spanning the entire stream width would count all fish moving through natural reaches and culvert reaches during specific test periods.

All fish captured will be examined for marks to determine if movement of the sample population occurred. As with initial capture, all new captures and recaptured fish will be measured for total length and weighed. During each subsequent resample, unmarked fish will be marked, and fishes that move will be re-marked with a color unique to the sample reach in which recapture occurs. Other unmarked fish captured in the trap situated downstream of the culvert (reach B) will be assumed to have passed through the culvert if collected in the downstream box trap. Likewise, fish captured in the upstream box trap will be assumed to have passed through the control reach. The trap in reach C wilt be operated in a similar fashion to determine the upstream movement of fish across the structure reach

A wide range of fish traps have been used to collect salmonids in streams (ODFW 1996). The most applicable trap type for collection of all migrating trout (juvenile and adult) in streams would be a frame-and-picket type, with separate box traps for upstream and downstream swimming fish.

Frame-and-picket trap design features include the following:

- Span Entire channel to bank-fill flow.
- Height - Bank-full flow plus 1-foot freeboard.
. Space between Pickets - 5/8" for adult fish, 3/8" for juvenile fish
- Anchor System - Steel posts driven into streambed, or rock anchors
- Frame - Tubular aluminum tripod legs, adjustable leg length and feet. Aluminum angle stringers span between tripods to hold pickets.
- Pickets Round aluminum tubing placed through series of stringers.
- Box Trap Welded aluminum box with vee-trap, removable lid, and shallow solid pan for safe handling of fish.

Traps would need to be durable enough to handle reasonably high flows (e.g. 10% exceedance flow) with proper hydraulic functioning for fish collection. In addition, fish traps installed in streams must withstand reasonably high flows (e.g. 2-year flood) even though the traps may be over-topped and/or plugged by floating debris (leaves, wood, etc.).

Operation of fish traps requires at least daily checks, preferably twice per day. 'Trapped fish are susceptible to injury from repeated attempts to escape the box trap, and are frequently harassed by predators. Holding periods exceeding 24 hours are considered unacceptable. Therefore, trapping would require intensive operation and maintenance attention during the sampling period. And although continous trapping may provide 100% sampling of fish movement, traps may discourage upstream (or downstream) movement of fish. Fish may avoid traps unless migration is necessary and critical to life cycle (e.g. upstream spawning runs).

A comparison of the two proposed fish capture techniques is summarized in Table 4.

3.2.3 Variables to be Analyzed

Measures of fish movement, habitat conditions, stream hydrology, culvert features, and culvert hydraulics will be gathered at each site.

3.2.3.1 Fish Movement Measures

At each study site, fish movement will be assessed through the stream crossing structure (between reaches B and C or between reaches A and C) and across the natural reach (between reaches A and B). Following Warren and Pardew (1998), fish movement between reaches will be expressed in terms of proportional daily movement (PDM). PDM is calculated as $M * R^{-1} * D$ -'where M is the number of fish that move, R is the total number of recaptures in both reaches, and D is the number of days since the first marking. Directional movement will be expressed similarly with M being the number of fish that moved upstream or downstream PDM can be calculated using either electrofishing or fish trap methods.

Table 4. Comparison of two fish capture techniques proposed for monitoring the influence of culverts on fish movement.	
Fish Traps	**Electrofishing**
Capture Efficiency	
Fish traps can span entire channel width 24-hours per day = 100% capture efficiency.	Recapture methods are mostly "snapshots" with a higher probability of falsely not detecting movement
	Recapture often difficult under moderate to high flow conditions.
Fish Injury	
Minimal fish injury if trap is properly designed. built, installed. and operated.	Recapture usually labor intensive and stressful to fish.
Fish Measurements	
Collected fish can be sampled for weight, length, species, tags, etc.	Collected fish can be sampled for weight, length, species, tags, etc.
Practicality	
Adaptable to most streams of small to medium size.	Adaptable to most streams of small to medium size, although potentially limited in waters exceeding 4 feet in depth.
Requires intensive operation and maintenance attention during trapping period.	Requires labor intensive effort only during sampling days.
Costs	
High construction cost.	Lower upfront costs for equipment.
Construction and installation costs for aluminum frame-and-picket traps depend on design and site variables. A reasonable "planning range" for costs would be $600-$1,200 per foot width of the stream channel. This cost range is based on data reported by ODFW (1996) and recent (summer 1999) experience with construction of an adult trout trap in Slate Creek near Metaline Falls, Washington	Rental costs for electrofishing equipment and nets average $100 day.
Fish Behavior	
Traps may discourage upstream (or downstream) movement of fish. Fish may avoid traps unless migration is necessary and critical to life cycle (e.g. upstream spawning runs).	Capture of fish may effect fish behavior unless migration is necessary and critical to life cycle.

Fish passage efficiency (FPE) will be calculated as the ratio between the proportional movement of marked fish that pass upstream through a control reach to the proportional passage of marked fish through the study structure (e.g., if 40% of fish move upstream through the control reach, and 20% move upstream through the structure, then the FPE is 0.2/0.4 = 0.5). Fish passage efficiency can only be effectively measured in study sites where fish traps are installed. This method also assumes that all fish moving across the control reach intend on moving upstream of the treatment reach.

Because PDM and FPE are derived from proportional data, transformations (e.g. arcsine square root) may be required to approximate equal variances and normality of distributions.

In sites where adult anadromous fish passage is an issue, but capture and marking of them is difficult (e.g. small number of fish and long run time) or prohibited, a surrogate FPE will be calculated as the number of spawning fish (or redds) observed upstream of the culvert divided by the number observed in an equal area downstream of the culvert. This approach assumes that habitats downstream and upstream of the culvert have similar spawning and adult holding habitat, the propensity for fish to move upstream (default FPE) is 1.0 (e.g., at least half of the fish that reach the culvert would attempt to pass through it), and enough adult fish or redds can be observed to obtain meaningful data.

3.2.3.2 Habitat Descriptors

Data describing stream size, flow regimes, and habitat characteristics will be used to test for relationships among fish movement and habitat characteristics within or near to the study site.

The habitat assessment procedures described under the inventory phase (Section 2.2) provide a core of general habitat information. The lineal extent of available upstream and downstream habitat and distance and accessibility to any known unique habitats situated along the channel network, including lakes, pond systems, or groundwater seeps, will be obtained from maps.

In the field, the average bankfull channel width will be measured at each site. Other measurements of habitat complexity and instream cover, including pool frequency, substrate composition, large woody debris loads, and distance to next prominent upstream movement barrier, will be gathered for each study site (Table 5). Bankfull width and other habitat measures will be made once during the initial sampling visit and will only be repeated in the event of a major channel altering event or following conspicuous input or depletion of large wood. Stream discharge and water temperature will be measured during each sample visit. Stream stage will be measured continuous stage recorder devices.

In addition to obtaining field measurements and map attributes specific to the study site, a barrier survey will be conducted a minimum of 1000 feet upstream or downstream of each study site. All natural and human-made barriers (including stream crossing structures) will be mapped and distance from the study site will be measured. The lineal extent of habitat by gradient class within 1000 feet of either direction from the study site will be obtained from maps,

Table 5. Measures of fish movement and habitat descriptors at each study site during the passage validation phase of the TFW stream crossing structure monitoring program.

Attribute	Description
	Site Information
Date	Date of each re-capture period
Site situation category	Category as defined on Table 3; combination of-1 variables
	Fish Movement
	Fish movement measures will be calculated for each (or groups of) fish species and lifestage.
Proportional daily movement (PDM)	Calculated as the ratio of number of marked fish observed to move across a reach divided by the total number of recaptured fish, all divided by the number of days elapsed between sampling
Fish passage effectiveness (FPE)	Fish passage efficiency is defined as the ratio between the proportional movement of marked fish that pass upstream through a control reach to the proportional passage of marked fish through the study structure (e.g., if 40% of fish move upstream through the control reach, and 20% move upstream through the structure, then the FPE is 0.2/0.4 = 0.5).
	Habitat Measures
Bankfull Channel Width	Average for the site
Wetted Width	Wetted channel width during time of survey
Channel Slope	As taken by hand-held Abney level over a distance of several channel widths; segment average slope
LWD Tally	A tally of LWD (by class) within the bankfull channel width and depth following TFW Monitoring Protocol
Dominant/Subdominant Substrate	What is the dominant and subdominant or codominant channel particle size (e.g. gravel/small cobble, large cobble/boulder, etc.)
Upwelling habitat	Presence/absence call of known wall base channel or other groundwater seeps in upstream direction
Upstream Lake	Distance and confirmation of accessibility to upstream lake
Downstream lake	Distance to downstream lake and confirmation of upstream accessibility
Pool Frequency	Number of pools per channel width
Barriers	Lineal distance to upstream and downstream barriers obtained from map and field effort
Accessible Habitat	Length of accessible stream by gradient class within 300 m of either direction from the study site
Elevation	Approximate elevation of the downstream-most extent of segment, determined from topographic map
Water temperature	Measured during each sample visit
Stream discharge	Measured during each sample visit

3.2.3.3   Hydrology Measures

The WAC fish passage design criteria used to determine if a culvert is considered a barrier to upstream fish movement includes criteria of maximum water velocity, maximum hydraulic drop, and minimum flow depths under specific design flows. Some type of barrier is assumed to be present when these criteria are not achieved. The factors include : a) lack of streambed material throughout the culvert bottom and sufficient culvert width; and b) hydraulic drop >0.8 ft, or culvert slope >1%; or c) minimum water depth is not achieved during the 95% exceedance flow during the months when fish migration is considered important; or d) maximum mean column water velocity is exceeded at the 10% exceedance flow during the months when fish migration is considered important. These criteria require a hydrologic analysis to determine the fish passage design flow and construction of flow duration curves to determine the percent of time that target hydraulic conditions are met or exceeded.

There are four levels of hydrologic analysis that are acceptable for estimating the 10% exceedance flow at a site. The availability of data will dictate which level is applied to a specific project. They are, in order of preference:

1. Stream gauging;
2. Continuous simulation model;
3. Local regression model;
4. Regional regression model.

Another option is to use data obtained from one of the above methods to calibrate a basin-to-basin correlation between recorded flows in a nearby system and spot flows measured in the stream system where design flows are needed. Extreme care should be used when creating this correlation as the probability of induced errors increases.

Interpretation of historic stream gauging data for a specific stream is the most preferred type of analysis but adequate data for specific sites are rare. With a few flow data points, however, a regional flow model can easily be verified and calibrated. Calibration data should be within 25% of the fish passage design flow to be valid. Continuous flow simulation models are acceptable though not normally justified solely for a fish passage design. Single event models are generally not acceptable since the fish passage design flow is based on a flow recurrence frequency rather than a peak flow.

Whatever model is used, future watershed conditions should be considered when choosing the fish passage design flow. Continuous flow simulation models and calibrated regional models most likely provide the best estimate of future conditions.

The low fish passage design flow is used to determine the minimum water depth at any time. The low flow used is the two-year, seven-day low flow as described in WAC 220-110-070.

3.2.3.4   Culvert Measures and Hydraulic Analysis

Measures of culvert features and hydraulics will be made at each site (Table 6). The purpose for the hydraulic analysis is to calculate the maximum average cross-sectional velocity and minimum depth in the culvert at the high flow design discharge, and compare with target hydraulic conditions from WAC 220-l 10-070. The values in the WAC table are the minimum depth (design depth) and maximum average cross-sectional velocity (design velocity) allowed at high flow design discharge. The hydraulic analysis follows methods described by the WDFW barrier assessment manual (1998a). Physical measurements of the culvert and channel required to conduct the analysis are described in Section 2 of the WDFW manual and are provided in Appendix C.

The results of this analysis will be a determination whether or not the structure is considered a barrier under WAC 220-l 10-070, the percent of the time during each month of the migration period the structure is considered in compliance with the target hydraulic conditions (*culvert compliance rating*), and the range of modeled stream discharge that the culvert is out of compliance with hydraulic targets.

In addition to these modeled values, measurements of stream discharge will be obtained at all study culverts during each fish sampling period. A continuous stage recorder will be installed to track stream flow throughout the course of the study. Discharge will be measured at each gage a minimum of five times over the range of flows experienced during the sampling periods combined. It will be important to conduct the flow measurements during a wide range of stages in order to obtain a valid stage/discharge relationship for each of the study sites. This will allow accurate determination of the range of flows that occur during the sampling period. These discharge measurements can then be used in the culvert hydraulic analysis to calculate the range of water depths and velocities that would have been encountered by fish during the sampling period.

Table 6. Measures of culvert structural features and culvert hydraulic conditions evaluated at each study site during the passage validation phase of the TFW stream crossing structure monitoring program. Details on culvert and channel measurements required to conduct hydraulic analysis for determination of compliance with WAC are provided in Appendix C.

Attribute	Description
Culvert Structural Measures *Measured once or beginning of study*	
Culvert design option	As described by WDFW road crossing design manual (WDFW 1998b).
Shape	Specify the shape of culvert using one of the following codes: rnd = round, box = rectangular, arch=bottomless arch, sqsh= squash (pipe arch), ell=ellipse, oth = other
Material	Specify the material of which the culvert is constructed using one of the following codes; pcc=precast concrete, cpc=cast in place concrete, cst=corrugated steel, sst=smooth steel, cal = corrugated aluminum, sps = structural plate steel, spa = structural plate aluminum, pvc = plastic, tmp=timber, mry=masonry, oth=other
Span	The horizontal dimension of the culvert.
Rise	The vertical dimension of the culvert.
Length	The length of the culvert. Includes apron if present.
Streambed material in culvert	Specifies the presence of streambed material throughout the entire length of the culvert. Values are; yes and no
Outfall drop	Distance from the water surface at the downstream end of culvert to the water surface of the plunge pool.
Culvert slope	Slope of culvert, reported in percent determined with a standard level and tripod or a hand level in association with a staff of pre-established height; both are used in conjunction with a stadia rod. For reasons of accuracy, the use of a clinometer is no, recommended.
Culvert Hydraulic Measures *Following WDFW hydraulic analysis techniques*	
Stage	Daily stage in stream during each period of field study using continuous stage recorder
Discharge	Range of stream discharge during each period of field study as determined by stage discharge relationship developed with stage recorder and periodic flow measurements
Height	Height of hydraulic jump required by fish to enter structure
Minimum depth encountered during sampling period	Minimum water depth inside structure encountered during sampling period as modeled using WDFW hydraulic analysis and site discharge measurements
Velocity encountered during sampling period	Mean column water velocity inside structure as modeled by WDFW hydraulic analysis using site discharge measurements; the mean, minimum, and maximum is calculated for the entire sampling period
Barrier status	Results of Level A culvert evaluation - barrier determination. Values are: no = not a barrier; yes = barrier according to WDFW culvert slope and hydraulic drop criteria; flow = flow dependent barrier requiring hydraulic analysis
Target flows	Following the WDFW hydraulic barrier analysis technique, calculate the stream discharge at which the design depths and design velocities (minimum water depth, maximum water velocity) are predicted to occur
Culvert compliance rating	Using monthly flow duration curves and target flows described above, calculate the percent of the time during each month of the migration period the structure is considered in compliance with the target hydraulic conditions established in WAC 220-110-070

3.3 Hypothesis Evaluation

Methods to evaluate each hypothesis and answer associated monitoring questions are presented in this section. Statistical models are proposed to test each of the hypotheses presented in section 3.1. There are wide array of multivariate techniques, including clustering and discriminant analysis procedures, which could be applied to the data set as an exploratory analysis. However, simple, straightforward analysis that attempts to distinguish the relation of fish movement, stream and channel conditions, and culvert features are proposed. Statistical analysis would of course not be limited to the pr-ocedures listed below.

3.3.1 Volitional Fish Movement

Monitoring Questions: In what stream settings does upstream movement of the various salmonid species most often occur? Do site situation categories affect overall, directional, or seasonal movement of fish?

Null Hypothesis: Overall, directional, or seasonal fish movement (as defined by PDM) is independent of site situation category and season.

Evaluating fish passage through culverts requires volitional movement of fish, which may vary among species and life stage, available habitats, and seasons. This component of the monitoring is designed to determine if fish are moving in the reach and to identify and account for the variability in fish movement under a range of watershed settings during different seasons. The preferred method of fish recapture involves installation of fish traps at reach B to insure that movement of fish is detected should it occur over a short time period and fish move beyond the sampling reaches.

Variables to be Analyzed

- Proportional daily movement of fish (by species or groups of species) through natural channel "control" reach (between Sampling Site A and Sampling B Figure I) grouped on site situation category
- Date that lies midway between fish marking and fish recapture, grouped particular season
- Habitat descriptors

Statistical Model

A two-factor analysis of variance will be used to test site situation categories and season as the main factors in affecting fish movement. If the two-factor analysis of variance reveals a significant difference in proportional daily movement among the site situations or seasons, or if significant interaction exists between site situation and species, then we can determine which combination of factors are typically associated with higher measures of movement. Pairwise comparisons of the relative frequency of movement means will be made with the Student-Newman-Keuls multiple range test or other appropriate multiple comparison test. Overall movement, upstream movement, and downstream movement will be analyzed separately for each species (or groups of species/life stages). Further exploratory analysis focusing on relationships between fish movement, habitat characteristics, and extent of naturally accessible habitat conducted through regression analysis or other multivariate techniques.

3.3.2   Culverts Influence on Fish Movement

Monitoring Questions: Does a stream crossing structure provide equal fish passage to the adjacent natural stream reach? In what stream types and locations in a basin do culverts influence fish movement?

Null Hypothesis: Culvert structures have no effect on overall, directional, or seasonal fish movement regardless of the site situation and season.

Variables to be Analyzed

- PDM measures (by species or groups of species) grouped on site situation
- Season of sampling

Statistical Model

To evaluate effects of culvert treatment, site situations, and season on fish movement, the PDM across natural reaches (Sites A and B) will be compared to PDM through the culvert (Sites B and C). A three-way analysis of variance will be used to test site situation categories, season, and treatment (culvert vs. no culvert) as the main factors in determining fish movement. As with the volitional fish movement testing, if the three-factor analysis of variance reveals a significant difference of PDM among levels of factors (site situation, season, treatment), or if significant interaction exist between the factors, multiple comparisons will be made to identify the combinations of factors in which culverts have a demonstrable effect on fish movement. Overall movement, upstream movement, and downstream movement will be analyzed separately for each species (or groups of species/life stages).

3.3.3   Correspondence of Fish Movement and Culvert Barrier Status

Monitoring Questions: Are barrier status determinations (complete barrier, flow-dependent barrier, not a barrier) and culvert compliance ratings (percent of time passage design criteria exceeded) accurate in portraying the influence of culverts on fish movement? Does a culvert that is considered a barrier for only a short duration affect fish movement as much as one that is considered a barrier under all flows?

Null Hypothesis: Culvert structures have no effect on overall, direction, or seasonal fish movement regardless of the culvert barrier status or culvert compliance rating.

This analysis is tailored to evaluate the correspondence between fish movement and the factors that are used to determine if a culvert is considered a bar-rier to upstream fish movement. Methods used to determine a culverts barrier status consist of comparing physical and hydraulic features with specific design criteria. Yet it is recognized that culverts identified as barriers according to the WAC guidelines may be impassable to upstream fish movement only under limited flows conditions and for only short durations. Currently there is no measure of partial, or flow-dependent, culvert barriers on fish movement, nor is there a means to compare the significance of a culvert that is considered a barrier under most flows to one that is a barrier for only very limited flows.

Variables to be Analyzed

- Fish movement measures (by species or groups of species) grouped on site situation
- Culvert compliance rating and barrier status

Statistical Models

We will test for the association of barrier status and seasons with PDM and FPE. A two-way analysis of variance will be used to test season and barrier status as the main factors in determining fish movement. Overall, upstream, and downstream PDM will be analyzed separately for each species (or groups of species/life stages). This test will reveal if significant differences in fish movement can be accounted for by the culvert barrier status determined by the WAC criteria. In addition, the relationships among the culvert compliance rating (% of time culvert is predicted to be passable by hydraulic analysis) and fish movement measures will be investigated through regression analysis. Further exploratory analysis aimed at accounting for differences in fish movement within similar barrier status groups will be conducted through investigation of culvert structural and hydraulic features as described in the next hypothesis test.

3.3.4 Culvert Structural and Hydraulic Features

Monitoring Questions: Is there a relationship between fish movement and physical and hydraulic features of culverts? What features and hydraulic conditions of stream crossing structures are most related to fish passage problems? Are some culvert designs more effective at providing for upstream fish movement? How can crossing structures be improved for fish passage?

Null Hypothesis: Fish movement through structures is not related to the physical and hydraulic design features.

While the preceding hypothesis investigate the linkages between fish movement, watershed setting, and barrier status determinations, this hypothesis focuses on identifying the relationship between culvert design features and fish movement. This analysis will determine if some culvert design types are more effective at providing for upstream fish movement. Evaluation of the relations among culvert features and fish movement will be based on a subset of the data used in the volitional fish movement tests. If no upstream movement is identified across the natural reach or through the culvert, then volitional passage cannot be expected at the culvert, and data from that study site will be excluded from further analysis.

Variables to be Analyzed

- proportional daily fish movement (PDM)
- fish passage efficiency (FPE)
- culvert design type
- culvert structural measures, including hydraulic drop
- range of depth and velocity encountered during sampling period as measured by hydraulic analysis using stream discharge measurements obtained from site via stage-discharge relationships and continuous stage recorder

Statistical Models

To evaluate effects of the various culvert designs (e.g. stream simulation option, bottomless arch, round culvert) on fish movement, a one way analyisis of variance will be used to test culvert design option as the main factor in influencing fish movement. In

addition, a variety of multivariate techniques are available to explore the effects of specific features and hydraulic condition of the culvert on upstream fish passage. For simplicity sake, PDM and FPE will be tested for relationships to the structural and hydraulic measures of each culvert and it's surroundings with stepwise multiple regression or other correlation techniques. Other clustering techniques could be used to evaluate the combination of features that are commonly associated with impediments or blocks to upstream migration.

Fish movement measures will be calculated, and statistical analyses performed, separately for at least 4 groups of fish as they are encountered: 1) juvenile salmonids; 2) adult resident trout; 3) adult pink and chum salmon; and 4) adult chinook, coho, and sockeye salmon and steelhead. Analyses may be further refined to each species and lifestage of fish, if enough fish are encountered to justify this level of resolution.

4 Practical Considerations

We have formulated monitoring hypothesis and suggest potential statistical models to evaluate the influence of culverts on fish movement under a variety of watershed situations. Specific statistical models used may vary depending on the initial screening of data. We may find that non parametric analysis may be preferred over the models presented. In addition, further exploration for differences in proportional movement can be conducted using a regression or other correlation analysis on a series of independent or predictor variables. For instance, examination of the role that accessible upstream habitat conditions has on upstream fish movement may reveal relationships that are otherwise obscured by reliance on the statistical models proposed.

We envision this study program being established as a regional, watershed-based monitoring program conducted by various TFW Cooperators and coordinated by TFW CMER and the Monitoring Advisory Group. A coordinated monitoring plan will decrease logistical and personnel constraints and enhance understanding of fish movement and passage needs in a variety of watershed settings in different regions of the state.

Ideally, the study period should cover more than one year at each study site, and cover a range of flows during the known migration season Effort should also be allocated to document conditions on a seasonal basis (or, alternatively, during or following specific flow conditions). Additional study during extremely high conditions would increase the knowledge gained, but sampling with mark-recapture during such events is not practical.

Evaluation of fish passage by site-situation category and structure conditions, combined with culvert inventory procedures, will simplify the task oftargeting specific sites where there is a high likelihood for fish to move, culverts that inhibit passage are common, and the potential for watershed-scale biological impacts from passage inhibition is greatest. Analogously, this information will help manager-s to realize which combinations are least likely to cause biological impacts, and where further detailed efforts may not be warranted. Depending upon relationships discovered, this analysis may form a basis for refinement of road restoration and maintenance needs.

5 References

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Appendix A.

WAC 220-I IO-070 Water Crossing Structures

WAC 220-110-070 Water crossing structures.

In fish bearing waters, bridges are preferred as water crossing structures by the department in order to ensure free and unimpeded fish passage for adult and juvenile fishes and preserve spawning and rearing habitat. Pier placement waterward of the ordinary high water line shall be avoided, where practicable. Other structures which may be approved, in descending order of preference, include: Temporary culverts, bottomless arch culverts, arch culverts, and round culverts. Corrugated metal culverts are generally preferred over smooth surfaced culverts. Culvert baffles and downstream control weirs are discouraged except to correct fish passage problems at existing *structures.*

An HPA is required for construction or structural work associated with any bridge structure waterward of or across the ordinary high water line of state waters. An HPA is also required for bridge painting and other maintenance where there is potential for wastage of paint, sandblasting material, sediments, or bridge parts into the water, or where the work, including equipment operation, occurs waterward of the ordinary high water line. Exemptions/j-year permits will be considered if an applicant submits a plan to adhere to practices that meet or exceed the provisions otherwise required by the department.

Water crossing structure projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat. The following technical provisions shall apply to water crossing structures:

(1) Bridge   construction.

(a) Excavation for and placement of the foundation and superstructure shall be outside the ordinary high water line unless the *construction site* is separated from waters of the state by use of an approved dike, cofferdam, or similar structure.
(b) The bridge structure or stringers shah be placed in a manner to minimize damage to the bed.
(c) Alteration or disturbance of bank or bank vegetation shall be limited to that necessary to construct the project. All disturbed areas shall be protected from erosion, within seven calendar days of completion of the project, using vegetation or other means. The banks shall be revegetated within one year with native or other approved woody species. Vegetative cuttings shall be planted at a maximum interval of three feet (on center), and maintained as necessary for three years to ensure eighty percent survival. Where proposed, planting densities and maintenance requirements for rooted stock will be determined on a site-specific basis. The requirement to plant woody vegetation may be waived for areas where the potential for natural revegetation is adequate, or where other engineering or safety factors preclude them.
(d) Removal of existing or temporary structures shall be accomplished so that the structure and associated material does not enter the watercourse.
(e) The bridge shall be constructed, according to the approved design, to pass the 100-year peak flow with consideration *of* debris likely to be encountered. Exception shall be granted if

preproject conditions upon removal of the temporary culvert.

(h) The culvert and fill shall be removed, and the disturbed bed and bank areas shall be reshaped to preproject configuration. All disturbed areas shall be protected from erosion. within seven days of completion of the project, using vegetation or other means. The banks shall be revegetated within one year with native or other approved woody species. Vegetative cuttings shall be planted at a maximum interval of three feet (on center), and maintained as necessary for three years to ensure eighty percent survival. Where proposed. planting densities and maintenance requirements for rooted stock will be determined on a site-specific basis. The requirement to plant woody vegetation may be waived for areas where the potential for natural revegetation is adequate, or where other engineering or safety factors need to be considered

(i) The temporary culvert shall be removed and the approaches shall be blocked to vehicular traffic prior to the expiration of the HPA.

(j) Temporary culverts may not be left in place for more than two years from the date of issuance of the HPA.

(3) Permanent culvert installation

(a) in fish bearing waters or waters upstream of a fish passage barrier (which can reasonably be expected to be corrected, and if corrected, fish presence would be reestablished), culverts shall be designed and installed so as not to impede fish passage. Culverts shall only be approved for installation in spawning areas where full replacement of impacted habitat is provided by the applicant,

(b) To facilitate fish passage, culverts shall be designed to the following standards:

(i) Culverts may be approved for placement in small streams if placed on a flat gradient with the bottom of the culvert placed below the level of the streambed a minimum of twenty percent of the culvert diameter for round culverts, or twenty percent of the vertical rise for elliptical culverts (this depth consideration does not apply within bottomless culverts). Footings of bottomless culverts shall be buried sufficiently deep so they will not become exposed by scour within the culvert. The twenty percent placement below the streambed shall be measured at the culvert outlet. The culvert width at the bed, or footing width, shall be equal to or greater than the average width of the bed of the stream

(ii) Where culvert placement is not feasible as described in (b)(i) of this subsection, the culvert design shall include the elements in (b)(ii)(A) through (E) of this subsection:

(A) Water depth at any location within culverts as installed and without a natural bed shall not be less than that identified in Table 1. The low flow design, to be used to determine the minimum depth of flow in the culvert, is the two-year seven-day low flow discharge for the subject basin or ninety-five percent exceedance flow for migration months of the fish species of concern. Where flow information is unavailable for the drainage in which the project will be conducted, calibrated flows from comparable gauged drainages may be used, or the depth may be determined using the installed no-flow condition.

(B) The high flow design discharge, used to determine maximum velocity in the culvert (see Table 1), is the flow that is not exceeded more than ten percent of the time during the months of adult fish migration. The two-year peak flood flow may be

and any required channel modification associated with it. Affected bed and bank areas outside the culvert and associated fill shall be restored to preproject configuration following installation of the culvert, and the banks shall be revegetated within one year with native or other approved woody species. Vegetative cuttings shall be planted at a maximum interval of three feet (on center), and maintained as necessary for three years to ensure eighry percent survival. Where proposed, planting densities and maintenance requirements for rooted stock will be determined on a site-specific basis. The requirement to plant woody vegetation may be waived for areas where the potential for natural revegetation is adequate, or where other engineering or safety factors preclude them.

(e) Fill associated with the culvert installation shall be protected from erosion to the 100-year peak flow.

(f) Culverts shall be designed and installed to avoid inlet scouring and shall be designed in a manner to prevent erosion of streambanks downstream of the project.

(g) Where fish passage criteria are required, the culvert facility shall be maintained by the owner(s), such that fish passage design criteria in Table 1 are not exceeded. If the structure becomes a hindrance to fish passage, the owner shall be responsible for obtaining a HPA and providing prompt repair.

(h) The culvert shall be installed in the dry or in isolation from the stream flow by the installation of a bypass flume or culvert, or by pumping the stream flow around the work area. Exception may be granted if siltation or turbidity is reduced by installing the culvert in the flowing stream. The bypass reach shall be limited to the minimum distance necessary to complete the project. Fish stranded in the bypass reach shall be safely removed to the flowing stream.

(i) Wastewater, from project activities and dewatering, shall be routed to an area outside the ordinary high water line to allow removal of fine sediment and other contaminants prior to being discharged to state waters.
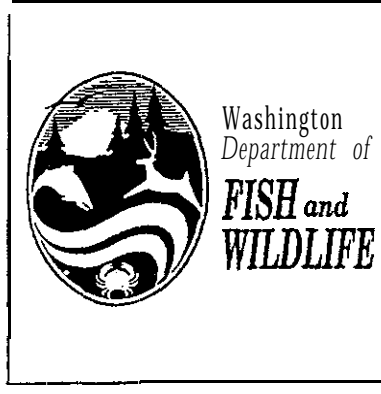
Appendix B

Fish Passage Design Flows for Ungaged Catchments in Washington

FISH PASSAGE DESIGN FLOWS FOR UNGAGED CATCHMENTS IN WASHINGTON

Patrick D. Powers, P.E.
Caleb S. Saunders

Washington
Department of
FISH and
WILDLIFE

The Puget Sound Region (Region 2) includes sections of Clallam, Jefferson, Mason, Thurston, Pierce, and all of King, Snohomish, Whatcom, and Skagit counties. Region two consists of streams that drain into the Puget Sound. In order to find the best correlation, the Region 2 data was dividsd into highland and lowland streams. The division was defmed at gage elevations of 1000 feet. In addition, Region 2 had a high percentage of urbanized streams (defined arbitrarily as greater than 20 percent impervious surfaces). Separate regression equations were run for this data.

The Lower Columbia Region (Region 3) is based on rivers that flow west of the Cascade Mountain Range and dram into the Columbia River. This region includes Wahkiakum, Cowlitz, Clark, and sections of Skamania, Pacific, and Lewis Counties. Again the best correlation was found when the region was divided into highland and lowland subregions. Again, the classification was based on the gage elevation.

Region four (Eastern Washington) is defined as the rivers in counties east of the Cascade Mountain Range. As defined by the USGS and U.S. Water Resources Council, Eastern Washington is divided into six regions. Too few fluvial systems fit the required criteria however to analyze any one region as a whole. Therefore, it was necessary to condense all of Eastern Washington into one region. No correlation was found amongst the small, unrepresentative data pool gathered within this large, diverse region.

Methodology

To create a usable model for estimating fish passage design flows, a data selection process was necessary. Parameters selected required the drainage areas to be less than 50 square miles with at least five years of data compiled by the USGS for January and May. All selected data were reported by USGS as either fair, good or excellent. Sites where the measured data was reported poor or had large periods of estimation during the months of interest were excluded from the analysis. Certain sites were also rejected because of major upstream diversions, lakes or reservoirs acting as stream controls. Data *was* compiled from USGS Hydrodata (Daily Values) and USGS Open File Reports 84-144-A, 84-144-B, 84-145-A, and 84-145-B. Basin drainage areas were gathered from the USGS Hydrodata. Mean annual precipitation and precipitation intensity were gathered from the USGS Open File Reports.. When figures were not available *in* the Open File Reports, values were determined by locating the latitudinal and longitudinal coordinates of the gage stations on Plates 1 and 2. The 10 percent exceedence flow values were calculated using the Hydrodata software via the Weibul formula;

$$P = M/(N+1)$$

where N is the number of values and M is the ascendant number in the pool of values

Reeression Analvsis

A least squares multiple regression analysis *was* run on a logarithmic transformation of the data.

5. Apply the percent standard error as appropriate In most cases the standard error is added to the result because the high end of the passage flow is desired, but in some cases if depth is a concern it may be subtracted.

Example 1:   Lake Creek Tributary (Lake Cavanaugh Road)
>From Table 1: Region 2, Elev <1000 ft, January
$A = 1.82$ sq mi
Latitude: 48'22' Longitude: 122°11'
>From Plate 2: $P = 80$ in/yr

$$Q_{fp} = 0.125(A)^{.93}(P)^{1.15}$$

$$Q_{fp} = 0.125(1.82)^{.93}(80)^{1.15}$$

$Q_{fp} = 34$ cfs, Standard Error is 48.6%

$Q_{fp} = 18$ to SO cfs …………………………………………………………………………………Answer

Example 2:   S. Branch Big Creek (SR 101)
>From Table 1: Region 1, May
$A = 0.87$ sq mi
Latitude: 47°09' Longitude: 123°53'
>From Plate 1: $I_{24,2} = 4.5$ in/24 hours

$$Q_{fp} = 2.25(A)^{.85}(I_{24,2})^{0.95}$$

$$Q_{fp} = 2.25(0.87)^{.85}(4.5)^{0.95}$$

$Q_{fp} = 8.3$ cfs, Standard Error is 30.6%

$Q_{fp} = 6$ to 11 cfs …………………………………………………………………………………Answer

Table 2. ‥ Maximum and minimum values of basin characteristics and R squared values used in the regression analysis, by region and land type.

|	Drainage Area (sq mi)	Mean Annual Precipitation (inches)	2-year 24-hour Precipitation (inches)	R^2 (January/ May)
REGION 1				
Maximum	4 8	‥	7.5	(0.91/0.84)
Minimum	2.72	▪▪	2.5	
REGION 2				
Lowland Streams < 1000 ft Elevation				
Maximum	48.6	160	‥	(0.81/0.77)
Minimum	l	2 8	▪▪	
Highland Streams > 1000 ft Elevation				
Maximum	45.8	170		(0.68/0.76)
Minimum	.19	6 0		
Urban Streams > 20% Effective Impervious Area				
Maximum	24.6	47		(0.74/0.76)
Minimum	3.61	35		
REGION 3				
Lowland Streams < 1000 ft Elevation				
Maximum	40.8	1 3 0	‥	(0.84/0.86)
Minimum	3.29	5 6	▪▪	
Highland Streams > 1000 ft Elevation				
Maximum	37.4	132	_ _	(0.7310.81)
Minimum	5.87	7 0	- -	
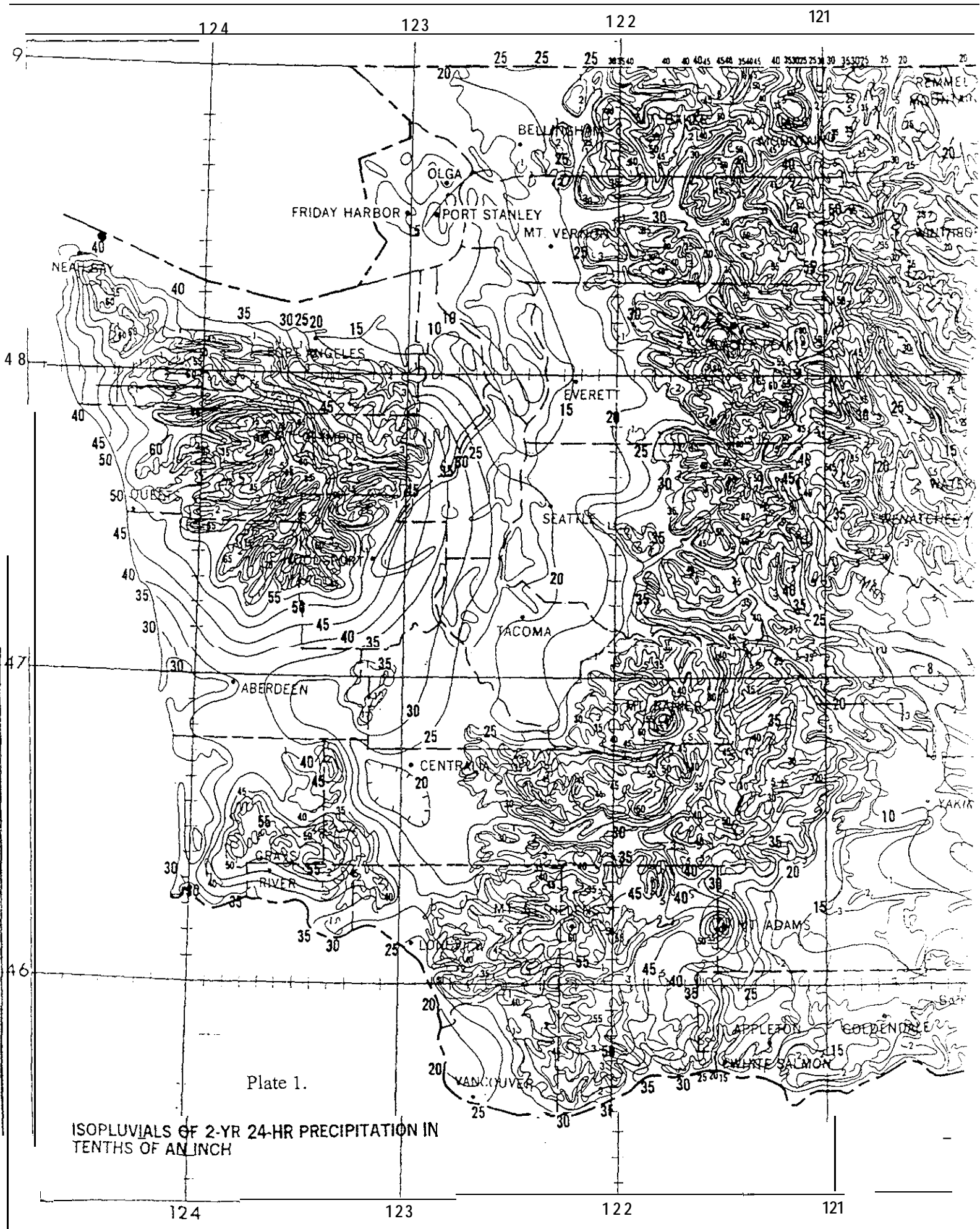
Plate 1.

ISOPLUVIALS OF 2-YR 24-HR PRECIPITATION IN
TENTHS OF AN INCH

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Appendix C

Culvert Evaluation Techniques Excerpted from

Pages 1-19 of the WDFW
Fish Passage Barrier Assessment and Prioritization Manual

1. Introduction

The purpose of this manual is to provide guidance on how to identify and prioritize culverts that impede fish passage, The process is described in the text but the actual data that must be collected and the format for storage are contained in tables. This manual is divided into five sections. The first section is the introduction which gives a brief overview of the entire process. The second section covers the culvert evaluation methodology. The location of the culvert must be determined by obtaining its global positioning system (GPS) coordinates. A determination must be made as to whether the stream is fish bearing or not; if the stream is non-fish bearing, then limited information is collected on the culvert. On fish bearing streams, detailed physical measurements of the culvert and stream are taken to describe the site and allow for the barrier analysis. If the culvert is determined to be a barrier or a non-barrier (Level A analysis), no further culvert data collection is required. If the barrier status is still unknown, then a Level B analysis must be completed. The Level B analysis involves collecting more detailed information required to run a hydraulic model to determine the barrier status of the culvert.

The third section describes assessing the potential habitat gain that would be achieved if the barrier was corrected. A downstream check is first conducted to determine if the barrier culvert is physically accessible to anadromous salmonids or if a significant quantity of resident salmonid habitat exists immediately downstream. For resident salmonids, a significant habitat reach must be at least 200 meters in length, have a gradient < 20%, and be free of other natural point barriers. If there is no anadromous salmonid access or significant resident salmonid habitat below the culvert, no further evaluation would be conducted. In anadromous waters the habitat gain will always be upstream of the barrier culvert, but in resident waters the habitat gain is the smaller piece of habitat whether it is upstream or downstream of the barrier culvert. For instance, if there are 600 meters of habitat downstream of a barrier culvert and there are 2,200 meters·of habitat upstream, the downstream habitat would be quantified and used to prioritize the project for repair.

Two methodologies are described to estimate the potential habitat gain that would be realized if the culvert were repaired. The first is to complete a full physical survey and the second involves sampling a smaller section of the stream and using those data along with additional information to estimate the potential habitat gain. In the full survey, approximately a 20 % sampling rate is achieved by sampling 30 meters out of every 160 meters of stream or 60 meters out of every 320 meters of stream, depending upon the stream length. When complete physical habitat surveys are not practical an expanded threshold determination (ETD) is conducted to estimate the amount habitat upstream or downstream of a barrier. In this methodology, measurements are taken in the first 200 meters and expanded to estimate the total habitat gain.

The fourth section describes the Priority Index (PI) model. The PI takes into account the habitat gain, the mobility and health status of the fish stocks that would benefit from increased access to the habitat, and the projected cost of the project. The PI is a valuable tool to be used with other relevant factors to select projects for correction,

Utilization" (Williams, et *al*. 1975 and Phinney and Bucknell 1975).

• Water courses listed *as* fish bearing on *StreamNet (http://www.streamnet. org/).*

*Stream reaches (less than 20 percent gradient) that are found to be flowing during the summer months regardless of their size.

*Roadside ditches/streams that are accessible to fish and have flow characteristics that provide useable fish habitat (e.g., winter rearing habitat).

-Water courses with documented salmonid use determined by visual observation, electrofishing, or verification by local biologists.

Table 1.   Fish barrier assessment/inventory options.

Orientation		Barrier Assessment Only		Barrier Assessment and Prioritization			
Point (Road)	Crossings Located and Assessed	Yes	Yes	Yes	Yes	Yes	Yes
		All options require a significant reach assessment above and below the barrier to determine the appropriateness of correction.					
Watershed	Habitat Survey Technique	Linear Threshold		Areal Threshold (expanded)			Full
	Start of Reach/Watershed Survey: Confluence or a Specific Natural Barrier (probably the first below the target crossing in a jurisdictional inventory)'						
	End of Reach/Watershed Survey: The First Natural Barrier above the target crossing in a jurisdictional inventory or the Last Upstream Natural Barrier						
	Man-made Barrier Assessment	No	Yes	No		Yes	Yes
	Habitat Assessment	No	No	No	Verify[2]	Verify[2]	Yes
		Option 1	Option 2	Option 3	Option 4	Option 5	Option 6

resident salmonid only waters, the habitat survey may have to start below the confluence to assess the area of least production.
habitat quality and location of natural barriers.

2.2 Physical Measurements

Due to safety considerations, do not enter the culvert to collect this information. When measuring the water depth inside the culvert, stand at the downstream end of the culvert and measure the depth an arms length inside of the culvert. Always use extreme caution when working in and around the stream due to the instability of stream banks and the slippery nature of the stream bed. It is recommended that eye protection be worn by field personnel due to the risk of eye injury from streamside vegetation.

If barrier assessment is a goal of the inventory then the information in Table 3a must be collected for a Level A analysis and the information in Tables 3a *and* 3b must be collected for a

3

Table 2. (Cont.)

Attribute	Description
Name	Name of owner, include organizational subdivision (e.g. district, region) separated by hyphen.
Address	Street address of culvert owner.
Address2	Mailing address of culvert owner if different from street address.
City	Name of city.
State	Two character abbreviation for state (e.g. WA).
Zipcode	Standard Zipcode or zip+4.
Phone	Include area code in phone number. Format (123)456-7890.
Contact&Phone	Name and phone number of specific contact if other than the owner. Include area code in phone number.
Fish Use	Indicator of fish use in stream where culvert is located. Determines level of culvert evaluation. Values are; yes, no, unknown.
Decision Criteria	Basis for FISH USE determination: "mapped" indicates that stream is typed as 1 - 4 on DNR water type maps, "physical" means the stream meets the minimum physical dimensions specified in the Forest Practice Regularions, "biological" means fish have been directly observed, and "other" means criteria other than those listed was used (explain in comments). A "yes" FISH USE determination may be based on mapped, physical, biological or other criteria. A "no" determination may be based on physical, biological or other criteria. If unknown leave blank.
Species	The species (from the following list) expected or known to utilize the stream where the culvert is located. These species are used in the WDFW priority index model. Multiple entries are allowed, separated by /. Use the two character code for each species. SO = sockeye, CH = chum, PK = pink, CO = coho, CK = chinook, SH = steelhead, CT = cutthroat, RB = rainbow, DB = dolly/bull bout, EB = eastern brook trout, BT = brown trout
Structure Type	Record the type of potential fish passage barrier encountered, human-made or natural. Use one of the following values; culvert, fishway, dam, or other. If a culvert has any formal structure (e.g. log, plank, or rock controls, internal baffles, fish ladder) associated with it to aid fish passage it is considered a fishway. Barriers that are not culverts, dams or fishways are recorded as other. If the barrier is anything besides a culvert, please retain the information above and briefly describe it in the BT Comments field.
BT Comments	Description of the structure. Include type (e.g. log control, dam, waterfall, etc.), any pertinent measurements (height, length, width, etc.), and comments. If the inventory includes fish passage assessment on culverts, then this field may be skipped (culverts only).

5

Table 3a. (Cont.)

Attribute	Description
Water Depth Inside Culvert	Depth of water inside the culvert, measured at the downstream end away from the influence of outlet conditions. Expressed in feet to the nearest 0.1.
Water Velocity Inside Culvert	Field estimate of water velocity through the culvert in feet per second. Use flow meter or 3 chip method. Informational.
Interior Slope Break	Specify whether or not there is a slope break inside the culvert. Values are; yes, no, or unknown. Describe in comments. Answers procedural question 5.a.
Apron	Indicates presence and location of a" apron. Values are; "one, upstream, downstream, both (both ends).
Tidegate	Indicates presence of a tidegate. Values are; yes or no.
Skew Upstream	Angle at which stream enters culvert. Expressed in degrees right or left (e.g. 30L, 25R), straight in would be 0. Right or left reference is facing upstream.
Skew Downstream	Angle at which stream exits culvert. Expressed in degrees right or left (e.g. 30L, 25R), straight out would be 0. Right or left reference is facing downstream
Plunge Pool Length	Distance from the outlet of the culvert to the downstream control. Measured in feet to the nearest 0.1.
Plunge Pool Wetted Width	Width of the plunge pool at its widest point measured at the water surface. Expressed in feet to the nearest 0.1. Informational.
Plunge Pool OHW Width	Width of the plunge pool at its widest point measured at OHW. Expressed in feet to the nearest 0.1. Informational.
Plunge Pool Maximum Depth	Maximum depth of plunge pool. Expressed in feet to the nearest 0.1. Informational.
Plunge Pool Dominant Substrate	Best description of the dominant substrate in the plunge pool. Select one of the following; riprap, boulder, cobble, gravel, sand, mud, bedrock. Informational.
Comments	Concise description of culvert problem and explanation of any attribute where OTHER was selected.
Barrier	Results of culvert evaluation • barrier determination. Values are; yes = culvert is a barrier, no = culvert is not a barrier, unknown = culvert beyond Level A analysis.
Problem	Factor that determined barrier status. Applies only to barrier culverts. Entries include outfall drop, slope, velocity, and depth. Enter outfall drop if the measured outfall drop is > 0.8' or enter slope if the slope is > 1%(analysis Level A). The results of the hydraulic analysis (Level B) will indicate either water depth or velocity. Enter all that apply, separate each entry with a /.
Repair Status	Indicates the need for barrier repair. If there is insufficient habitat gain to warrant repair (see significant reach determination) the entry would be NG (no gain). If sufficient habitat is present enter RR (repair required). If the barrier has been fixed enter FX (fixed). If the fix involves conversion to a fishway enter FX/FW.

Table 3b. (Cont.)

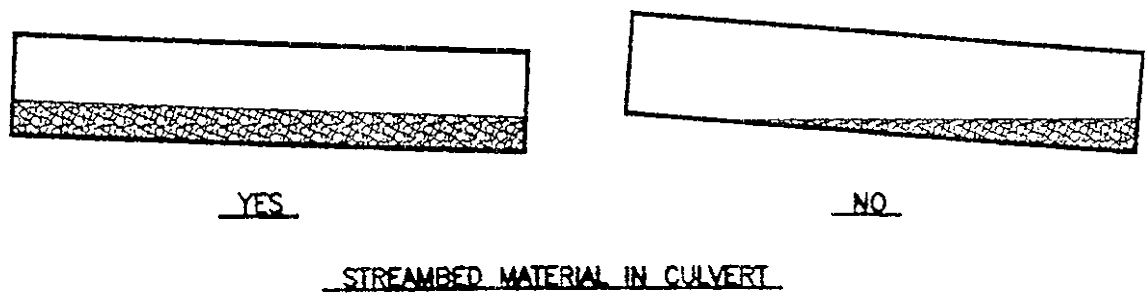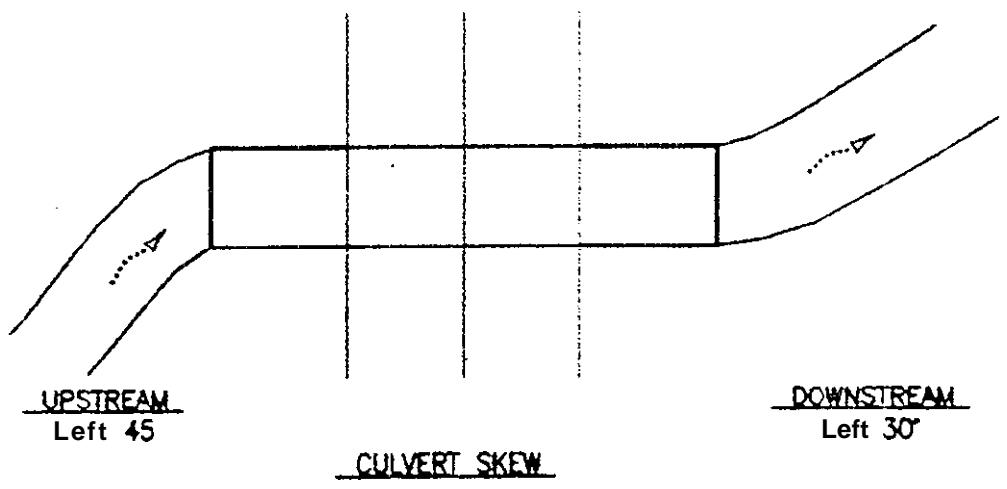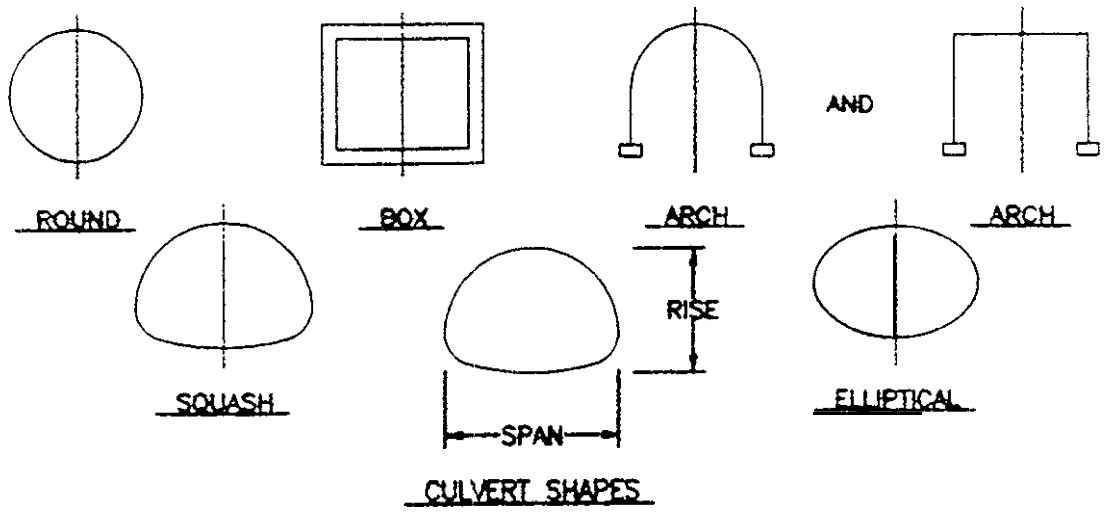| Attribute	Description
Downstream Control Cross Section ST0..ST6 EL0..EL6	The downstream control is typically the head of the first riffle below the culvert (1O-25 feet downstream). The cross section is derived from at least 7 points across the channel. Data is recorded as station (ST0..6) and elevation (EL0..6). Stan at th top of the left bank (ST0 & ELO), looking downstream, and work to the right. Measure elevations at the top of each bank, each toe, the thalweg, and other grade breaks. Value for ST0 will always be 0, values for ST1..6 will be the distance in feet measured to the nearest 0.1 from STO. Elevations are measured in feet to the nearest 0.01. Used in the hydraulic model. Each station and elevation is a separate field in the database.
DS Control Water Surface Elevation	Elevation of the water surface at the downstream control. Measured in feet to the nearest 0.01. Derived by adding water depth to the bed elevations at the control. Used in conjunction with the downstream culvert elevation and WDIC to determine hydraulic drop.
Streambed Elevation 50 Downstream of DS Control	Streambed elevation at the channel centerline, 50' downstream of the downstream control. Measured in feet to the nearest 0.01. Used in conjunction with water deptt to determined water surface elevation. Also used to plot stream profile.
Water Surface Elevation 50' Downstream of DS Control	Water surface elevation at the channel centerline, 50' downstream of the downstream control. Measured in feet to the nearest 0.01. Derived by adding Downstream Bed Elevation and water depth. Used in hydraulic model. Also used in conjunction with upstream water surface elevation to estimate stream gradient through the reach.
Channel Dominant Substrate	Best description of the dominant substrate in the channel between the culvert and the point 50' downstream of the downstream control. Select one of the following; riprap, boulder, cobble, gravel, sand, mud, bedrock. Needed for the hydraulic model.

ROUND BOX ARCH AND ARCH

SQUASH RISE ELLIPTICAL

SPAN

CULVERT SHAPES

UPSTREAM
Left 45

DOWNSTREAM
Left 30°

CULVERT SKEW
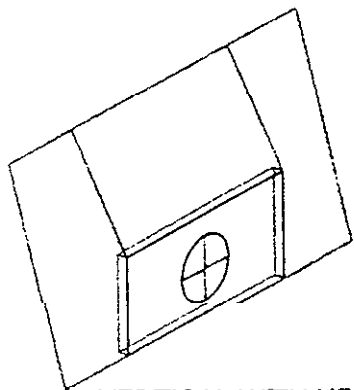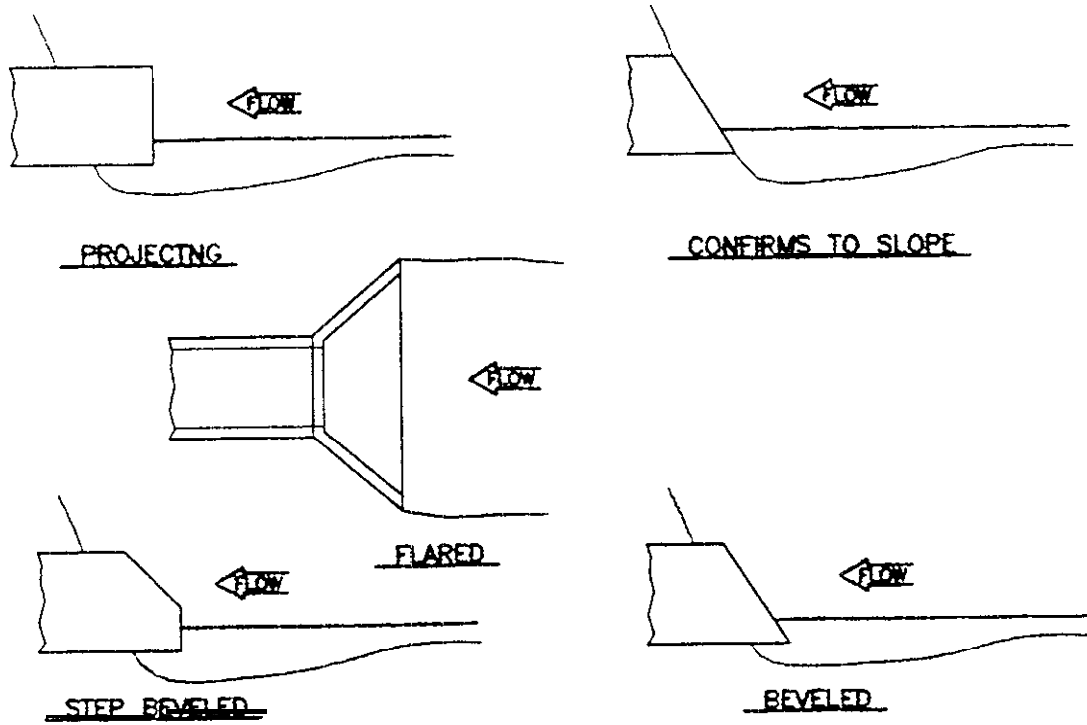
YES NO

STREAMBED MATERIAL IN CULVERT

Figure 1. Examples of culvert descriptors and physical measurements.

11

PROJECTNG

CONFIRMS TO SLOPE

FLARED
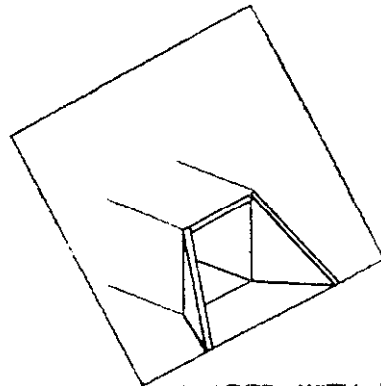
STEP BEVELED

BEVELED

VERTICAL WITH HEADWALL
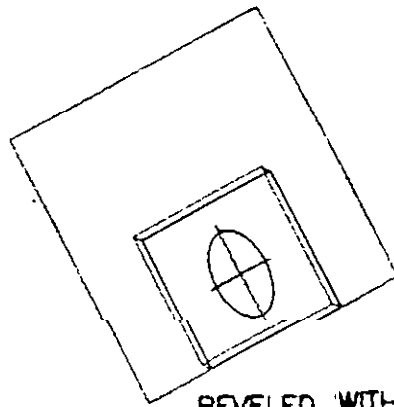
BEVELED WITH HEADWALL
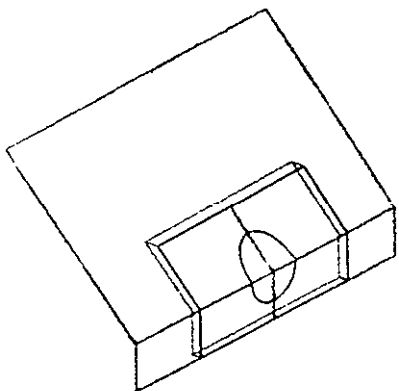
STEPBEVELED WITH HEADWALL

FLARED WITH HEADWALL

CULVERT UPSTREAM END TREATMENT

Figure 1. (Cont.)

using Manning's equation for normal depth If there is no outfall, and the culvert is backwatered the velocity and depth may meet the criteria at the outlet but exceed it inside the culvert. In this case, a backwater analysis is needed to find the point of maximum velocity/minimum depth inside the culvert. The following steps are a process which will lead an investigator through the needed calculations to determine if a culvert is a fish passage barrier.

Step 1: Calculate the high fish passage design flow

Before a hydraulic analysis can be done, the design flow must be determined. For gaged streams, use the 10% exceedence flow. For ungaged streams, an acceptable regional regression model for Washington State is the Powers-Saunders model (Appendix C). The standard statistical errors for the regression formulae vary from about 26 to 75%. For this level of analysis it is recommended that just the regression estimate be used.

Given: (Data from Culvert Evaluation Form and Appendix C)

Stream
Hydrologic Region
Drainage Area (A):
Annual Rainfall (P), or Intensity (I)

Calculations:

$$Q_{fp} = a\,(A)^b(P)^c, \text{or}$$
$$Q_{fp} = a\,(A)^b(I)$$

Step 2: Check Outfall Drop

If the outfall drop is greater than zero, the culvert is not backwatered, go to step 3. If the outfall drop is zero, the culvert is backwatered, go to step 4.

Step 3: Calculate Normal Depth and Velocity

Given: (Data from Culvert Evaluation Form)

Culvert Shape
Culvert Material
Culvert Diameter
Culvert Slope
Culvert Length
Manning's n (Determined from the corrugation attribute):
Where: Smooth   - 0.012
            ½" x 2%" -   0.024
            1" x 3"   - 0.027
            2" x 6"   -   0.032

Calculate the depth and velocity using the Manning's equation or a commercially available

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Calculations:

　　Equation:　　　　　　　　　　　$Q_{fp} = .125 \, (0.33)^{0.93}(55)^{1.15}$

　　Q_{fp}　　　　　　　　　　　　　5 cfs

Step 2: **Check the outfall drop**

　　Outfall Drop　　　　　　　　　0.7　(therefore go to STEP 3)

Step 3: Calculate Normal Depth and Velocity

Given: (Data from Culvert Evaluation Form)

Culvert Shape:	RND
Culvert Material:	PCC
Culvert Diameter:	30 inches
Culvert Slope:	1.3 percent
Culvert Length	70 feet
Manning's n	0.012 (smooth concrete)

Calculations : (use the Manning's equation or a commercially available computer software such as FlowMaster™)

Velocity	6.6 fps
Depth	0.5 feet
Design Velocity'	4.0 fps
Design Depth'	0.8 feet

Therefore, the calculated velocity is greater than the design velocity, and the calculated depth is less than the design depth, so the culvert would be recorded as a barrier.

<u>Example 2</u>
Step 1: Calculate the high fish passage design flow

Given: (Data from Culvert Evaluation Form and Appendix C)

Stream	**Steelhead Creek**
Hydrologic Region	2
Drainage Area (A):	0.45 sq mi
Mean Annual Precipitation (P):	55 in/yr

'From WAC 220-l IO-070 Section 3(b)(ii) Table 1 Adult Trout

These calculations *can* be done by hand. Text books such as *the Handbook oj Hydraulics* (Brater and King 1982), *or Open-Channel Hydraulics* (Chow 1988) have examples and directions for making these calculations. Computer software which analysis culvert hydraulics can give fast results with the proper input. However, *a basic understanding of open channel flow hydraulics is needed to interpret the output.*

One situation where this model will *not* work is in the case of a grade break in the culvert. This is somerimes the case where a culvert has been extended and the new section is installed at a different elevation or slope than the old culvert. This can also occur when a section of the culvert settles or a joint fails. In these instances, a more sophisticated analysis may be required. However, in cases where the slope of any portion of the culvert exceeds 1% or the drop inside the culvert exceeds 0.8 feet, then it can be categorized as a barrier. If the slope does not exceed 1% and the drop does not exceed 0.8 feet, *or* if these parameters can not be measured, then the barrier status of the culvert is unknown.